Perspectives from a human-centred archaeology

Iron Age people and society on Öland

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PERSPECTIVES FROM A HUMAN-CENTRED ARCHAEOLOGY

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The photographs that introduce each chapter show details of Iron Age burials in Öland. All photographs are used with kind permission of ATA (Antikvarisk-topografiska arkivet) and digitized by Torbjörn Linnerud.

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Hannah Arendt

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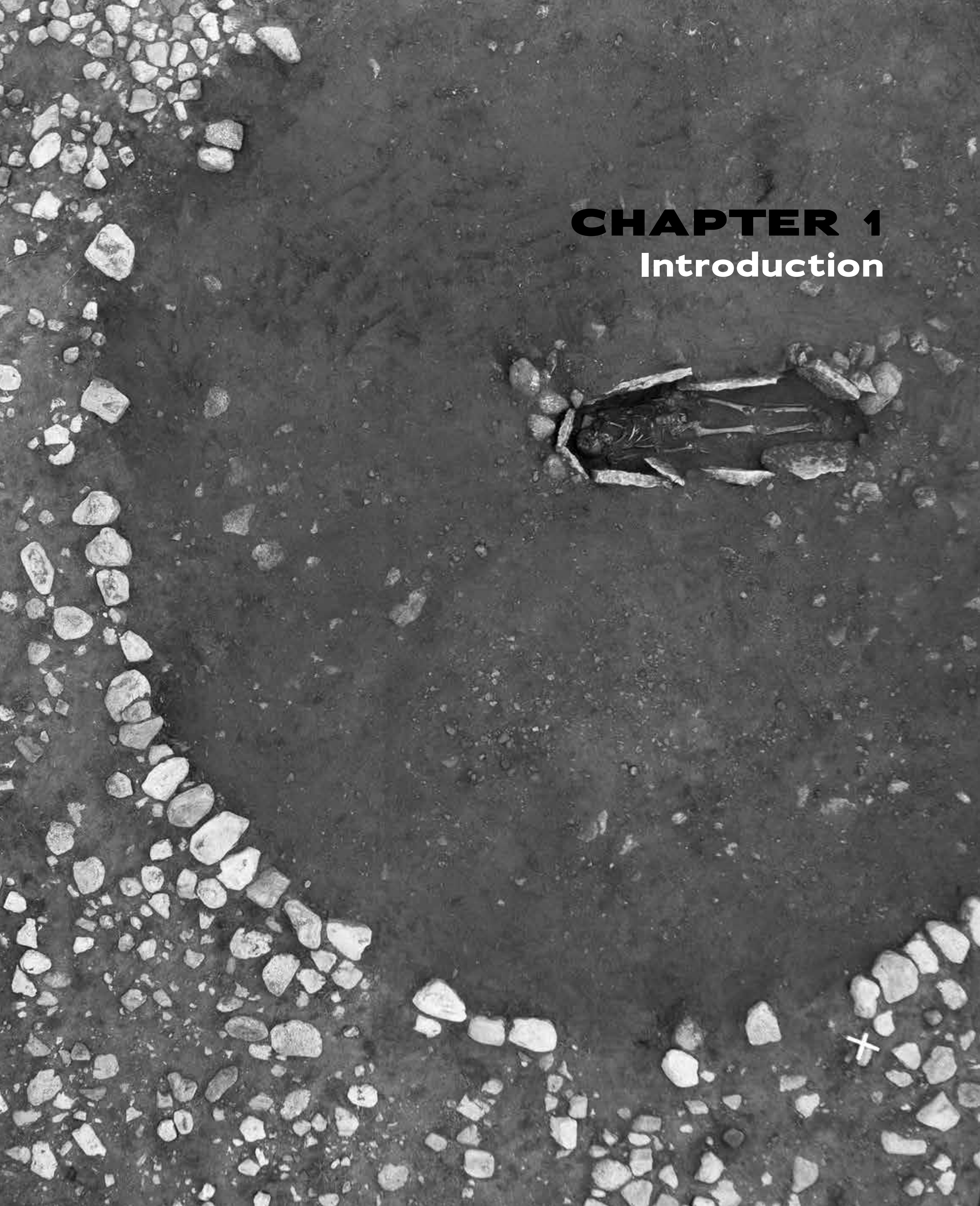
> *.....one day you´re going to rise up singing*
> *then you´ll spread your wings*
> *and take to the sky...*
>
> *Summertime, lyrics by Edwin DuBose Heyward*

Helene Wilhelmson
Lund, 11th of January 2017

CHAPTER 1
Introduction



1.1 Why a human-centred archaeology?

The human body is the most direct source for studying and understanding human life, and death. All aspects of the constantly-changing living human body are influenced by the combination of culture and biology that is our insignia, the very thing that defines us as human. Similarly, in death the body is shaped by the actions of humans dealing with it (or not) as a biological and cultural entity. As we expand our understanding of how our skeletons respond to what the body is subjected to and part of – in life and death – our understanding of the past can also expand. Different aspects of the skeleton (morphology, surface, colour, chemical composition, spatial distribution) can give detailed direct and indirect information both about a person's life, the society they were part of and, sometimes, about their death. It is possible to study the short term (for example, moments of violence) as well as the long term (for example, in dietary shifts or migration). We can contextualize ourselves in a sense by centring the archaeological approach upon the skeleton since this links the past and the present in a direct physical way.

The fields studying human skeletal remains in archaeological contexts can today use a range of different approaches (i.e., both theory and method) to human remains, exploring the material, physical and visual properties of the same source – the skeleton – differently. I argue these are best practiced when combined in an interdisciplinary manner by integrating different interpretations from the different approaches. In this study, I have devised an interdisciplinary approach referred to here as the *human-centred approach*. This approach consists of elements already in focus in archaeology, only they are not specifically articulated as such yet. This approach, *the human-centred archaeology*, is outlined in detail here as a theoretical framework and applied to a case study, Iron Age Öland. In this text, I will discuss the definition of the approach, demonstrate it "in action" as applied to Iron Age Öland, before evaluation and conclusion.

Why the human-centred approach to Iron Age Öland?

1.2

Öland is a long, narrow island in the Baltic Sea wedged between the coastline of current mainland Sweden and the larger island of Gotland (Fig. 1). Since the 1900s, a variety of archaeological contexts from the Iron Age (500 BC–AD 1050) have been a focus of documentation, excavation and research (e.g. Stenberger, 1933; Hagberg, 1967; Näsman & Wegraeus, 1976; Näsman, 1984; Stjernquist, 1994; Räf, 2001; Fallgren, 2006; Tegnér, 2008; Monikander, 2009; Telldal, 2012). Subsistence, mobility and contacts, social organization and violence have each been discussed in these and other publications. Engström's meta-study (2015) examined how specific archaeologists' works and approaches impacted upon Öland research, particularly the Eketorp fort. The Iron Age graves on Öland have been published in four volumes compiling information from excavations from the nineteenth century onwards, primarily regarding burial practice and artefacts and with little osteological analysis of the skeletal remains (Beskow-Sjöberg & Arnell, 1987; Beskow-Sjöberg & Hagberg, 1991; Hagberg & Beskow-Sjöberg, 1996; Rasch, 2001).

The well-preserved skeletal remains, hitherto little investigated, present the possibility to investigate several aspects of Iron Age society in Öland. Moreover, the island component (a natural geographic delimitation), as well as the nature of the available skeletal assemblage from large parts of the Iron Age, give extraordinary circumstances for investigating societal development during this time. Based on the available human skeletal remains and related sources of information (such as grave/context attributes), I anticipate the following four themes as particularly worthy of exploration in Öland to further the current understanding of the society and people during the Iron Age:

- Taphonomy (any processes and changes affecting the dead body)
- Diet
- Migration
- Social organization and hierarchy

Fig. 1: The location of Öland in the Baltic Sea

Öland is an ideal base from which to study migration since it was an island also during the Iron Age, making migration to and settlement on Öland a deliberate and resource-demanding process. Dietary development is also a rewarding topic because of the island setting. Indeed, the human remains found on Öland cover a greater time-scale than other archaeological sources. Methodologically, both diet and migration can be investigated with isotope analysis of skeletal remains and are thus considered as primary sources of information, being directly connected to once-living humans on Öland. The island also presented a complete case for investigating taphonomy, and the integration of archaeology with osteology in fieldwork. The island, and the human remains in particular, also present an excellent possibility for exploring social hierarchy, primarily through variations in burial practice, artefacts, violence, and other skeletal markers. All of these aspects of Iron Age Öland have one thing in common – they are centred on primary sources which derive from actual human beings living on Öland during that time.

Aim

1.3

The aim of this thesis is to formulate an approach that will increase the understanding of society and people within an archaeological context, in this case, for Iron Age Öland in particular. I have outlined some specific goals and ambitions in pursuing this aim below. If human remains were to be the focus of the study, this could allow for a more comprehensive chronological view of the Iron Age on Öland than before as the remains, contrary to other archaeological sources (such as settlements or artefacts), cover the period more coherently and with more continuity as a single source. Moreover, human remains can be a direct source of knowledge about human beings who have died, and probably lived, in Öland, as well as the society present there at large.

Goals

1.3.1

The specific goal of this thesis is to:

- integrate osteology, isotopes, and archaeology in an interdisciplinary approach – *human-centred archaeology* – and show the advantages and limitations of this approach as applied to Iron Age Öland.

My ambition is to investigate both the human-centred approach and the development of specific aspects of people and society in Öland during the course of the Iron Age. I will focus on four main themes: taphonomy, diet, migration, and social organization in Iron Age Öland. The themes correspond to four specific goals:

(i) to apply an interdisciplinary approach to taphonomy and human remains as part of the archaeological context (Corresponding to Paper I);

(ii) to investigate dietary isotope variation and contextualize interpretations of dietary development in Öland (Corresponding to Paper III);

(iii) to explore isotope approaches to the study of migration in Öland (Corresponding to Paper II and IV);

(iv) to discuss social hierarchy and organization throughout the Iron Age in Öland (Corresponding to Paper IV and V).

The detailed goals are pursued in one or more papers as noted above. These results are synthesized further in this text, however, in order to address the detailed themed goals, as well as the overall goal, of this study.

1.4 The overview

This compilation thesis is divided into several parts: this text i.e. the “kappa” (a Swedish word often translated to either, or both, introductory, and summary chapters), five papers (of which three are coauthored), and an appendix. The “kappa” will clarify the research outline and how the papers relate to one another, as well as provide an overview of the most significant results and a synthesis. The background is a significant part of this text detailing existing research on Iron Age Öland and discussions on the methodologies employed in this specific study that form a human-centred approach. The most important results of this study, combining all the individual papers, are presented (Chapter 5) and then synthesized and discussed (Chapter 6). Finally, the human-centred approach is discussed (Chapter 6) and evaluated. The appendix should serve as a tool for accessing specific details on the human remains of each individual included in the study and to act as a resource for future studies investigating new research questions.

CHAPTER 2

Background

THIS CHAPTER WILL OUTLINE the theoretical framework for this thesis and detail earlier research on Iron Age Öland. As a design of my own, the theoretical framework requires presentation and definition in relation to the field of archaeology and, specifically, in studies dealing with human skeletal remains. This framework is the backbone of the study; it is the concept that runs throughout the papers and allows their connection to the study at large, supplying flexibility and direction.

2.1 The study of human skeletal remains in archaeology

2.1.1 A field of many names: from bioarchaeology to osteology

The study of skeletal remains is most properly addressed as osteology and includes humans and animals from past to present times. It has its roots as a profession in the early twentieth century, with medical doctors, biologists, and geologists all taking an interest in skeletal remains in archaeological contexts. *Osteology* is the study of bones: *oste* 'bone' and *–ology* 'science/knowledge' (Online Etymology Dictionary). The term is used more regularly in Europe than in the US where *physical anthropology* is mostly used synonymously alongside *biological anthropology* (Digangi et al., 2013: Martin et al., 2013:31; Larsen, 2010; review in Little & Sussman, 2010). It is focused on human skeletal remains but includes primates in all time periods. Forensic anthropology can be included under the term *physical anthropology* but it is a relatively young subfield, starting around the time of WWII (Little & Sussman, 2010:31). In the US and UK, zooarchaeology (also referred to as archaeozoology or animal osteology), the study of animal bones, is considered a separate field in contrast to human osteology. Internationally, the most popular concept today is *bioarchaeology* which primarily relates to human bones, although may well include animal bones. This has a wider definition than allww the other concepts. The practitioners defining themselves as bioarchaeologists are wide in range, identifying as archaeologists, medical doctors, forensic experts, geologists, chemists, DNA-experts, zoologists, and veterinarians. Also, those trained specifically in studying skeletal remains in an archaeological context often refer to themselves as bioarchaeologists, osteologists, or osteoarchaeologists.

The specific concept of bioarchaeology, with focus on integrating archaeology and osteology/physical anthropology, is ascribed to Buikstra (1977). The essence of bioarchaeology, the study of human remains in an archaeological context in an interdisciplinary manner, was already in practice in the 1960s in Binford's processual archaeology. However, the roots of bioarchaeology go much deeper (for review see Buikstra et al., 2012), and are entrenched in the concepts of biological anthropology, osteoarchaeology, physical anthropology, and so on, as detailed above. In 1972, Clark propagated a form of bioarchaeology but did not connect physical anthropology with archaeology at large. Instead, he connected it with other particular areas of expertise, such as paleobotany and archaeozoology, adapting a reductionist ecological perspective to fit a processualist approach. Such an approach was very different than the one Buikstra suggested five years later. Both approaches have been practiced simultaneously yet exclusively, forming two "tribes" of bioarchaeology in the US as defined by Rakita (2014). The first tribe, and up until now the tribe which has had the most publications, is *The biological adaptation tribe* and is defined by a strong focus upon bone and includes those researchers primarily trained as physical anthropologists rather than primarily as archaeologists. The second tribe is argued as coinciding with the current version of bioarchaeology in Europe (c.f. Agrawal and Glencross, 2011), however, this might be a bit simplistic a generalization as the tribes cannot be directly applied to the European setting (c.f. Knüsel, 2010), probably mostly due to a more comprehensive rejection of the processualist approach early on in Europe. Not only is there an agreement that the bioarchaeology practiced in Europe is different compared to that in the US (c.f. Buikstra et al., 2012; O'Donnabhain & Lozada, 2014), there are also clear variations within Europe itself. As pointed out in his review of bioarchaeology, Knüsel (2010) attributes some of these variations to the fact that research focused upon animal bones, often denoted as archaeozoology, is more integrated in bioarchaeology in Europe. One manifestation of this integration, for example, is *The Paleopathology Association* (https://paleopathology-association.wildapricot.org/) where any research relating to pathology on bone, whether human or animal, is included.

The significance of context and taphonomy, as successfully disseminated by the French school of *Archaeothanatology/Anthropologie de terrain*, initiated by Henri Duday, has recently received much attention in reviews on bioarchaeology (Knudson & Stojanowski, 2008; Knüsel, 2010; Rakita, 2014). This approach is spreading via the English works of Duday's academic descendants, e.g. Bello & Andrews, 2006; Duday & Guillon, 2006; Gerdau-Radonic, 2008; Nilsson-Stutz, 2003), but is still most explicitly integrated in bioarchaeology in Europe so far. In a recent American review, Knudson and Stjoanowski (2008) also highlighted the significance of *Anthropologie de terrain*, and its unique approach to bones as part of the archaeological context in excavation. However, they emphasize that it is too expensive and time consuming to be applied on a large scale. Similarly, Knüsel (2010) repeats the significance of *Anthropologie de terrain* in his review on bioarchaeology, although with a discussion focused on the great advantages of the approach rather than the drawbacks. The integration of contextual observations and interpretations of skeletal remains is clearly anticipated to have a greater role within bioarchaeology in the future. The development of a specific cost-efficient methodology and protocol is necessary before this can be realized, however.

Larsen recently (2015) published a revised version of the textbook *Bioarchaeology*. Despite seeking the integration of osteology with archaeology and using the term *bioarchaeology* instead of *osteology*, he only defines it as the study of aspects of life and biographies – not death. In the context of trauma and violence, however, the significance of taphonomy (from post-mortem modification and fracturing of bones to interpreting the bones in the archaeological context) is actually emphasized, creating a conflict of statement. Indeed, this conflict apparently unnoticed by Larsen actually pinpoints the difficulties of trying to design a bioarchaeology which deals only with life. In contrast to Larsen, Martin et al. (2013) devoted an entire chapter of their recent textbook to defining bioarchaeology. They also emphasize the archaeological context, taphonomy, and excavation to an unusually detailed extent for this type of introductory text (compare Larsen, as one example).

The biocultural perspective is a popular approach viewing human remains, culture, and environment as integrated with one another (Martin et al., 2013:9). This approach has been an inherent part of studies of human remains since the very beginning of anthropology, although the focus has shifted significantly up until today (for review see Zuckerman & Armelagos, 2011) and has been extensively debated around the following question: Is biology the most significant factor influencing culture, or is culture influencing biology? Recently, Goodman (2013) claimed that culture should be given more consideration as a significant factor in understanding human biology – not so different from arguments in Sofaer (2006), who views the body as an artefact. A recent volume devoted to the theory and practice of this concept (Schutkowski, 2008a) has argued that biology and culture are so intimately linked that it is pointless to discuss them as separable or to order them hierarchically: "Cultural behavior is intrinsic to human nature: we literally cannot live without it" (Schutkowski, 2008b:2). This version of biocultural perspectives is thus pushing the pendulum back a little from the one extreme, giving precedence to neither biology, as in early approaches, nor culture, as in recent times. Nonetheless, the focus of the approach – whether biological, cultural, or a blend of both – will still have merit if it contextualizes skeletal remains, taking consideration of the local/regional and long-term changes in, for example, subsistence. If bioarchaeology is to truly integrate with archaeology, the emphasis placed upon biology by the biocultural perspective might be a hindrance, and terminology preferences too idiomatic. The use of biological terms such as *behaviour* (e.g. Goodman, 2013) clashes with today's postprocessual archaeology and would therefore be replaced with, for example, *agency* (Schutkowski, 2008a), allowing for a shared terminology. In the greater number of bioarchaeological studies, however, it is not articulated that the approach includes a biocultural perspective.

Biocultural approaches today draw explicitly from social theory. However, this does not necessarily equate biocultural bioarchaeology to social bioarchaeology. The more explicit application of social theory has served to integrate archaeology and bioarchaeology and has resulted in some theory-focused works. Sofaer (2006) devoted an entire book to advocating an approach to the human body as material culture, leaving a resounding echo in bioarchaeology internationally. Other important volumes are the edited compilations of *Social Bioarchaeology* (Agrawal & Glencross, 2011) and *Social Archaeology of Funerary*

Remains (Gowland & Knüsel, 2006). Recently, two volumes in the *Bioarchaeology and Social Theory* series were announced (Tilley, 2015; Osterholtz, 2016). Furthermore, in a special issue of the C*ambridge Archaeological Journal*, Crandall and Martin (2014) recently revived the approach of agency, focusing on post-mortem agency in particular. Both Knudson and Stojanowski (2008), and later Agrawal and Glencross (2011), vouched for the potential of social theory in interpreting skeletal remains using various examples. This social theory-based version of the biocultural approach could include context but also potentially gender (biological or social sex and age) (c.f. Grauer & Stuart McAdam, 1998) and activity indicating skeletal markers (for example, entheseal changes or trauma) and violence. In the past few years, violence, closely tied to social theory, has become one of the most vibrant and theorized topics in bioarchaeology which will no doubt be emphasized in future reviews and definitions of bioarchaeology (c.f. review in Martin & Harrod 2015 and in addition Martin et al., 2012, 2013; Schulting & Fibinger 2012; Knüsel & Smith, 2014; Martin & Harrod, 2015; Martin & Anderson, 2014).

When considering the history of the fields that study human remains in archaeology, two concepts should be mentioned: *mortuary* and *funerary* archaeology. *Mortuary archaeology* is usually centred on a study of burial organization, structure, artefacts (e.g. Douglas, 2005). *Funerary archaeology* has an object or the grave in focus, rarely the skeleton. Both concepts have recently been heavily critiqued for their lack of account for, and inclusion of, human skeletal remains in the analysis of the grave and, in addition, for rarely addressing the funeral or death *per se*, making the name of these archaeological approaches rather inappropriate (Knüsel & Gowland, 2006; Robb, 2013; Lorentz, 2015).

2.1.2 The local setting: osteology in Sweden

The study of human skeletal remains in archaeology has a specific Swedish context and studies taking on aspects of a human-centred approach are available. The 1960 thesis presented by osteologist Gejvall is a landmark publication in terms of human-centred archaeology. In *Westerhus: Medieval population and Church in the light of skeletal remains*, Gejvall performs an in-depth osteological analysis, integrating it with archaeological context (stratigraphy, spatial distribution, finds, church architecture) and written sources discussing social differences and societal development. Gejvall claimed: "The evidence derived from the skeletal material is the foundation of our study, onto which the rest has been added" (Gejvall, 1960:12). Before Gejvall's thesis, and a few decades after, most osteology was reported as lists or short appendices, both by Gejvall himself (e.g. 1967) and others. However, this grew less common and is now quite unusual, unless dealing with very small samples in Sweden. Arcini (1999) integrates a spatial interpretation of the cemeteries, but instead of being interdisciplinary, as Gejvall was, he has an expert archaeologist (Cinthio, 1999) supply an interpretation of the local urban environment. Arcini uses this context and makes some social interpretations but is, in this sense, more crossdisciplinary or multidisciplinary than interdisciplinary. Other contributions with a similar inclination for integrating context and multiple approaches for a human-centred archaeology include Sjøvold (e.g. 1994), Iregren (e.g. 2009), Kjellström (e.g. 2005), and to a lesser extent due to their stronger osteological methodologic focus, Molnar (2008) and Liebe-Harcort (2010:63ff). So far, only Ahlström has published an explicit integration of fieldwork and osteological analysis considering necrodynamics and taphonomy and assemblage level (e.g. 2009, 2013), but distancing it from the approach of *Anthropologie de terrain*. In this same context, the work of Nilsson-Stutz (e.g. 2003), who used drawings and excavation photos to study taphonomy, should also be noted. Nilsson-Stutz's work, although unfortunately not integrating other osteological (lab) analysis, pioneered the use of an *Anthropologie de terrain* approach to graves in Sweden. Despite not using actual bones in the field or in the lab, but only drawings and photos of them, this was still an important step in integrating archaeology and osteology in an interdisciplinary manner. On a theoretical level, with specific regard to interdisciplinarity and field discourse, other than Gejvall, it is Nilsson-Stutz who has made contributions to an approach in line with a human-centred archaeology.

2.1.3 Chemical approaches to human remains in archaeology

Archaeology is a field borrowing from, and collaborating with, various fields including art, history, linguistics, sociology, geology, physics, mathematics, computer science, medicine, and many more. The chemical analysis of bone and other skeletal tissues – whether investigating isotopes for chronology, diet, migration or genetic ancestry – is, for obvious reasons, of particular relevance to bioarchaeology. Along with general technical developments, the cost of chemical approaches has decreased and processing times have become shorter which, all in all, has led to an increased use of such approaches in archaeology exponentially over the past 20–30 years. Not only are lower prices and shorter processing times responsible for this increase, archaeologists are also willing consumers of these scientific results.

Goldstein (2006) highlights the use of isotopic analysis of diet and migration as something that successfully binds together archaeologists and physical anthropologists in a bioarchaeological approach. She also shares some pessimism: “the irony of these [isotopic] analyses is that this time the archaeologists can use the bone samples without doing much more than noting that they are human bone” (Goldstein, 2006:383). A lack of time and/or of funds for an osteological analysis of skeletal remains, or deciding that reliance on old reports is satisfactory, has unfortunately led to studies that I would refer to as pure “sample archaeology” rather than bioarchaeological study. It is long established that certain pathologies, with traits recognizable in skeletal remains, can affect the isotopic level of $\delta^{13}C$ and $\delta^{15}N$ in human collagen in those elements (e.g. Katzenberg & Lovell, 1999). Despite this knowledge, information of the specific pathologies relevant to this are not routinely screened for, or at least reported, in isotopic studies. There is a further advantage of an osteologically-trained bioarchaeologist carrying out sampling which is seldom emphasized; graves, especially those from burial grounds used over long periods of time, often contain remains of more than one individual, and sampling bones from the correct individual (the primary burial, associated with artefacts, etc.) may not always be straightforward unless one is specifically trained in skeletal anatomy. Generally in isotope studies, the only basic information required is naming the skeletal element sampled. I find this approach unfortunate as this leaves considerable sampling issues unattended that could have a great significance in interpreting the results of the isotopic analysis.

Another problem with some isotope studies today is their scale. Some very small studies are used to pursue some big questions. For example, Montgomery & Evans (2009) sampled only 13 individuals; Hemer et al. (2014) sampled 12; and Eerkens et al. (2015) just six. The few individuals sampled can also be a problem in the sense that these are often selected for being deviant in some way (such as artefacts found with them, or being victims of violence), making it very difficult to interpret the results on a wide scale, as some researchers have come to realize (c.f. discussion in Eckhardt et al., 2014). Since these studies aim to discuss phenomena on a wide basis (mobility in the community, for example), using a small, often deviant, sample becomes a problem. In essence, this too can be attributed to a less defined and selective sampling strategy, similar to the problems regarding taphonomy and pathology.

Undertaking destructive sampling of human remains since the very beginning, and then comparing these to today's enormous samples is an ethically challenging aspect rarely addressed in isotope studies. Mays et al. (2013) have formulated some official guidelines for English archaeology. They list a number of important issues to take into account when planning any study using destructive methods. The most important question they ask, however, is whether it is really necessary, or whether the research questions can be sufficiently answered using non-destructive techniques. This too would need to be put in context with how destructive the sampling is, as there is a constantly developing tendency in studies towards smaller and smaller samples used and yet an increase in the complexity of information which can be extracted from them.

2.1.4 Sciences, humanities and archaeology?

Almost a decade ago, Pollard and Bray (2007) suggested that part of the problem with the sciences and humanities meeting in archaeology relates to linguistic difficulties, i.e. incompatible discourses (*sensu* Foucault, 1989). They also propose a mutual respect for the types of training that both fields require rather than emphasising scientific training as being intellectually superior due to its demands of knowledge of how to operate complex machines, chemical preparation, and so on. On the other hand, scientific archaeology has been accused of being devoid of theory and lacking specific and context-related research questions (c.f. review in Martinon-Torres and Killick, 2015). According to Killick, this is an issue to do with lack of control and rigour within the sub discipline of scientific archaeology. The practice of journal publication is the dominant form of research dissemination in the scientific subfields, unlike in archaeology which is also part of the problem. This is resulting in the publication of sometimes very small studies, or studies lacking specific research questions or archaeological relevance. Since these studies present scientific results (measurements acquired through scientific sampling), they are able to pass through peer review, the main focus being upon the accuracy of the science part of the paper. Martinon-Torres and Killick (2015) argue in their review of the state of scientific archaeology that there is a need for being more explicit in expressing, similar to in archaeology at large, the role that theory plays in designing a research study. They also recommend that the potential that comes with new methods should be used in designing the research questions. Questions asked should not be the same, repeated old ones; new methods make new questions a possibility, and these should be the focus of new research. In my opinion, one way of achieving this could be to use a theoretical framework such as human-centred archaeology to devise new research questions *originating* from the human remains rather than being directed *at* them.

The theoretical framework: human-centred archaeology

2.2

Is there really a need for yet another approach, the human-centred archaeology as I define it here? Is not the well-established, popular, and highly inclusive concept of bioarchaeology sufficient? I argue that the human-centred archaeology is sorely needed and fills a gap by allowing researchers to define a scientific discourse in more detail than bioarchaeology has allowed for so far. I see a need for defining research using an interdisciplinary approach with a focus on humans as the subject. Moreover, I argue that the concept of interpretation is not given sufficient weight in bioarchaeology in comparison to archaeology at large. I will develop these arguments in more detail below after a closer look at the existing concept of bioarchaeology.

Bioarchaeology is not enough?

2.2.1

Bioarchaeology is a widely-used concept which has a lot of potential; it is literally transcending the divide of the humanities and hard sciences by its very definition. *Bios* (Greek) means 'life' and the prefix *bio*- can take on two meanings:

1. indicating or involving life or living organisms: biogenesis, biolysis
2. indicating a human life or career: biography, biopic (Collins English Dictionary, 2012).

Archaeo means 'to begin' (from Greek *arkhaio*) and is equivalent to ancient, while *-ology* is simply a science or other branch of knowledge (Collins English Dictionary, 2012). The concept of bioarchaeology is complex and dynamic if both meanings of *bio*- are given equal importance: The first meaning is concerned with the physical biological aspects of humans as living animals; The second, however, sets humans apart and deals with life on a more abstract level, including social and cultural behaviour. By the very definition of 'human' in relation to other animals, cumulative culture is our only distinction valid throughout the field of paleoanthropology today, hence biology and culture should be studied in relation to, and with, one another when based on human remains. While processes such as the accumulation of isotopes and the development of disease and growth are biological in nature, the initiation of these processes is inherently cultural. In other words, while dietary and provenance isotopes mirror the isotopic composition (more or less clearly) of what is ingested by a human at a given time in life, as changes in the skeleton reveal adaptions or physiological stress, decisions made by the human concerning what foods to ingest or what actions to do (the lifestyle, in essence) are not only biologically determined (by food intolerances, availability of edible foods, and so on), they are culturally determined too (food taboos, prestige foods, etc.).

Without going so far as equating living human bodies with material culture, as Sofaer (2006) does, I consider human bodies, and to some extent the skeletal remains, as clearly interrelated with their physical and cultural environment. One most tangible aspect of entanglement (c.f. discussion in Hodder 2012, chapter 5) in my interpretation of the concept, is that of dietary isotopes. The dietary isotope composition in bone, for example, is a biological imprint of a cultural expression. However, the isotope ratios are intrinsically an unintended byproduct rather than a conscious signal of social/ cultural choices (such as body modifications like filing of teeth). The specific isotopic signal that eating a certain food will result in is not a factor of consideration for the person selecting food. This makes dietary isotopes an unconscious form of cultural expression, influenced by both biology and culture.

Defining bioarchaeology as the *archaeology of life* is not sufficient in my opinion, however. Rather, an archaeology of *death* should be included too, here defined broadly as including any aspects of the physical human remains relating to the time of death (such as the mode of death, if possible to discuss) and any peri- or post-mortem changes to the bones (such as taphonomical processes like disarticulation, fracturing, animal gnawing, etc.), whether a result of biology or culture. The archaeology of death is a somewhat ambiguous concept, often focused on everything except the actual death and the dead body itself. Instead, the primary focuses are usually artefacts and burial form as indications of social meaning (c.f. Chapman et al., 1981; Parker Pearson, 1999), as well as some aspects of the life of the deceased (age, sex, pathology, etc.), also interpreted with social factors. In his review of this type of study, Robb recently argued that "We have not had an 'archaeology of dying' or an 'archaeology of death'; we have had an archaeology of already dead persons" (Robb, 2013: 442). Interestingly, Robb emphasizes that the way forward towards an actual archaeology of death is if osteology and taphonomy (defined by Robb as *Anthropologie de terrain*, 2013:446) "abolish the disciplinary boundaries" (2013:455), thus, studying life or death from skeletal remains would fall under the same subject. Although I agree that this is the way forward, I disagree that taphonomy is in any way separate from osteology. The concept of bioarchaeology, emphasizing life, which seems to be what Robb is referring to, is, however, less appropriate than the older osteology (or physical anthropology) if death should be included in the focus of study. Today, taphonomy is sometimes referred to as funerary taphonomy (e.g. Knüsel & Robb, 2016) to signal it as the specific taphonomy of human remains. That concept implies an exclusion of remains buried in a manner other than funerary, such as the concealment of a body, or unburied all together, such as a wetland deposition. Consequently, I prefer to use a concept that by definition includes *all* contexts where human remains are found, regardless of whether these remains are the result of funerary acts or otherwise. Such a definition and an appropriate concept is, as far as I know, not yet available which is why I suggest the introduction of a new concept: *mortographies*. Because those studying skeletal remains often discuss what happened to the individuals in life – *biographies* – discussing what happened to the individuals in death could therefore be appropriately named *mortographies*. I define *mortographies* as including the events from death (including the manner of death) up until excavation and today. In approaching *mortographies* all aspects of the human remains that are relevant in order to understand death and skeletal decay should be included and specifically studied *in relation to* the archaeological context in which the remains were found.

Archaeologists generally have a higher status attached to their fieldwork expertise than I would argue is the case in bioarchaeology, probably due to the active acknowledgement of the significance of excavation as a scientific approach (c.f. Berggren & Hodder, 2003; Berggren et al., 2015). The claim that the process of interpreting the past starts both methodologically and theoretically "at the trowel's edge" suggests a higher status than a simple "recovery" of material later studied by specific experts. The information available when viewing the skeletal remains within their context *and* in the lab should not be seen as primary and secondary. Excavating skeletal remains is an activity that is greatly benefitted by a detailed anatomical knowledge, an understanding of non-skeletal concretions of pathological origin and, not least, a knowledge of the taphonomical processes involving bones. These are skills that are as important as a general archaeological understanding achieved through the experience of excavation. The integration of archaeologists with osteologists is crucial for the progress and development of archaeology, not substituting one for the other. The status of the excavation process of the skeletal remains still needs to be voiced both within osteology and in communication with archaeology at large and there is room for further improvement. In addition, since the excavation process can never be fully "reversed" and is by definition destructive (see further discussion below), if anything, more resources should be directed to analysis and documentation during excavation rather than post processing. Once the bones are collected, lab work is not compromised in the same way as the bones are still in the museums, even if not fully investigated after the excavation. The archaeological context, however, is not preserved at all in the same way. The value of skeletal collections is well acknowledged as they generate important questions about population-level patterns in areas such as diet, migration, genetic variation, stature, and health. This information is possible to extract (and review with the development of new methods) at any time once the remains are excavated, but only if collected and curated, of course. Today, as I see it, the more imperative issue is the documentation of the destructive excavation process. The best way to achieve this higher status of fieldwork, in my opinion, is to develop the current standards and formulate a detailed and specialized methodology. Such a methodology should involve specialists – osteologists – and should strive to integrate with archaeology, but it does not necessarily need to be called ‘bioarchaeology’. Moreover, this methodology needs to be demonstrated to be investigating interesting research questions that relate to archaeology at large. For relevance to both fields, it is also crucial that the methodology is up to date with archaeological excavation techniques, and is not too time consuming to carry out which would result in delays of excavation.

In conclusion, there are several problems with the definitions and use of bioarchaeology as an approach, but the primary problem is that it is too broadly defined.

2.2.2

Forensic anthropology as a human-centred approach

Forensic anthropology, or even forensic science broadly speaking, presents a good likeness to what I argue is a human-centred approach. In fact, it is the definition of human-centred in the sense that the overall aim with all investigation is to understand what happened to a human being in life and in death. In doing so, various disciplines or fields – such as sociology, psychology, entomology, sedimentation, DNA, isotopes, osteology, archaeology (excavation), medicine, and so on (c.f. contributions in Dirkmaat, 2012) – are integrated into an interpretation. This interpretation serves to conclude what could have happened to a human being, that is, what is more likely or unlikely. This is achieved by the integration of all sources of information potentially relevant – not just a human body, but all lines of evidence such as objects, spatial relations, psychological analysis, textual evidence, etc. Such an approach is thus a truly integrated and interdisciplinary one.

Since the context of forensic science is not archaeological, it is not appropriate to call it an archaeological approach. Forensic archaeology, and the use of archaeological methods in forensic contexts or forensic methods in archaeological contexts (c.f. Hunter et al., 1996; Blau & Ubelaker, 2009), is mainly focused on either fieldwork or analysis of human skeletal remains. Forensic archaeology is not an appropriate substitute for human-centred archaeology since it is only the focus on humans which is shared. The focus on criminal activity that is the very definition – and limitation – of “forensic” is precisely the reason why using this term for anything else in archaeology is misleading. It is a paradoxical explanation but I would say that a human-centred archaeology is, in essence, forensic science without a crime focus, and of course in an archaeological context.

2.2.3 Why the human-centred archaeology is interdisciplinary

On an epistemological level, humans are a perfect example of a phenomenon more complex than any one specific aspect of their being; humans transcend both culture and biology through the very definition of what it is to be ‘human’. In my opinion, if the study of humans is used as a source for increasing knowledge about the past, the complexity involved in this study requires approaches involving more than one single discipline. There are many similar definitions and names of concepts which include more than a single discipline. Inter-, pluri-, multi-, cross-, and transdisciplinary are often used without definition, or as synonyms, either deliberately or accidentally. Gibbons et al. (1994) and van den Besselaar and Heimeriks (2001) have given some well cited definitions of some of these concepts as well as discussing the development of research addressing more than just one discipline. I will not account for all these concepts but focus on the definitions of *multidisciplinary* and *interdisciplinary* to differentiate these central, and different, approaches which I find to be most relevant to archaeology. The definitions given by Gibbons and van den Besselaar and Heimeriks are quite consistent:

> [P]luri-/multidisciplinary is characterized by the autonomy of the various disciplines and does not lead to changes in the existing disciplinary and theoretical structures. (Gibbons et al., 1994:30)
>
> Interdisciplinarity is characterized by the explicit formulation of a uniform, discipline-transcending terminology or a common methodology. (Gibbons et al., 1994:31)
>
> In multidisciplinary research, the subject is approached from different angles, using different disciplinary perspectives. However, neither the theoretical perspectives, nor the find-

> ings of the various disciplines are integrated in the end. An interdisciplinary approach, on the other hand, *creates its own theoretical, conceptual and methodological identity.* Consequently, the results of an interdisciplinary study of a certain problem are more coherent, and integrated. (van den Besselaar & Heimeriks, 2001:706, my emphasis)

In my definition of interdisciplinary research, based on the two latter citations given above, I would like to specify that it is an approach that means to synthesize results from different methods under two specific prerequisites: (i) that the researcher(s) has a deeply rooted understanding of all the methods used, as well as the resulting biases, and (ii) that the material and all relevant aspects of the transformation processes resulting in its current form are also taken into account. The part of the research process that is interpretation becomes transparent when the results are specifically screened from a methodological perspective. I further define research as any study that is not purely a descriptive collection of data/observations but which claims to make inferences – interpretations – from these. Interpretation is the second element that I argue is crucial for human-centred archaeology and will be addressed in detail below.

Why human-centred archaeology emphasizes interpretation

2.2.4

The definition of archaeology that Pollard and Bray (2007) use in their discussion, on integration of scientific techniques in archaeology, highlights the importance of interpretation as a concept of central meaning within archaeology. Archaeology is:

> the complete study of human society in the past through an *interpretation* of its material remains. (Pollard & Bray 2007:246, my emphasis)

The concept of interpretation is rarely defined in archaeological theory, but frequently discussed, (compare Olsen, 2001; Johnson, 2011; Hodder, 2012), probably because it is so fundamental to the field today. A simple definition of interpretation can be: "an explanation *or opinion* of what something means" (Cambridge dictionary, web resource: my emphasis). For me, this definition, and the concept of interpretation, is crucial to acknowledge in all forms of, or fields interacting with, archaeology. If subjectivity is acknowledged as always present to some extent – in the description of empirical evidence, in the choices of methodology (and theory behind these), as well as the selection of material – then this can unify all fields in or related to archaeology, however defined. It is a challenge to be transparent with the process of the interpretation whilst simultaneously expressing that it is, indeed, an interpretation. Most archaeological research is more or less transparent in its explanation of the process leading up to conclusion. However, since the advent of post-processualism in archaeology, the active acknowledgment and explicit use of the term *interpretation* is a crucial element of the field discourse in a way that is simply not comparable to most other disciplines. Indeed, it is an important signal to use and, actually even more so, to *not* use the term for the archaeologist readership. The vernacular used in the sciences, for example, is different, and articulating this concept is not necessarily frowned upon (c.f. Dror et al., 2011) but neither is it a *necessity* as is expressed so clearly in the very definition of archaeology. So, to succeed in developing an interdisciplinary approach to archaeology (characterised by a shared terminology, see discussion in 2.2.3), I argue that the use and awareness of the term *interpretation* in the dissemination of research results is pivotal.

2.2.4.1 The excavation filter: the starting point for all archaeological interpretation

The significance of the initial recovery of archaeological sources, the excavation process, is impossible to overstate in any archaeological study. It is the one filter that all future uses and interpretations originate from and are limited by. The very act of investigating, excavating, is one of destruction so the one experiment all other studies are based on is one that can never be replicated. By this reasoning, it can be questioned whether archaeology is science *per se* as a principal component of any scientific methodology is reproducibility. In order to consider archaeology as science, in my opinion, it must be acknowledged that the excavation *process* needs to described as transparently and detailed as possible. Documenting the process of excavation, including explanations of all decisions made, is as important as collecting the actual remains. This is where the interdisciplinary approach should start as well, with experts being part of this process *in the field*, participating in these decisions and helping to describe the process. Working from a human-centred archaeology, this “filtering” of the excavation should be given more importance and research focus. It is no coincidence that Paper I, dealing with excavation in particular, is presented first of all the other papers accompanying this thesis. This is intentional, to make a statement that this comes before everything else.

Definition

2.2.5

I define *human-centred archaeology* as an interdisciplinary approach that emphasizes the interpretational aspect of any observation and discussion relating to humans in the past. Interdisciplinary studies involving archaeology are difficult to define. Archaeology, by definition, involves any field studying “human society in the past” (compare Pollard & Bray, 2007:246, see 2.2.4 above), yet at the same time is a field of its own (compare discussions and field development in Pollard & Bray, 2007; Martinon-Torres & Killick, 2015). Here, I choose to see osteology, and isotopic and digital approaches, as fields different to archaeology. These three fields are regarded as subfields in archaeology, which is true if you see them as applied simply to archaeological questions. However, as I see it, these fields have a viable, scientific use expanding well outside of archaeology, using some of the exact same scientific methods. For example, osteology in forensics, isotopes in food provenance studies, or digital approaches to landscape analysis gives the fields relevance independent of archaeology. They can, and I argue should, be regarded as fields of their own, thus adding another discipline, either in a multi-disciplinary or interdisciplinary manner, to archaeology at large. I am sure not all archaeologist, bioarchaeologists, osteologists, and isotope or digital experts would be happy making this distinction due to a fear of alienating instead of integrating these fields with archaeology. I see this acknowledgement as the way to integrate these approaches and as a means for actively differentiating multi-interdisciplinary from interdisciplinary studies.

The human-centred approach is not just about studying human skeletal remains and researchers do not have to be trained osteologists to practice it. Neither is the approach broadly about humans in the past – the very definition of all archaeology. It is instead about applying a human and individual perspective to any archaeological sources. When querying any material or phenomenon, the question to be answered in a human-centred approach is always 'How does this relate to the actual, physical individuals that it was in any form of contact with in the past?'. The relation with the specific human being(s) is the focus. The human being is influenced by both biological and cultural elements which are intertwined and need to be understood as a whole, not simply as unconnected parts. This makes an interdisciplinary approach ideal, if not even a necessity. The human-centred approach is not about understanding the material uncovered, it is about understanding the people who engaged with them. This understanding can come from investigating the materials themselves, or other phenomena, as well as human remains.

2.2.5.1 Current examples of a human-centred approach in practice in archaeology

Human-centred archaeology need not be a study using human skeletal remains as a primary source, as mentioned above, but I have chosen human skeletal remains as the basis of this study as I consider these remains as the best primary source available to me to successfully investigate my research questions. However, the scope of the human-centred approach I suggest here is larger and could include all studies that fulfil the following criteria:

- it is clearly interdisciplinary
- interpretation is emphasized
- has the individual human being in focus
- has an archaeological context

One example of this approach being used without consultation of human skeletal remains is the artisanal perspective (Botwid, 2016). There, the understanding of the artisan/crafter is retrieved from today's craft experts. This allows the researcher to investigate not only how the artefacts where manufactured (technique) but also to make interpretations of the crafter's skill and even possibly age (Botwid, 2016). In this example, ceramic sherds are presented as the main material but are explored both from an archaeological and craft perspective (i.e. interdisciplinary) and the human (the artisan/crafter) is clearly the centre of the study rather than the ceramic sherds themselves. This parallel is also interesting in that many chemical analyses are performed on the ceramic sherds in a manner similar to isotope studies on bone and also often without addressing the human and individual perspective, only the material itself.

Others have tread this path before me in a similar manner to the approach taken in this thesis, with human remains as a basis of the study. They have not articulated it to be a specific path as I have done through naming their approach, but aspects of these studies are still very similar. I will give two specific examples of studies which used human remains as a primary source and which I define as having an excellently executed human-centred approach. I have found their focus on interdisciplinarity and interpretation/ reinterpretation especially inspiring.

Scorrano et al. (2014) present a case of a young Iron Age woman with signs of extensive pathology on her skeleton. They discuss conflicting interpretations of these signs from osteology (poor health indicating a "poor" person), isotope study (diet high in protein indicating a "rich" person), and archaeology (a fine tomb indicating a "rich" person) in coherence with DNA (which indicated a person with celiac disease). The discussion finds that these interpretations are not necessarily conflicting; the evidence of a "rich" diet could also be indicative of starvation, where the protein source becomes the person's own tissues, not food. The skeletal changes found would be coherent with a person starving from a very young age, as a person with celiac disease may well have. Both the interdisciplinary and the interpretation aspects are very well presented in this study.

The second example is the study of Pearson and Meskell (2015) regarding corporeality and flesh in Neolithic Catal Huyuk. This study is also addressing interpretation of different sources, although not on an individual level, as Scorrano et al. (2014), but on a population level. They use isotopes, osteology (age, sex), burial taphonomy, the use of plaster on skeletal remains, and artefacts in an interdisciplinary discussion. Their interpretation of society is very different from that previously suggested which had discussed the society as practicing a fertility cult, an interpretation based on the figurines which have been understood as representing fertile women. Pearson and Meskell instead see the figurines in context with the plastering of exhumed skeletonized remains and thus as representative of a society obsessed with the body. The society was celebrating the specific bodily expression of aged individuals (of both sexes as the figurines are reinterpreted), as well as their interaction with the dead by fleshing their bones with the plaster. The corporeal aspects of these figurines, such as the depiction of larger bodies with older age, can be correlated with burial space (volume) and isotopes indicating a more carbohydrate-rich diet in older age for both sexes (age and sex osteologically investigated). This study integrates an interdisciplinary methodology, has a clear human focus, and is most transparent with the interpretation of the sources they have included.

Although I cannot claim that the recent research has been a direct inspiration for formulating the concept of human-centred archaeology, this does not mean it is not connected to the archaeological theory of today. I argue it clearly is, as evident in the three specific examples discussed above. Furthermore, an interesting voice to this "trend" was given very recently, in an explicitly theoretical context, where *humanness* was launched as a perspective in archaeology (Barrett, 2016). Barrett's discussion is a continuation of the highly popular concept of materiality. He argues we should be studying a human "presence" in the archaeological record, not just the material *per se*. This "presence" is exactly what human-centred archaeology is also about. But in Barrett's work, and many similar earlier versions (c.f. Olsen, 2010; and contributions in Meskell, 2008 and reviews in Knappett 2011; Olsen, 2012; Jones, 2016), materiality is presented as primarily, if not solely, applicable to artefacts and monuments. How can it be claimed that we should use materiality to study the human presence in the archaeological record and then not even include human remains explicitly in such a definition? In my opinion, it is a problem that human skeletal remains are virtually ignored as sources in these explicitly theoretical discussions (there are, however, exceptions, such as Sofaer, 2006, and to some extent Hodder, 2011). Although the will to address human presence, humanness in particular, is articulated in archaeology, this concept needs to be developed further. A human-centred archaeology could be a starting point, or part of this movement, or merely a parenthesis. Only the future will tell.

Positioning 2.2.6

The theoretical framework for human-centred archaeology presented here is not only my attempt to find a way to include fields with very different traditions and origins (archaeology, isotopes and osteology) in one study, it is also my positioning in relation to an archaeology that is conflicted between the theoretical, largely post-processual archaeology, compared to compared to what is, in my opinion, an often processual approach inherent in scientific archaeology (c.f. discussions in Pollard & Bray, 2007; Martinon-Torres & Killick, 2015). Isotopic analysis, practiced to a much greater extent in ecology and biology, is, in archaeological terms, infused with processual elements. Methodology (measurements, numbers, models, and calculation) is in focus in publications, while overall interpretation (what does this tell about society) takes second place to "facts" (they ate mainly fish since the isotope values are x and x). The results from isotopic analysis are seen as direct primary data, often claiming precedence over other types of evidence (such as interpretations of subsistence from material culture, archaeozoological assemblages). Osteology, in my opinion, is more of a middle ground with some clear processualist scientific attitudes towards interpretation, but with an awareness of, and emphasis on, representativity more similar to archaeology generally. *The osteological paradox* (DeWitte & Stojanowski, 2015; Wood et al., 1992; Wright & Yoder, 2003) is a prime example of the discussion on representativity and is a truly essential concept in the field. Human-centred archaeology, although including elements such as isotopic analysis, is first and foremost an archaeological approach emphasizing interpretation. As such it is more post-processualist than processualist, but is really neither one or the other in a strict definition.

2.3

Iron Age Öland

Öland is an island in the Baltic Sea and is today the second largest Baltic island belonging to Sweden. It is visible from the mainland and accessible by crossing the 10-km sea barrier that is the Kalmar Strait. The long and narrow island is approximately 140 km from north to south and, at its widest part, 15 km east to west. During the Iron Age, and continuing up to the late 1900s, the island has been accessible only by sea. The long coastline offers access to marine resources as well as maritime communication. The island is mainly composed of calcareous bedrock that has been extensively quarried since the Iron Age and used to build houses and other still-standing monuments, rendering an unusually apparent visual presence also today in the landscape (Fig. 2). The geology has also provided close to optimal conditions for the preservation of the human skeletal remains.

The Iron Age (500 BC–AD 1050) in South Scandinavia is divided into many subperiods depending on the archaeologist studying Öland and on the descriptions and definitions of the graves: the Pre-Roman Iron Age (500 BC–AD 0), Early Roman Iron Age (AD 0–200), Late Roman Iron Age (AD 200–400), Migration period (AD 400–550), Vendel period (AD 550–800), and ending with the Viking Age (AD 800–1050) (definitions from Beskow-Sjöberg & Arnell, 1987; Beskow-Sjöberg & Hagberg, 1991; Fallgren & Rasch, 200; Hagberg & Beskow-Sjöberg, 1996). These periods are in turn often grouped (Table 1), and the Early (500 BC–AD 500) and Late (AD 500–1050) Iron Age is the most important division.

Early Iron Age	Pre Roman Iron Age		500 BC–AD 0
	Roman Iron Age	Early Roman Period	AD 0–200
		Late Roman Period	AD 200–400
Late Iron Age	Migration Period		AD 400–550
	Vendel Period		AD 600–800
	Viking Age		AD 800–1050

Table 1. The chronology of the Iron Age in Öland as used in this study.

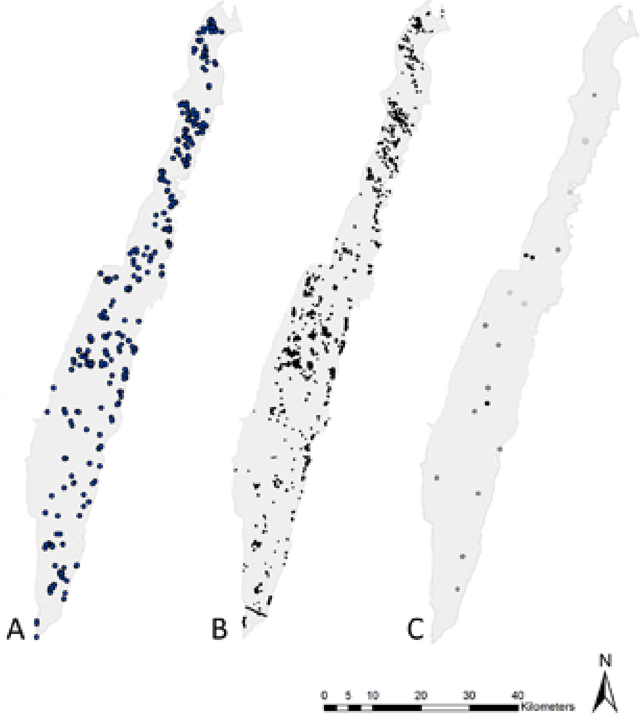


Fig. 2. (A) The partitioning wall systems. (B) The spatial distribution of the preserved house foundations over the island. (C) The ringforts (Black: oldest type of forts [Hässelby, Vannborga, Norra Möckleby]; grey: forts dated AD 200–600 by typology and/or finds; light grey: destroyed forts of unknown specific typology [Sörby, Svarteberga, Åkersberg, Östra Vässby]). Data from http://www.fmis.raa.se/cocoon/fornsok. Supplemented with Fallgren (2009) for the ringforts. Esri, HERE, DeKorme, MapmyIndia, ©OpenStreetMap contributors and the GIS user community.

The Iron Age in Öland has been the focus of research on and off ever since Mårten Stenberger (1933) took an interest in the island. The data collected by Stenberger, and many of his interpretations, are, to a large extent, still valid. Numerous theses since the 1960s have explored different aspects of Iron Age Öland (in chronological order: Hagberg, 1967; Herschend, 1980; Näsman, 1984; Räf, 2001; Fallgren, 2006; Monikander, 2009; Telldal, 2012). These studies, and other smaller studies, portray a complex and intense Iron Age. There is a heavy focus on artefacts and the period AD 200–600, with the votive finds in Skedemosse (Hagberg, 1967; Monikander, 2009), the gold (Herschend, 1980), and the imposing structures of the ringforts (e.g. Stenberger, 1933, 1934, 1948; Hagberg, 1979; Andrén, 2006; Fallgren, 2008, 2009; Tegnér, 2008; review in Engström; 2015). Many of these studies have dealt with new aspects of the same sites, for example Skedemosse (Monikander and Hagberg) and Eketorp (Telldal, Näsman; see also Engström, 2015). Only one study covered a longer time span, focusing on landscape organization of settlement and graves (Fallgren, 2006). For a detailed and full review on the archaeological history of Öland and research covering other periods on the island see Paphmel-Dufay (2015). Since the graves are the focus in this study, I will first discuss the Iron Age research in general on Öland to give an overview on the state of current understanding of the Iron Age society. Research on burials and/or human remains will be detailed in a separate section following that account.

2.3.1 Archaeology

The archaeological research focus on Iron Age Öland gained momentum with the comprehensive works of Mårten Stenberger (c.f. Engström ,2015). In *Öland under äldre järnålder* (*Öland during the Early Iron Age*; Stenberger 1933), he put forward hypotheses on the use of the landscape for grazing and extensive animal husbandry that have since been strengthened in the following 80 years of excavations, methodological development, and further research. Some chronological issues have been addressed in later works such as Fallgren (2006), who argues against a crisis in the fifth century based on continuity in settlements. In his thorough and detailed investigation in settlement patterns on Öland, Fallgren argues that the stone foundation houses (*jättegravar*/giant graves) began being built around AD 200. There is a shift in the Late Iron Age (after AD 700) where some new settlements are established (with new building techniques, using wood rather than stone) between and outside older villages which could indicate a change in ownership to land and possibly a different social system. Still, Fallgren claims there is an overall continuity in settlement on Öland. This was recently challenged by Fabech and Näsman (2015) who claim a disruption occurred around the sixth century AD and that the record is fragmentary. In the nearby island of Gotland, a decline in settlement was recently suggested as occurring sometime around the fifth century (Svedjemo, 2014). The type of settlements during these periods in both Gotland and Öland show great resemblance to one another and it is likely their development is connected. A decline in settlement during the fifth century AD could be a trait they share.

It is estimated some 230 villages were established in Öland in the Roman Iron Age. The settlements represent an organized communal society, with infields between farm houses. There seems to be very few single farms (Fallgren, 2006:186). In the Viking age (800–1050 AD) hoards (Thurborg, 1988) and runic stones appear to be clearly coastal, primarily found on the east coast and central part of the island (Fallgren, 2006: 180). An increase in the coastal activity and maritime communication could be explained by the great technological leaps in seafaring taken in Scandinavia during this period (c.f. Randsborg, 1991; Callmer, 1992).

The introduction of stone foundation houses is set to AD 200 by Fallgren due to ^{14}C and artefacts with reference to the dates from the (approximately) 50 houses excavated of the 1039 known. The extensive settlement of the island is characteristic of how settlements and burial grounds were tightly knit (Fallgren, 2006: 24ff, 117ff). This is a bit curious as the settlements apparently manifest, as these stone foundation houses, at the time when the burials have declined in intensity. This decline in burials was first noted by Stenberger (1933:56) and is still a valid finding after the large burial-ground excavations in the 1960s and 1970s (c.f. Hagberg, 1979:14; Beskow- Sjöberg, 1987). Beskow-Sjöberg (1987:415) attributes the few Late Roman graves to either being undated (lacking artefacts) and/or because burial occurred in areas not yet investigated. This discrepancy in a dense settlement occurring after AD 200 (the Late Roman period) while the majority of burials occur before (in the Early Roman period) is a cause for concern. When these conclusions were drawn, the use of routine ^{14}C-analysis to date burials was not an option and many burials were excavated long before ^{14}C-dating was even a possibility. Another significant social development, besides the shift in burial practice, can be traced in the many forts in Öland that are believed to be established mainly from AD 200 onwards (see review in Fallgren, 2009). However, the type of fort lacking house foundations has in one case, Hässelby borg, been established to have been in use already in AD 0, and possibly even in 200 BC by ^{14}C-dates (although reliability in this ^{14}C is questioned) (Fallgren, 2006:220).

The division of the landscape with the partitioning stone walls (*hägnadssystem*) that appears more or less concurrent with the house foundations (discussion in Fallgren, 2006: 41f,), is undated on Öland. Compared to similar phenomena in Scandinavia, it could be dated somewhere between the Roman and the Vendel period but Fallgren (2006: 162f) has suggested it could be earlier in Öland. However, for the entire time that Öland has been archaeologically researched, the partitioning system has been seen as a sign of an introduction of a specific subsistence relying on grazing domesticates (e.g. Stenberger, 1933; Hagberg, 1967; Herschend, 1980; Fallgren, 2006). Consequently, it is likely that the introduction of this system would be connected to a change in diet (probably to a highly domesticate-based diet). Due to the lack of specific chronology for the partitioning system, the timing of the change in diet is very difficult to determine. However, stable isotopes in human remains with detailed dates (typology and/or ^{14}C) could potentially allow researchers to trace such a shift in diet in more detail.

The extensive partitioning of the landscape by low stonewalls, interpreted as separating animals from the different fields, indicates an intensive use of the landscape suggesting a significant animal husbandry practice (noted by Stenberger, 1933; discussed in Fallgren, 2006). At first, this was interpreted by Stenberger (1933) as indicative of grazing-type husbandry practice in general (most likely referring to both sheep and cattle in a closer reading of his chapter, which includes pictures of sheep stalls), but was later designated only as cattle husbandry by Hagberg (1979), while still acknowledging Stenberger's publication as the original source of this interpretation. It is possible Hagberg might have chosen to interpret Stenberger's choice of words as referring only to cattle as this interpretation fits well with his own interpretation of the half-moon knives as being directly indicative of cattle hide production and export (Hagberg, 1967) and which has been questioned by Räf (2001). In historical times, from the Medieval period up until the seventeenth century, Öland has been characterized as relying on animal husbandry rather than crops and with, at certain periods, a significant marine (mainly herring) subsistence (Nordmark, 1949). Furthermore, the midland forests in Öland are often pointed out as high yielding in terms of providing complementary leaf fodder which is particularly useful in animal husbandry.

Hagberg (1967, 1987:17f, 21) and Herschend (1980) have taken somewhat different approaches to subsistence in the Roman period, suggesting cattle hide export (Hagberg) and wool export (Herschend) respectively. The basis for these arguments is the partitioning wall systems dividing the landscape to such an extreme degree. Herschend builds his argument on the amount of gold found on Öland, and since at that time recently published osteological reports suggested there were more sheep than cattle in Öland during this period. It is possible that both scenarios could coexist in a sense. The gold hoards are present after AD 400, centuries later than the half-moon knives found in Roman period graves (i.e. from AD 0–400).

Apart from animal husbandry, fishing, both in freshwater (only by Eriksson et al., 2008; see below) and the sea, has been suggested as an activity of subsistence during the Iron Age (see below 2.3.3). There are some small lakes and possibly some fens which could have produced fish in the Iron Age. Fishing implements have been found in the largest fen system on the island (Skedemosse), but they are dated to the Bronze Age when the water level was higher. In the Iron Age, the shallow lake was gradually shrinking and was considerably overgrown by the end of the period (Hagberg, 1967b:85ff; Königsson, 1967). Marine resources such as fish, marine mammals, molluscs, and seaweed could also be available due to the long coastlines, potentially across the entire island. The marine resources, like those of freshwater, could have been used both as food and possibly fodder for domesticated animals during the Iron Age.

Archaeobotany 2.3.2

Archaeobotanical analysis has shed some light on the local situation in Öland during the Iron Age (Königsson, 1967, 1968; Hansson & Bergström, 2008; review in Grabowski, 2011). However, the record is mostly incomplete, especially the chronology. In the Early Iron Age, barley was primarily grown and later rye, with oat being introduced at the end of the Roman period. During this period, C4-plants, specifically millet (which gives higher $\delta^{13}C$ isotopic values similar to a marine-based diet), were not likely to have been grown or imported to any significant extent in South Scandinavia. There are only a few finds from the Early Iron Age and none from the Later (Grabowski, 2011:488). Hansson and Bergström (2008) claim that cereals could have been a status symbol in the Iron Age on Öland. Furthermore, they are not entirely confident that all crops were grown locally and suggest importing could have occurred. At the fort of Eketorp, the paleobotanical analysis is interpreted as indicating that the land was farmed to its maximum potential and that some cereal was probably additionally imported (Helbaeck, 1979:115, 125). The magnitude of the trade with the Roman Empire has been established using different artefactual sources for Öland (Stenberger, 1933; Hagberg, 1967; Herschend, 1980) and in detail by Näsman (1984). Possibly the establishment of extensive trade could have caused a change in subsistence or social organization in the Roman and/or Migration period.

2.3.3 Archaeozoology

The investigated archaeozoological assemblages from settlements in the Iron Age are remarkably coherent and cover the same time. Three of the assemblages derive from fortifications, i.e. ring-forts (Eketorp, Gråborg, and Hässelby borg), of which there are 15 remaining on the island today. There are records of a further four destroyed in modern times, although even more are likely to have been present (Fallgren, 2009). The Eketorp ringfort, located in the southern part of the island, adjacent to the Alvar plain, represents the largest assemblage with a total bone weight of 562.4 kg (Boessneck & von den Driesch 1979; Hallström, 1979). The second largest assemblage is also on the southern part of the island, the ringfort Gråborg (Vretemark & Sten, 2008). Two smaller assemblages are available from Hässelby (Bäckström, 1986) and the settlement Ormöga (Sellstedt, 1966), which are situated close to the centre (on a north–south axis) of the island. The four assemblages span the very same period, AD 200–600 (summarized in Table 2), although typology and ^{14}C suggests Hässelby to date

	CATTLE	SHEEP/ GOATS	PIGS	CHICKENS	FISH	TOTAL WEIGHT	PERIOD	ARCHAEO-ZOOLOGICAL ANALYSIS
EKETORP	30947	37032	6938	327	1106*	564,2	AD 100–700	Boessneck & von den Driesch 1979; Hallström 1979
HÄSSELBY BORG	1029	1392	448	unknown	8	21 kg	AD 200–600	Bäckström 1986
ORMÖGA	180	302	58	unknown	13	33 kg	AD 200–700	Sellstedt 1966
GRÅBORG	549	600	181	15	249	60 kg	AD 300–650	Vretemark & Sten 2008

Table 2. Overview of the representation of different animals (NISP, number of identified specimens) in the bone assemblages from settlements. The data used here from Eketorp are the phases labelled as I, I/II and II in the original source. * of which two specimens are from freshwater species.

from at least 0 AD, and possibly even from 200 BC (Fallgren 2006:220). It is notable that the Viking Age (AD 800–1050) and most of the Early Iron Age (500 BC–AD 200, the Pre Roman and Early Roman Iron Age), are so poorly represented in the faunal record from these sites.

In addition to the samples from the forts and the contemporary settlement Ormöga covering the Late Roman to Vendel period (AD 200–700), there are two assemblages that cover the Late Iron Age to Early Medieval period (circa AD 550–1200): Östra Wannborga and Köpingsvik. These sites have only been partially analysed (Bäckström 1994) and reported which is why they are not summarized with the other sites in Table 2 above. For Östra Wannborga, Bäckström (1994) reports a Vendel and Viking Age settlement (i.e. circa AD 550–1050), with subsistence activities including freshwater and marine fishing and fowling, and the keeping of domesticates such as cattle, sheep/goats and pigs. Less frequent are other domesticates and wild game, such as horses, domestic fowl (primarily geese), seals, beavers, and hares. In comparison to the forts, which are likely to be earlier, both Östra Wannborga and Köpingsvik (here, material dated circa AD 700–1200) have a slightly different profile which includes more pigs. This has been interpreted as potentially indicative of a more urban character of these sites (Fallgren, 1994:131–135). Östra Wannborga is possibly compromised with regards to bone assemblages by Stone Age remains (of which only graves were easily distinguished) as argued by the excavator (Fallgren, 1994:112).

The most frequent animals within the larger archaeozoological assemblages were sheep/goats, cattle, pigs, and domestic birds (Table 2). The heading ‘fish’ is represented by marine/brackish species, mainly herring, with only two specific freshwater fish specimens in total (Hallström, 1979; Vretemark & Sten, 2008). This pattern could largely reflect taphonomy: both poor preservation of fish bones, and the more difficult detection of these bones in excavations. However, the lack of freshwater fish in comparison to marine fish cannot be explained by taphonomy alone; if this was the result of a purely taphonomical effect, both marine and freshwater fish would be proportionally poorly represented. The small contribution of birds in the assemblages is probably also reflective of taphonomy as these bones are less resilient compared to mammals.

Sheep/goats (in many cases difficult to differentiate osteologically) are the most frequent animal and there is a tentative dominance in ewes as well as a kill-off pattern of yearling lambs. This is described by some osteologists as a practice not focused on wool but on milk and/or meat (Boessneck & von den Driesch, 1979:410). Others interpret this as specifically milk oriented (Vretemark & Sten, 2008). Cattle are the second most frequent species and it has been suggested their use was mainly for meat and milk (Boessneck & von den Driesch, 1979; Vretemark & Sten, 2008). Pigs are less common than sheep and cattle, and primarily used for meat. It has been suggested that pigs were likely stabled inside the settlements, like the cattle, while the sheep were grazing further away (Vretemark & Sten, 2008). Apart from these three domesticates, only chickens are considered a potentially significant dietary component (Vretemark & Sten, 2008) alongside fish. Fish are interpreted as being of only minute significance compared to their status in the Medieval period, however (Hallström, 1979; Vretemark & Sten, 2008). Minute and fragile fish and bird bones are much less likely to be preserved than the more resilient domestic mammal bones. The degree of fish and bird bone underrepresentation varies with each assemblage environment and is therefore not easily quantified. However, it is clear that in virtually any assemblage these animals will be underestimated if directly quantified in relation to the larger mammals.

The proportion of species other than sheep/goats, cattle, or pigs in all the assemblages is very modest in compar-

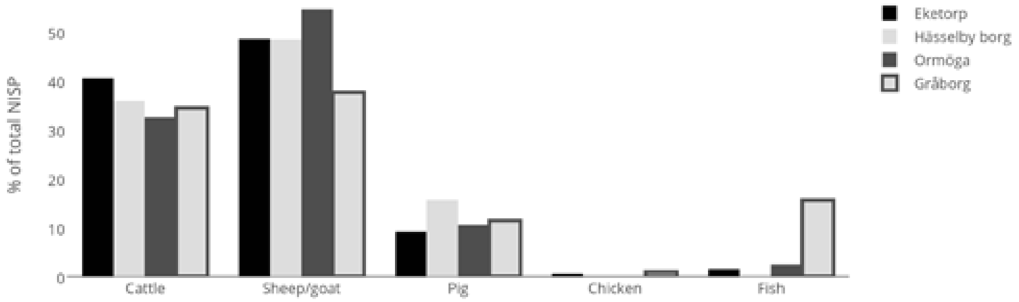


Fig. 3. The occurrence of the most important (dietary) animals in the archaeozoological samples based on NISP. The % is calculated from the NISP total of the selected animals for each sample. NISP: Eketorp (phase I and II) n=76350, Hässelby borg=2877, Ormöga n=553, Gråborg n=1594. The proportion of chickens are unknown in Hässelby and Ormöga as bird bones where not analysed. The presence of fish is also unknown in Hässleby. Östra Vannborga is not included here since there is no summary of NSIP for the site, just for some of the contexts.

ison (Fig. 3). This small number of other species consists mainly of horses, dogs, marine mammals, and even minor occurrences of other wild animals. The animals most likely to be part of the human diet are therefore the most frequent (sheep, cattle, pigs) and those most likely to be underestimated from the assemblages (fish and chickens). The significance of suckling animals as part of the human diet is difficult to estimate from bone assemblages principally due to the poorer mineralization of their bones (and problems with age estimation and suckling practice), but they do occur in these assemblages to a minor extent (Boessneck & Von den Driesch, 1979; Vretemark & Sten, 2008).

2.3.4

The graves

The Iron Age graves on Öland cover most of the island (Fig. 4) and have primarily been described in *Ölands järnåldersgravfält (The Iron Age Grave Fields of Öland)* I–IV (Beskow-Sjöberg & Arnell, 1987; Beskow-Sjöberg & Hagberg, 1991; Hagberg & Beskow-Sjöberg, 1996; Fallgren & Rasch, 2001). Predominantly, excavation results are integrated with osteological and/or archaeological determinations of age and sex in both lists and text. The results are synthesized mainly geographically and often by the very archaeologists that excavated many of these sites. This allowed them to take their significant understanding for disparities and similarities of sites and parts of the island into account. The detail and insight possible with this much first-hand information adds great value to the descriptions of the sites within local and regional contexts. The Iron Age inhumation graves in Öland can be limestone cists (con-

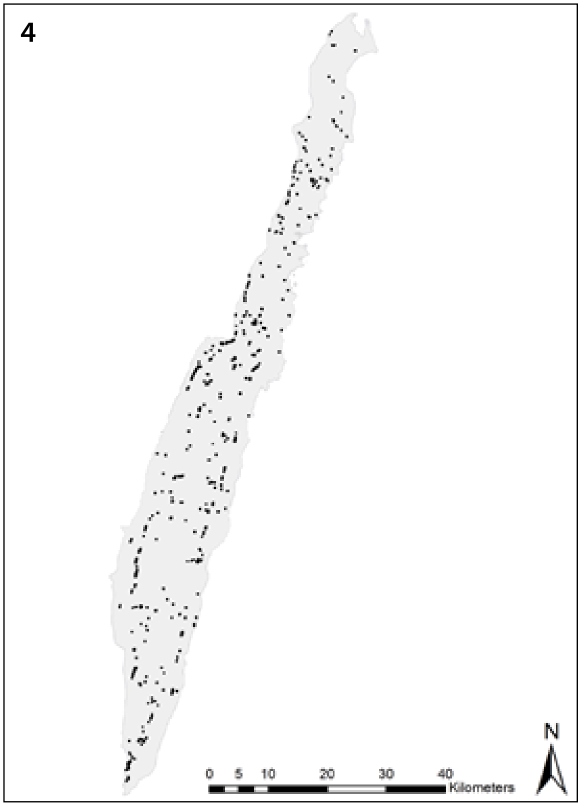


Fig. 4 (top left): The spatial distribution of the registered Iron Age graves on Öland. Data from http://www.fmis.raa.se/cocoon/fornsok.. Esri, HERE, DeKorme, MapmyIndia, ©OpenStreetMap contributors and the GIS user community. Fig. 5 a-c. Kastlösa parish, SHM 25392, Photo id 262:198 (from SSO), :199 (from S), and :1 (detail). A typical simple limestone cist (hällkista). The roof or lid stones (täckstenar) were removed in the later stage of the excavation. This cist, despite seeming undisturbed with roof stones largely in place, was clearly manipulated. The northern part with artefacts was where most bones were found in disarray, probably belonging to one individual. Since teeth (and the skull) was missing, this individual could not be included in this study. Photographs: KG Pettersson, 1955. Photographs used with kind permission of ATA (Antikvarisk-topografiska arkivet), digitized by Torbjörn Linnerud.

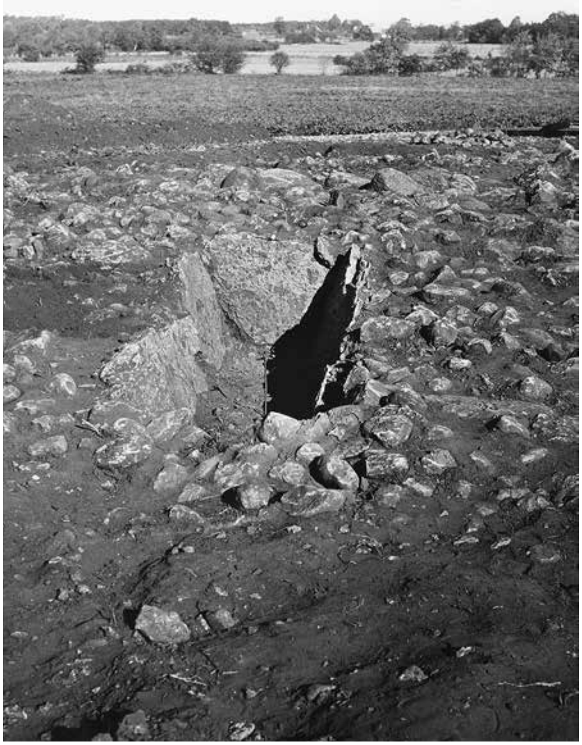
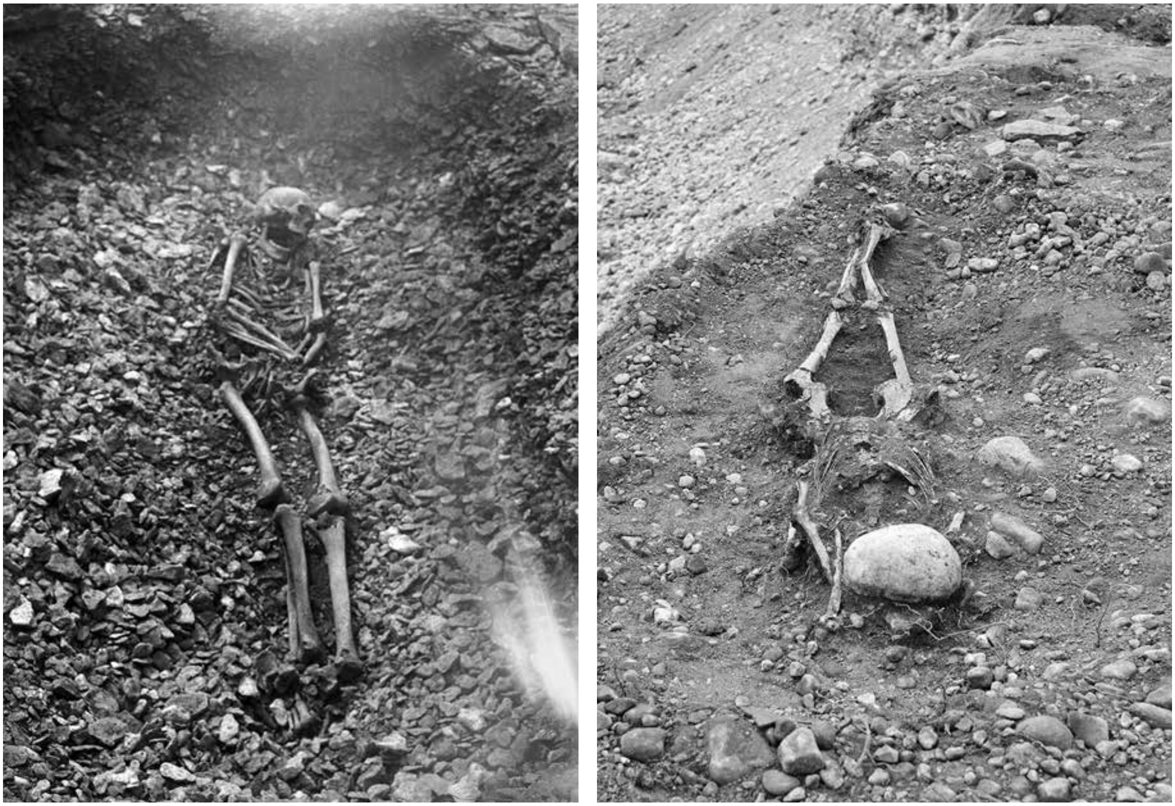


Fig. 6 (left). A2: Gärdslösa parish, Sörby-Störlinge, SHM 27702, A2. A lime cist with more irregular large slabs surrounded by extensive stone paving (stenpackning). This is the central tomb in the stone paving. Often there are more graves within the same paving. This grave contained ID 1033 and commingled skeletal remains in the fill from at least four other individuals. ID 1033 and associated artefacts are interpreted by the excavators as the last burial in the cist. Photo UE Hagberg 1964, from south, photo id A2:2. Photograph used with kind permission of ATA (Antikvarisk-topografiska arkivet), digitized by Torbjörn Linnerud.

Fig. 7 (below left and right). Pit graves (gravgropar) investigated in response to quarrying. Pit graves, but also cists, often lack datable artefacts in Öland making them difficult to contextualize. (A) Böda parish, SHM 21367, grave 24, photo id A7:181. Photograph: TJ Arne, 1935. This is ID 1101 in situ. (B) Resmo parish, N Kvarnbacken, SHM 28514. Photo FKI Sjögren, 1966, photo id A872-193. This is ID 1040 in situ. Photographs used with kind permission of ATA (Antikvarisk-topografiska arkivet), digitized by Torbjörn Linnerud.



structed in different ways with smaller or larger stones, examples in Figs. 5 and 6) or pits (Fig. 7) surrounded by cairns, mounds, or stone pavings (Figs. 6, 8). Artefacts are often recovered in the burials. There are also frequent signs of manipulation and possible retrieval of artefacts, such as disarray of parts of the skeleton (or proper reburials in cists, Fig. 8) and roof stones being moved or missing in parts of the cist (e.g. Fig. 9). But even roof stones being apparently in place is no guarantee of an unopened grave (Fig. 5).

Before the last two of these four aforementioned volumes were published, the conference proceedings *Prehistoric Graves as a Source of Information* (Stjernquist, 1994) arrived as a result of a conference on Iron Age graves held on Öland. It contains several important contributions to the interpretations of, and some very different approaches and attitudes to, the Iron Age graves on Öland. Näsman (1994) discusses the representativeness of Iron Age graves on Öland in this volume. He claims a major problem is that many grave fields are only partially excavated. However, the magnitude of this problem is contested by Hagberg (1994: 231) in the very same publication, claiming that the definition of grave fields is problematic due to their orientation which follows the roads in parallel bands, at times with low density and overlapping. In my opinion, it is Näsman who identifies the most crucial and underestimated problem of all – the many undated graves (simply Iron Age) and the long continuity in the same grave fields spanning the entire 1500 years of the Iron Age. He argues that since they make up such a great proportion (approximately 25% in one example), this violates the representativeness of all graves. The human remains are addressed in his analysis only as secondary to specific burial customs or artefacts and there is no mention of osteological results. Had the humans been included as source material, some of the questions Näsman raises for Öland, such as those on burial rites, would be possible to answer. Näsman's very cautious attitude to the utility of funeral studies, specifically on Öland, is most articulate and he sees graves as indirect sources to understand past societies. This is a reflection of the fact that he simply does not consider the human remains as a source, only the grave itself. An approach such as this is very different to the approach presented here in this thesis. However, Näs-

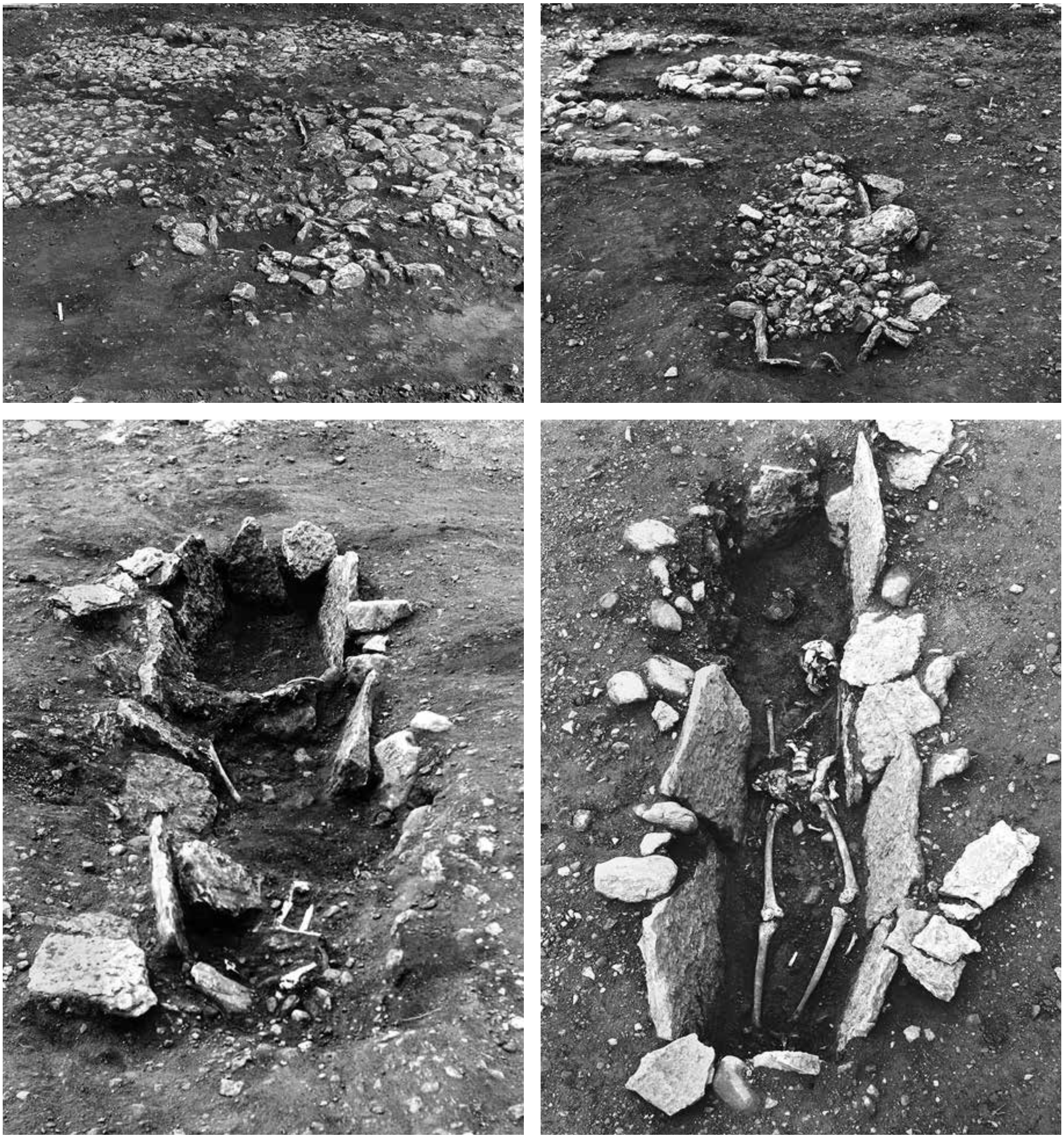


Fig. 8. Gärdslösa parish, SHM 28364, A 108. This is an example of a cist within a stone paving which could have been covered by a mound (gravhög). Photographs used with kind permission of ATA (Antikvarisk-topografiska arkivet), digitized by Torbjörn Linnerud. Photos A-E are in chronological excavation sequence and what was interpreted as different depositions excavated separately (stratigraphical levels).

(A) This is A 108 from south with the stone paving surrounding the grave intact. Photograph Å Nilsson, 1965, photo id 180:1.

(B) This is A 108 from south with the stone paving removed. The big stones filling the lime cist and the outline of the cist (irregular thin slabs of limestone, typical of Iron Age burials in Öland) are clearly visible here. Photograph: Å Nilsson, 1965, photo id 180:2.

(C) This is A 108 from south with the stone paving removed and commingled skeletal parts visible, A 108:II. These remains were commingled and not investigated in this study as it was not possible to associate teeth with other skeletal elements to one single individual with certainty. Except for the three clearly separated individual burials (ID 1014, 1105, 1106), skeletal remains of one or more small children (infants) and extra teeth

from one or more individuals were found collected with these individuals. A 108:I (ID 1105) was the top most individual and under this some commingled bones (A108:II, shown here) were found. Below these some more complete skeletons were found, A 108:III (ID 1014) and in the bottom A 108:IV (ID 1106). There is unfortunately no photograph of A 108:I (ID 1105) *in situ* in the archives or the reports but scaled drawings. This grave is a good example of the complex stratigraphy and disturbance of earlier burials associated here clearly with reburial at least to some extent. Photograph: Å Nilsson, photo id 180:3.

(D) This is A 108: III (ID 1014, see Appendix) which is a complete and seemingly undisturbed individual with an iron object under the left arm. Note the ceramic vessel close by the head in the most northern part of the cist. This vessel was suggested in the report to instead belong to the individual below (A 108:IV, ID 1106). With the human bones were also those of a small mammal which is a frequent find in the lime cist. This probably indicates that the cists were used as nests by these animals which could explain some cases of commingled remains or irregular disarticulation. Photograph: Å Nilsson, photo id 180:4.

(E) This is A 108: IV (ID 11106, see Appendix). This skeleton was disturbed, possibly by the later burial ID 1014, primarily the head was out of place. Note the vessel also visible with A 108:III exposed fully in situ here along with an iron object. It is possible the head was disturbed when these artefacts and/or the individual above (A 108:III, ID 1014) was placed in the cist. This skeleton was otherwise not associated with any other artefacts and a ^{14}C was therefore performed in this study. In my opinion, there is an ambiguity about whether the artefacts actually belonged to this individual or the one above from the documentation (scaled drawings). A108 is a good example of the complex reuse and manipulation of burials in lime cists in Öland. These contexts are very challenging to interpret during excavation. The movement of different skeletal remains and artefacts within the cist is very difficult to reconstruct today, even with the detailed documentation available, consisting of notes, scaled drawings, and photos. The reinterpretation made here, that the vessel is possibly not associated with this individual, can thus only be verified by a ^{14}C date of the skeletal remains (ID 1106) and not using, for example, a taphonomical approach. Photograph: UE Hagberg, 1965, photo id 180:5.

(F) The artefacts in the northern most section of the cist. A complete vessel (Gotlandic type according to report in ATA but of Ölandic type according to Beskow-Sjöberg & Arnell, 1987: 362), an iron dagger with bone handle, bronze fittings, goose humerus (*Branta bernicla*). The typology suggests Early Roman Iron Age (1987: 320) and the occurrence of goose bone is thus interesting, and puzzling, since this would be an early find. Photograph: Å Nilsson, 1965, photo id 180:5.

Fig. 9. Gärdslösa parish, Sörby Störlinge, SHM28364, A 164 (ID 1075). A lime cist filled with larger stones. Possibly some wall slabs were missing and some had fallen into the cist. The body is skewed but apparently in anatomical order (articulated), except for the left arm and leg below the knee. That arm and leg are displaced from the overall anatomical order but the bones in that body part are still as a unit in anatomical order. It appears these parts moved as the body was partially skeletonized and is suggestive of manipulation/reopening. Some other bones could well have moved when stones shifted with body decomposition or other materials decomposed in the cist. There are also additional fragmented remains under this individual, and multiple artefacts. In this case, the excavating archaeologists (M. Beskow) gives a detailed interpretation in the report of which finds are likely associated with which remains and how the remains have been moved/manipulated during the burial sequence. The later burial, the remains of which were most complete (ID 1075, visible *in situ* in the last photograph here), was ^{14}C dated as clearly datable artefacts were not available as clearly associated with the individual. Photographs M. Beskow, 1965, id 164:1, :2, :3. Photographs used with kind permission of ATA (Antikvarisk-topografiska arkivet), digitized by Torbjörn Linnerud.

man's statement is, in part, a product of its time, reflecting opinions held by many archaeologists at that point, and it needs to be considered in that context. Näsman does make an observation of key importance that few other archaeologists working with the grave fields have mentioned, let alone tried to address – how the many undated graves in grave fields with such long continuity present a significant bias not to be underestimated.

In the same publication, Rasch (1994) makes a theoretically grounded interpretation of the Roman Iron Age burial customs on Öland. Rasch claims that there was a shift in burial practice in the final century BC where inhumations were replaced by cremations and more females than males were cremated (Rasch,1994:190f). Unlike Näsman, Rasch has integrated osteological data, age, and sex (although most sex determinations appear archaeological rather than osteological), as well as taphonomy. Rasch also provides a very important and well-grounded discussion on the disturbance of graves and dispositioned bones. The emphasis he puts on the commingling/manipulation aspects of the burial rites by the positioning of the bones (and/or artefacts and/or elements of the grave architecture) gives way to an excellent discussion.

One of the few publications based on osteological analysis of some Iron Age human remains on Öland is also found in *Prehistoric Graves as a Source of Information* (Sjøvold, 1994). Sjøvold gives detailed accounts of selected graves (burial patterns, activity markers, trauma, etc.) and large scale patterns (stature during the Viking Age, for example) that he has seen in osteological analysis. He sees great potential in the completion and full analysis of the Iron Age graves, both the inhumations and cremations, believing this will assist future studies looking to answer questions about society. Where Näsman (1994) sees limitations in both representativity and significance in studying Iron Age graves, Sjøvold sees possibilities, for example: "The great advantage with the skeletal material from Öland is therefore that the number of inhumations through the Iron Age is large" (Sjøvold, 1994:214). The two articles could not be more dissimilar in their approach to the potential of the Iron Age graves on Öland.

Two recent archaeological theses deal specifically with Iron Age human and animal remains on Öland: one in the context of burial (Räf, 2001) and one including bones from the Skedemosse fen (Monikander, 2009). Räf's focus was on the function and meaning of animals in graves, but also on gender (and biological, not archaeological, sex). It is striking that both Räf and Monikander express clearly and repeatedly their frustration with the lack of in-depth osteological analysis of the bones in the contexts they are investigating. The human remains from Skedemosse have, to some extent, been ^{14}C dated to the Iron Age and in the 1960s were osteologically reported by Gejvall (1968). Gejvall makes short notes focused on trauma, on single bones and assemblages assigned as individuals (mainly pieced together post-excavation). The material is fragmented and it is difficult to interpret why Gejvall gives a rather sparse account of the context and the human bones but interprets it as a sacrificial context. In Monikander's case, a more thorough taphonomical analysis as part of a renewed osteological analysis (which was rarely performed for human bones at the time of Gejvall's analysis) would have helped to develop the interpretation of the activities involving humans and animals in the Skedemosse context. For the most part, the human remains are highly commingled and fragmentary, limiting their analytical value.

There is another recent thesis, taking a more regional approach and reviewing Viking Age (AD 800–1050) burial practices in South Scandinavia, which also deals with Öland to some extent (Svanberg, 2003). Rather than focusing on human remains, this study is focused on variations in grave form, artefact occurrences, and spatial distribution for a discussion of social patterns on a landscape level. Svanberg describes how the bi-ritual (cremation and inhumation) cemeteries on Öland are a feature similar to that found in Southwest Scania and Denmark, but not on the neighbouring island of Bornholm. On the other hand, he emphasizes that Öland has a specific character of grave construction and orientation that sets the island clearly apart from these other regions. For example, in Öland, there is no apparent social differentiation of high-status burials, which are frequent in both cremations and inhumations, whilst in other regions, cremations are generally of lower status (as defined by grave goods). The only exception could be the area of Möre, the Swedish mainland coast directly to the west of Öland, which shows some similarities despite a comparatively limited source material (Svanberg, 2003:172ff). Svanberg further interprets these differences as representing at least two groups of people using distinct rituals to distinguish themselves. Nevertheless, it is clear that Öland was defined as one region (Eowland) with a separate identity in some contexts (Svanberg, 2003:175). Svanberg mentions that the varied ritual practice in Viking Age Öland might be explained by a large-scale immigration (Svanberg 2003:174).

Iron Age graves on Öland have been osteologically analysed since the 1960s, using both human and animal bones. As was common practice at the time, many of the osteological results were only presented as appendices to archaeological reports, mainly lists of sex and age. These analyses are summarized in *Ölands järnåldersgravfält I–IV* for each grave field, although the sex determinations in these lists of graves are not always specified if determined by osteological analysis or artefacts. Exceptions are Sjøvold's early synthesis mentioned above (Sjøvold, 1994) and the more recent intricate discussion by Ingvarsson-Sundström (2006) which primarily focused on infant health issues and growth. The various osteological analyses have used different methods and approaches as the methods, aims, and analyses have developed significantly from the earlier studies, leaving it difficult to compare published results.

Using *Ölands järnåldersgravfält I–IV* I have compiled a detailed record of excavated Iron Age burials (Table 3), divided by cremation or inhumation for the subperiods by the authors of each parish chapter. Many graves were found to be empty and/or looted or excavated without documentation and in some cases the bones were not collected or have disappeared. The uncollected remains are still included here when there is a note if uncremated or cremated bones were present. Additionally, cists without bones are counted as an inhumation (since they usually contain only inhumations). In cases with many individuals in one grave, each individual was counted, not just the grave. This could include graves with multiple complete individuals, as well as single duplicate bones; the rationale behind the number of individuals is rarely noted in the tables. The level of detail in recording commingling has not been verified by osteological

Chronology	**Cremations**	**Inhumations**	**Total**
Pre Roman Iron Age (500 BC–AD 0)	48	15	63
Pre Roman/ Early Roman Iron Age (500 BC–AD 200)	30	4	34
Roman Iron Age (AD 0–400)	16	135	151
Early Roman (AD 0–200)	79	203	282
Late Roman (AD 200–400)	22	59	81
Early Iron Age (500 BC–AD 400)	64	45	109
Migration period (AD 400–550)	45	8	53
Late Roman/ Migration period	14	4	18
Vendel period (AD 550–800)	2	6	8
Viking Age (AD 800–1050)	106	206	312
Late Iron Age	6	5	11
Iron Age	239	297	536
Total	**652**	**987**	**1639**

Table 3: A compilation of the number of individuals buried on Öland during the Iron Age. All data is from *Ölands järnåldersgravfält I–IV* and everything is included that has been excavated (unexcavated grave cremation or inhumation could obviously not be deducted). Many graves were found to be empty and/or looted or excavated without documentation or collection of finds (mainly in the late nineteenth to early twentieth century). These figures are of individual human remains (although rarely confirmed by osteological analysis) and not just the grave. If multiple individuals were found during excavation, these are all counted here, not just the grave. The cremations are just cremated bone, seldom osteologically confirmed as human bone. It should be noted that this compilation includes all ages, also infants which are not included in this study due to the sampling selection (only including individuals over seven years of age).

analysis in general but is primarily based on archaeological observations during excavation. Human bones are rarely specified in cremations, but I have included them here as they are considered to be in the burial context.

As can be seen in Table 3, the burial practice started out with more cremation than inhumations in the Pre Roman period. Then, in the early Roman period, the situation is reversed which could be true also for the Late Roman period. In the middle Iron Age (the Migration Period), it seems there is an almost exclusive cremation practice. For the Vendel Period, there are extremely few burials overall. In the Viking Age, both inhumations and cremations appear commonplace although inhumations are dominant. The undated burials, only dated simply as ‘Iron Age’, comprise almost a third (30%) of the inhumations. In my opinion, this is probably an underestimation as reburials in the same cist are often given the same date as those burials which included artefacts, even though these reburials lacked any artefacts of their own. The low occurrence of burials in the middle centuries of the Iron Age is curious. In the Pre Roman period, it could possibly be explained by the burials only dated as Early Iron Age, or possibly indicating a smaller population. The large undated group could be expected to fill either of these “gaps” to make a more continuously large population size likely. It is of course possible that there were periods of decline in population size as well, although without dating (by ^{14}C) the undated burials, this is too risky a deduction considering the very large number of undated inhumations in particular.

2.3.5 Isotope-based studies

In the most recent years, bioarchaeological studies of Öland – bioarchaeological in the sense that they rely on isotopic analysis of human bones – have been published as parts of two theses. Fornander (2011) investigated the Neolithic period on Öland but her results of ^{87}Sr/^{86}Sr baseline values (Fornander et al., 2011, 2015) are applicable also for the Iron Age. This thesis also includes a paper (Eriksson et al., 2008) dealing with diet, δ^{13}C or δ^{15}N from bone collagen or tooth dentine on human remains also from the Iron Age. The results of their Roman Iron Age samples are interpreted as indicating a diet high in freshwater fish. Howcroft et al. (2012) have done similar sampling, primarily focused on a discussion of childhood diet and weaning, concluding that freshwater fish and possibly suckling animals were very important in the diet. These results are of great interest to compare to those from this study, both the actual isotopic values of humans and animals from Öland, as well as their interpretations of diet. Neither children nor intra-individual variation in diet will be in focus in this study because these are already discussed in the earlier two studies and my aim is to add a different perspective on Iron Age life in Öland. Additionally, earlier and later burials than those investigated previously elsewhere will be included here to trace chronological variation and add this perspective to the existing results.

2.4

Research design

The detailed goals of the thesis (i–iv) are explored in the papers as specified in 1.3. They will also be addressed specifically in Chapter 5 (*The human-centred approach "in action"*) under four themes:

- Taphonomy
- Diet
- Migration
- Social organization

The overall aim of the thesis requires that these results should be discussed to show both the advantages and the limitations of this approach on a more general level, as well as for Öland in particular. This discussion will be presented under the same four themes in Chapter 6 (*New perspectives: rethinking old, and new questions*) as:

- Rethinking taphonomy
- Rethinking diet
- Rethinking migration
- Rethinking society

These are all focused on highlighting the specific new perspectives on society on Iron Age Öland from this study, taking the interpretation a step further from the papers and the basic results presented in Chapter 5. I will also address the significance of the outcomes of practicing a human-centred archaeology on a more general level, not just specifically for Öland, and will offer some specific limitations and advantages of such an approach.

2.4.1

The papers

Papers I–V are aimed at addressing issues raised specifically to further the understanding of people and society in Iron Age Öland.

- Paper I, *Virtual Taphonomy: A new method integrating excavation and postprocessing in an archaeological context,* includes a methodological and theoretical element. This work draws on *Archaeothanatology/Anthropologie* *de terrain* and Duday's body of work (e.g. Duday, 2006) while also acknowledging the American origin of this approach: necrodynamics (Wilder & Whipple, 1917). The approach is interdisciplinary and was developed in collaboration with an expert in digital archaeology. A model was presented to highlight both the heuristic relevance and the reflexive approach that the methodology, *Virtual Taphonomy*, contributes.

The paper is published in *American Journal of Physical Anthropology.*

Author contributions:
Both authors planned the acquisition of data and designed the study. The methodology was developed and formulated as a collaboration. For the first part of the excavation (2013), Helene Wilhelmson (HW) collected the data (images) used by Nicolò Dell´Unto (ND) to make 3D models. HW excavated and analysed the human skeletal remains. ND participated in the second season of the excavation, also excavating the very same context, and collected his data (images) in dialogue with HW. ND was responsible for the construction of 3D-models and integration of models in 3D GIS. The database connected to the models in 3DGIS was designed and constructed by both authors. HW performed all osteological analyses, both in the field and lab, and selected taphonomical aspects to highlight. Both authors are the interpreters of the dataset, from field to finished paper.

- Paper II, *Iron Age migration on the island of Öland: Apportionment of strontium by means of Bayesian mixing analysis*, explores the possibilities of an approach based in isotope analysis of Strontium ($^{87}Sr/^{86}Sr$) for provenance. Here, the method itself is the starting point of the study and therefore the entire population is in focus. This allows for the posing of entirely new questions about migration on Öland. The gravity model, an approach hypothesized to allow disentangling the $^{87}Sr/^{86}Sr$ distribution found in the Öland sample, successfully explains the migration pattern detected in both the Early and Late Iron Age. The article is interdisciplinary in the sense that it draws on geology, economics, sociology and statistics and is coauthored with a bioarchaeological researcher specialized in Bayesian statistics.

  The paper is published in *Journal of Archaeological Science.*

Author contributions:
HW planned the study, collected the data (isotope data, archaeological data, osteological data), and performed all osteological and archaeological analysis. The methodology using the gravity model and Bayesian mixing was developed as a collaboration. Torbjörn Ahlström (TA) performed the Bayesian calculations. Both authors were the interpreters of the combined dataset.

- PAPER III, S*hifting diet, shifting culture? A bioarchaeological approach to island dietary development on Iron Age Öland, Baltic Sea*, addresses the dietary development on Iron Age Öland. It uses an interdisciplinary perspective to analyse human remains with emphasis on the interpretation of isotope values from bone collagen (δ^{13}C and δ^{15}N). It is a metastudy on two levels: (i) on the methodology of interpreting diet isotope samples, and (ii) on the relevance of archaeological relative chronology as a basis for attempting to trace dietary shifts. The diet is interpreted using contemporary local animals, unlike earlier studies of Öland's Iron Age diet. The addition of ^{14}C sampling to refine the chronological development of diet is compared to typological chronology from artefacts. I test two different versions (both currently accepted in the literature) of a significant factor for interpreting the isotope results, the TLE (Trophic Level Effect; c.f. Schoeninger & Schwarz 2011:731) for δ^{15}N. The two scenarios can be interpreted as reflecting two very different diets and they are compared to other archaeological evidence from Öland concerning the Iron Age diet and subsistence.

  The paper is accepted for publication in *American Journal of Physical Anthropology.*

  Author contributions:
  The article is the single-authored work of HW.

- PAPER IV, *Migration and integration on the Baltic island of Öland in the Iron Age*, is a study in interpretation of provenance isotope results (^{87}Sr/^{86}Sr and δ^{18}O) in a social and cultural context. The focus is on both the interpretation of the isotope baseline for $^{86/87}$Sr and δ^{18}O combined and the social aspects of migration. Grave form, orientation (or other context), and specific artefacts are considered, and age, sex, and cultural modifications are compared for both locals and non-locals for a discussion on integration.

  The paper is published in *Journal of Archaeological Research: Reports.*

Author contributions:
HW planned the study, consulting Douglas Price (DP) on sampling for provenance isotopic analysis. DP provided isotope analysis for a fee. HW collected the data (archaeological data, osteological data), and performed the osteological and archaeological analysis. The interpretation of isotope results as local/non-local and undetermined provenance was performed in collaboration. The interpretation of the complete results from all analyses was undertaken collaboratively.

- Paper V, *Island hierarchy, violence and society: a bioarchaeological approach to Iron Age Öland*, is an interdisciplinary study with an emphasis on transparency in the interpretation process. The focus is primarily on the most theorized theme in bioarchaeology – violence – and its relation to osteological, isotope, and archaeological parameters. The cases of violence encountered in the Öland population are discussed in detail and interpreted within the population context for a discussion on hierarchy and social organization. Social network analysis and graph theory are used to explore transparency in the interpretation process.

  The paper is submitted to a pending BAR conference volume with contributions from the session "Islands and Archipelagos" in the European Association of Archaeology (EAA) conference in Glasgow in 2015.

  Author contributions:
  The article is the single-authored work of HW.

2.4.1.1 A note on the use of *bioarchaeology* in the papers

The papers III–V all have specific mentions of *bioarchaeology* in the title and/or dedicated subsections. Because the contents explored could not be summarized as archaeology, isotopes or osteology alone, *bioarchaeology* – currently a widely-used concept for indicating this complexity – seemed an appropriate choice of terminology. However, as explained in great detail above (2.2.1), I find *bioarchaeology* to be too broadly defined to sufficiently describe the approach I am using throughout this project. The specific concept that better describes not only the papers but also this entire study – *a human-centred approach to archaeology* – has not, as far as I am aware, been defined elsewhere before this book. I chose to signal the papers as using bioarchaeological perspectives when presenting them to the scientific community, instead of as specifically human-centred, but I must emphasize that this does not mean I subscribe to anything labelled *bioarchaeology* as being a proper human-centred approach by definition.

CHAPTER 3

Material

The material used in this study is related to aspects of uncremated human skeletal remains. Osteological analysis of the physical bones, as well as representations of the skeletons (excavation documentation in the form of excavation reports, drawings, photographs, 3D models, etc.) and chemical analysis (samples of bone or enamel), make up the main material. Other sources of archaeological relevance to Öland are consulted for comparison with the interpretations from the human skeletal remains. All periods of the Iron Age, as well as all types of archaeological contexts for human skeletal remains, were considered. In this chapter, I discuss the selection of the material (the individual human remains) and the resulting bias and limitations, as well as the material's potential.

3.1 Selection of human remains: advantages and limitations

Uncremated human remains from many different types of archaeological contexts other than "burials" are included in this study. This enables a perspective which takes into account whole populations in its discussion of some aspects of the Iron Age society, rather than only those individuals who were "properly" buried. Alongside looking at data for whole populations, individuals and biographies are also taken into account, as well as what I would like to define as *mortographies*, as explained earlier in this thesis. An analysis of human remains within their archaeological contexts is often referred to as *funerary archaeology* or *funerary taphonomy*. I find this concept too narrow as it excludes remains not buried at all or in a manner other than funerary, such as the concealment of a body, for example. *Mortographies* is a more neutral concept as it does not begin with the assumption of a funerary ritual. Instead, it includes all contexts where human remains are found. Furthermore, *mortographies* as I define it, includes investigating what happened just before death, and possibly relating to the cause of death, as well as after death and up until now. These different levels – population vs individual, biographies vs *mortographies* – are taken into account in the selection of the material in order to investigate how this allows, or not, for a human-centred perspective of Öland.

A selection of 109 uncremated human remains was made to accommodate the following criteria:

- the individual remains should be datable to a subperiod of the Iron Age, possibly through subjection to ^{14}C analysis or by close spatial and contextual relation in order to be considered to one specific period;
- as a minimum, the remains sampled should have permanent teeth with preserved enamel and bone from the mandible or a similar bone of prominent cortical robustness (when this was the case usually the skeleton was fairly well preserved overall);

- if needed, a selection should be made to prioritize as far as possible an equal representation of sex and age across the sample;
- if needed, a selection should be made to include all areas of the island;
- all types of contexts should be sampled;
- all periods should be included in the sample and undated graves dated to the greatest possible extent with the available funding acquired for ^{14}C dates (if graves without dates are available in areas with already suitable samples, these should primarily be selected for ^{14}C dates over those areas with many graves);
- At least 100 individuals (with a minimum of seven years of age) should be investigated for both provenance isotopes and the diet isotopes, and as many as possible for ^{14}C.

As argued by Näsman (1994), a major problem with Iron Age burials is the long continuity in burial custom that they present, spanning the entire Iron Age. Another problem is the degree of manipulation, reburial, and disturbing of older graves in order to make new ones, as noted by Rasch (1994). To address these problems, only individual human remains that were unambigiously identified as uncommingled were analysed by osteological and isotopic analysis. In addition, a large number of individuals dated ambiguously (or not dated at all), and a few with definite dates, were ^{14}C dated in this study (n=42). The ambition with this approach was to be able to include:

(i) individuals with less normative burials of uncertain date;
(ii) individuals in burials with a potentially chronologically, or socially, specific ritual where they were buried without preserved artefacts;
(iii) individuals included as multiple consecutive burials in the same grave.

My aim with this approach was to increase the number of inhumed individuals from the most poorly represented periods on Öland, i.e. the late Roman period, and the Migration and Vendel periods. The selected burials/individuals are located all over Öland (Fig. 10).

Selecting which remains to include in the study was decided using a comprehensive inventory of the museum collections in Stockholm (the Historical Museum) and in Kalmar Museum (the local museum in relation to Öland today). Those skeletal remains well-preserved enough to be suitable for further analysis were noted and potential commingling taken into account. These were then screened in the compiled documentation in *Ölands järnåldersgravfält I–IV* for dates as a limited number of ^{14}C samples were possible in this study. In the end, 109 human remains were chosen, although many more were studied for suitability according to the criteria above and were rejected. All types of "archaeological" background to the finds of the human bones were considered in this study to maximize the potential material, not just those from specific grave fields. When selecting material and sampling the bones, it became evident how common the commingling and manipulation of buried individuals was. Skulls were often missing excluding many individuals because the sample required teeth. This could be indicative not only of reburials (Fig. 11) but also the reopening of graves for looting, as suggested by Rasch (1994) and other excavators with first-hand experience of excavating graves in Öland. I would like to add that reopening for other purposes than looting (c.f. Fig. 12) is also a possibility (c.f. Klevnäs, 2016).

Information about the artefacts and grave architecture was retrieved from the archived excavation reports in *Antikvarisk-topografiska arkivet* (the national archive), often summarized in *Ölands järnåldersgravfält I–IV* where more specific chronological determinations of artefacts were usually available. Unless otherwise indicated (c.f. Appendix 1), the dates used are those from *Ölands järnåldersgravfält I–IV.* Determinations of artefact type and provenance/style were retrieved from *Ölands järnåldersgravfält I–IV* since these were further detailed and researched there in a way that is often impossible for the excavation reports. Observations on positions and articulation of the skeletal remains was instead based on archaeological information from reports, photographs, and drawings (e.g. Figs. 11 and 12). The material used here comes from all types of excavations/retrievals of skeletal remains. Especially in the beginning of the twentieth century, but also up to the 1960s, at times, the investigations were carried out as simple recoveries of already excavated bones, often whilst being unable to see the actual feature being excavated, whilst at other times as small excavations of one grave or a small

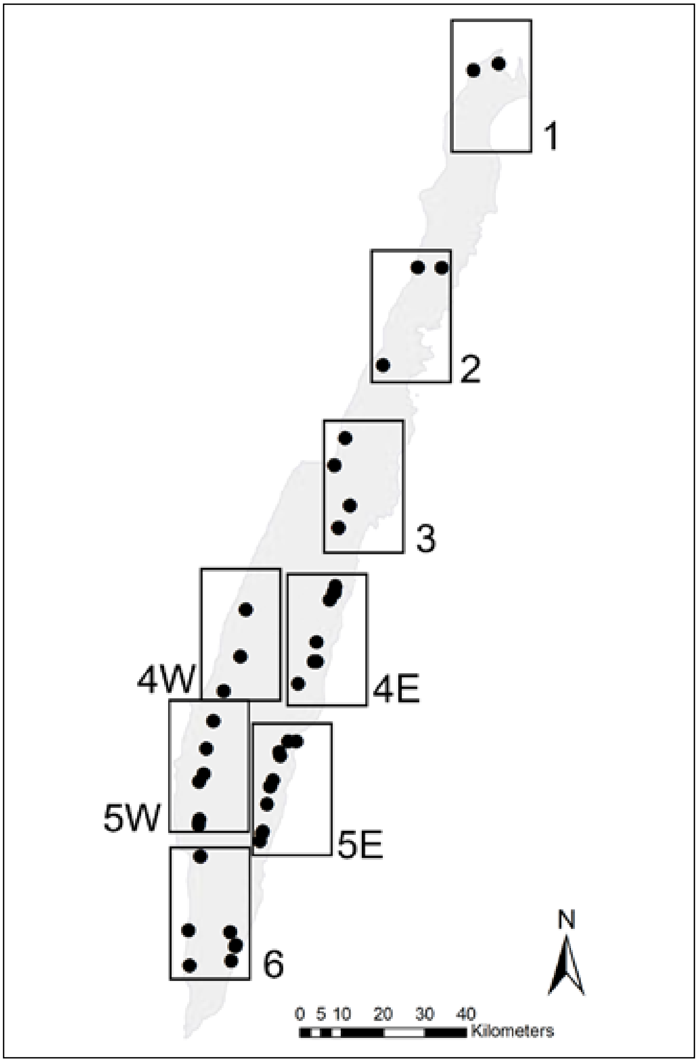
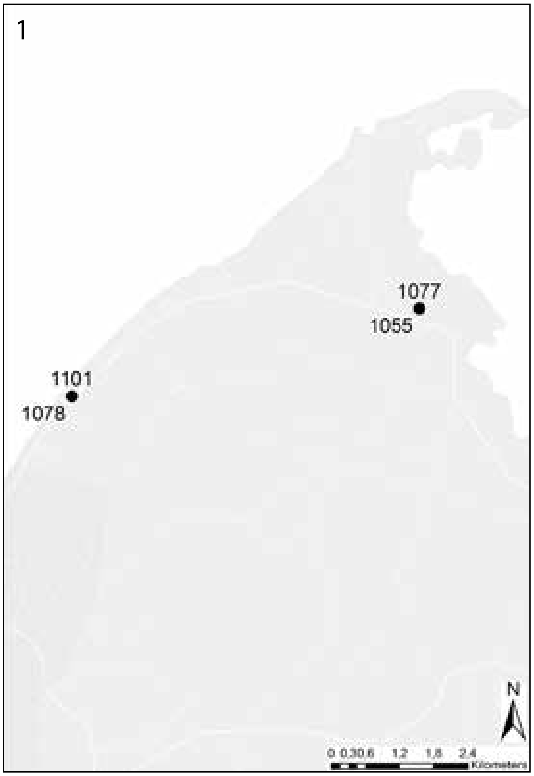


Fig. 10 (above and following pages): Maps of all the selected burials/individuals. Created in ArcGIS using coordinates for each site found in http://www.fmis.raa.se/cocoon/fornsok/search.html.

number of graves. During the 1960s–1980s, both research and contract archaeology became established on the island. The level of documentation, and even retrieval of skeletal remains, is therefore very diverse. Only in two cases (ID 1108, 1109) was I able to participate in an excavation in Öland and, for that time, select an unusually high level of documentation for these remains.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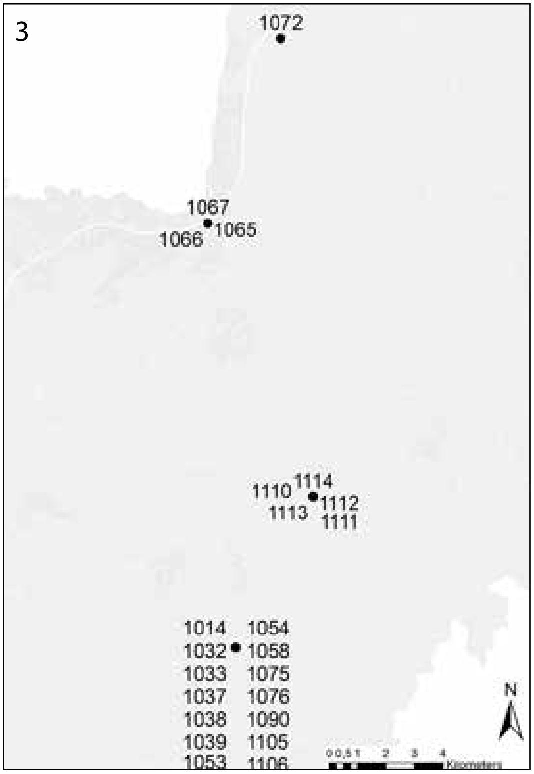
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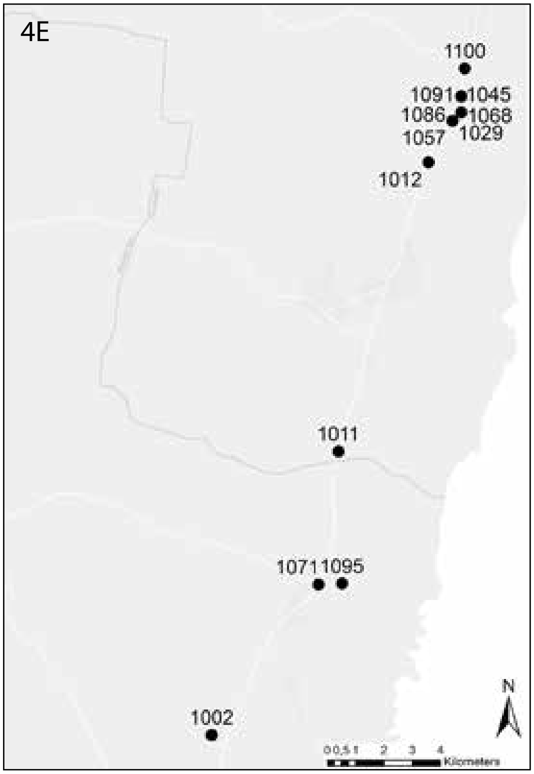
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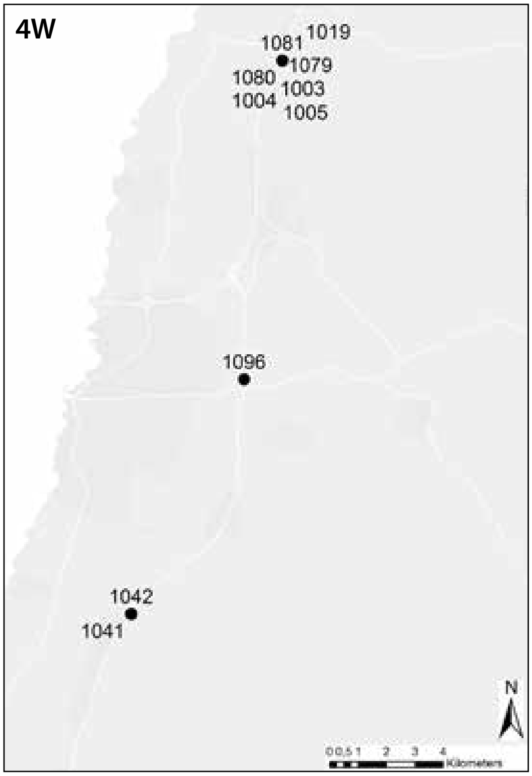
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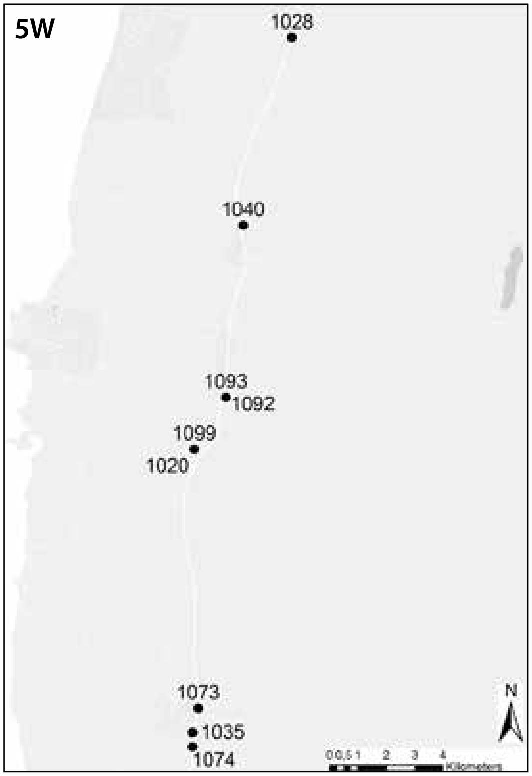
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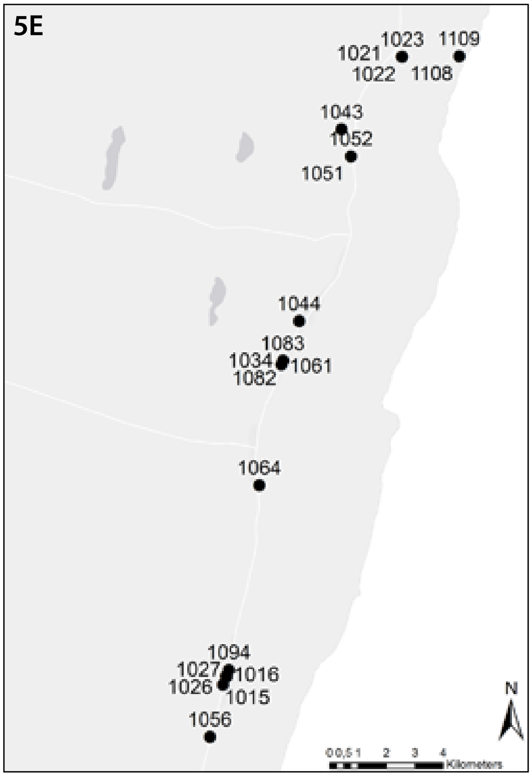
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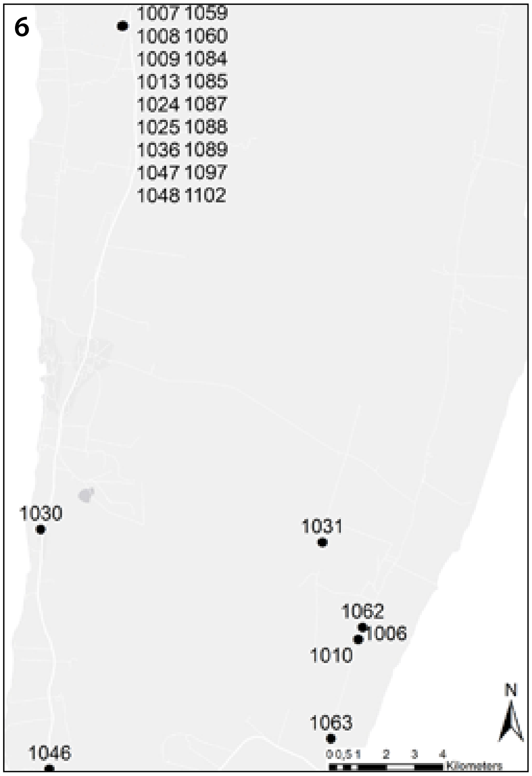
1056
N
0 0,5 1 2 3 4
Kilometers


6
1007 1059
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1025 1088
1036 1089
1047 1097
1048 1102
1030
1031
1062
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0 0,5 1 2 3 4
Kilometers

Fig. 11. Mörbylånga parish, SHM 12142, Grave 9. This is an example of an early excavation of a cist burial in Öland in which two individuals were placed in sequence (one over the other). This was noted and the remains separated during excavation (ID 1092, 1093 [see Appendix]). This effort is remarkable as this was at a time when skeletal remains were not collected routinely. Note the wooden crate with the remains to the right in the image. Photograph: TJ Arne, 1904, photo id 75.31. Photograph used with kind permission of ATA (Antikvarisk-topografiska arkivet), digitized by Torbjörn Linnerud.

Fig. 12. Kastlösa parish, SHM 25392. A common find is commingling due to looting/reopening of lime cists. In this case, the commingling was surprising as the roof stones of the cist were largely in place. Visible in the top right corner is a ceramic vessel. The bones are both those of the lower limb and torso, clearly in non-anatomical positions, and appearing to be shifted/raked together in the northern part of the cist where artefacts are commonly located. This individual was missing the skull and teeth which is why it is not included in this study. See also Figure 5 for more details on the grave. Photo id 262:1. Photograph: KG Pettersson, 1955. Photograph used with kind permission of ATA (Antikvarisk-topografiska arkivet), digitized by Torbjörn Linnerud.

Bias 3.1.1

There are many factors influencing the representativeness of the selected material. To begin with, as is true for all archaeological material, that what is preserved and found in modern times is but a fraction of the original record. The commingling of skeletal elements is especially compromising in Öland where the burials in cists appear to take place virtually throughout the entire period of the Iron Age, and even in the same cist (Fig. 8). In order to avoid discriminating against a certain social stratum or potentially a chronological period when grave goods were less common, individuals lacking grave goods and typologically dated were also included in the study. These were ^{14}C dated along with some individuals also typologically dated as a reference (details in Paper III). The human remains either lost after excavation or otherwise unavailable at the time of this study are also a bias.

This study only addresses the uncremated human remains when cremation was practiced, with varying intensity, in parallel to inhumations and other treatments of human remains. This removes a potentially significant proportion of the population from the study. However, since cremation means that the organic component of bone (collagen) is destroyed and only the inorganic (apatite) is left, this excludes the possibility of using isotopes (δ^{13}C and δ^{15}N) to study diet. Furthermore, the osteological analysis of cremations is usually very limited, and age, sex, pathology, and violence are rarely possible to discuss (at least not in the same level of detail as with uncremated remains) which is why the decision to forgo the cremations was made. Just recently, the possibility to investigate ^{87}Sr/^{86}Sr in cremated remains has been confirmed (c.f. Harvig et al., 2014; Snoeck et al., 2015), but at the time of the design of this study, this was not yet a possibility to factor in. Types of burial or disposal of the body other than inhumation or cremation (burial at sea, for example) that would leave no preserved bone today could mean that a specific social stratum (e.g. slaves, kings) is excluded from study. For this reason, human remains from all types of contexts – not just "proper" burials – were considered and included in the study if preservation allowed the possibility of isotopic analysis such as designed for this study.

Lastly, the age criteria used in this study excludes the individuals who died in early childhood. This decision is related to the nature of the isotopic approaches for diet and provenance in this study. The diet isotopes studied in the organic component of bone (collagen) are metabolized throughout life and consequently show diet over a duration of time, years or even decades before death (see 4.3.4 for a detailed discussion). The provenance isotopes are deposited in the tooth enamel which allows for an investigation of childhood residence. Unlike bone that forms throughout life, the tooth enamel acts as a time capsule since the enamel is completed at a certain age. As different teeth form at different ages, they record the isotopic composition at that specific age (for details see 4.3.1). Here, I aim to study both dietary development and migration on a population level which means excluding children. The young children, many under two years of age, were included in two previous studies of dietary isotopes in Iron Age Öland (Eriksson et al., 2008; Howcroft et al., 2012). These children would probably have had a dietary history different from that of adults, and samples of their bone collagen would include the infant diet as their bones stopped growing and incorporating isotopes when they died at this young age. Furthermore, for these young children, migration could not be discussed at all as data would potentially be compromised from teeth formed during weaning. To avoid a potential bias caused by this weaning for both diet and provenance (during weaning, results would reflect the mother's isotopes), I have chosen not to sample children under seven years of age. Furthermore, there are significant problems with many of the young children's graves lacking specific typological dates such as those included earlier (Eriksson et al., 2008; Howcroft et al., 2012). In addition, there are detailed reports that some of these children were showing signs of metabolic disorders (Ingvarsson-Sundsström, 2006) which might have an effect upon the isotopic composition due to changes in metabolism rather than due to what had been ingested through diet (see discussion under 4.3.4.3). In a recent review on isotopic approaches to infant diet and weaning, Reynard and Turnoss (2015) put forth some further caveats regarding the understanding of isotope studies of childhood diet. They emphasized the importance of non-dietary related development, gut biome, and the isotopic effect (non-protein nitrogen) of maternal milk. In the general field of isotope studies in the past few years, it is increasingly recognized that childhood diets are particularly complex to interpret from isotope values (c.f discussions in isotopes in known historical context of starvation in Beaumont & Montgomery, 2016). I would argue that in order to have a better understanding of childhood diets, it is key that we also look at adult isotope variation from a chronological perspective. In conclusion, considering the aims of this study, like the cremations, children are excluded from my sample as they do not significantly aid in addressing the specific research questions of this thesis.

CHAPTER 4

Method and theory

This chapter is named “Method *and* theory” to emphasise how closely the two concepts are intertwined. There is no method without theory in any form of research. However, the use and presentation of these concepts, I argue, is approached very differently within archaeology, osteology, and science. This is a problem when working in an interdisciplinary manner, and also when attempting to reach outside one of these groups. According to Martinon-Torres and Killick (2015), this is mainly because theory is imbued and not explicitly spoken in many methods used in archaeological science (and science generally). Therefore, theory is rarely presented as its own entity or concept in the studies. In contrast, in archaeology there is a strong discourse of separating theory to enforce its significance, which often leaves method as secondary in rank and attention. To some extent this is a vernacular problem, where the sciences inherently include theory but do not see the need to articulate their doing so which can be highly provocative for archaeologists who see this articulation of theory as centrally important. Here, I will attempt to over-bridge these vernacular problems by specifying the methods I have used while discussing them with the specific relevant theory. I will only discuss method and theory together, and will do this using the following topics/subfields: osteology (lab- and field-), taphonomy and digital methods, isotope analysis, artefact and contextual analysis, violence, and statistical and network approaches. The purpose of this is to emphazie the equal importance of *both* method and theory.

4.1 Laboratory osteology

Details regarding the osteological methods chosen to estimate sex and age are given in papers I, IV, and V. Paper V also accounts for definitions of relevant osteological criteria. All data was entered into a purpose-designed database in Windows Access to facilitate the compilation of all osteological, isotopic, and archaeological data. This is summarized in the Appendix for all 109 individuals. The selection of specific methods was made in accordance with specific research questions as presented primarily in papers IV and V. Details regarding osteological analyses are available in the Appendix.

Biases potentially affecting the results of the sex and age estimations made for the material of this study include the following:

- choice of specific methods (detailed below);
- the estimations are based purely on visual observations and therefore, to some extent, are potentially subjective as are most methods in osteology;
- preservation of the bone surface.

Inter observer errors that would lead to differing estimations of the sample as a unit can be ruled out as all estimations presented are made only by me, without knowledge of any potential previous estimation, whether based on the same or different methods. Only bones with intact morphology and/or a well-preserved shape (according to requirements of the specific methodology) were used. Both left and right sides in bilateral characters were estimated and the estimation weighted together. Pathology in the specific bone or individual at large, which could affect morphology, rendered that/those trait/traits as unsuitable for age or sex estimation. Spinal and/or joint pathology in the pelvis was carefully considered as it could potentially be misguiding age estimations based on pelvis morphology. Only changes that were unambiguously age-related and non-pathological were considered for age estimations.

Sex estimation 4.1.1

Biological sex, as estimated in human skeletal remains, is part of the most basic information that can be used when comparing for social differences. However, this is not as straightforward as determining an individual as male or female with absolute certainty. Varying ambiguities surround the estimation, the reliability of the methods and, of course, the state and number of criteria available due to preservation of the bones. All criteria described below are visual observations, that is, they are not quantified by metric measurements. These estimations are based on comparisons to criteria of morphological expression which have been written and/or drawn. This focus on morphology follows the focus of the "Standards" (Buikstra & Ubelaker, 1994). There are possibilities for identifying sex based on measurements of long bones, for example, or taking pelvic measurements using different methods (i.e. Washburn, 1948) and by devising an intrapopulation definition (comparing to remains of morphologically estimated sex). I have chosen only to use morphology, not metrics, as there could be a variation in body size during this long period which could result in misleading classifications, mainly in misclassifying smaller males.

Pelvis 4.1.1.1

The morphology and dimensions of the human pelvis are, to varying extents, correlated with sexual dimorphism. It has recently been suggested that sexual dimorphism is variously linked to the anterior and posterior spaces of the pelvis, the anterior space being more related to body mass and biomechanics and the posterior to sex and obstetrics (Brown, 2015). This is paradoxal as most of the traditional and well tested osteological methods for estimating sex generally give higher credence to traits in the anterior pelvis over those in the posterior.

Buikstra and Ubelaker (1994) collected, and in some cases developed, the most popular methods for estimation of sex based on the pelvis in a manual which is widely referred to in the osteology field. The method of Phenice (1969), with a binary division of traits (only male or female) for the pubis (the anterior part of the pelvis), has been tested in numerous studies for one or all of the traits (Bruce & McLaughlin, 1990; Kelley, 1978; Lovell, 1989; Rogers &

Saunders, 1994; Ubelaker & Volk, 2002; specifically for the ventral arch: Anderson, 1990; Suchey & Sutherland, 1991). When using the Phenice method, Buikstra and Ubelaker added a category of 'ambiguous' alongside the male and female categories given by Phenice. This addition is seldom acknowledged despite its highly significant difference. In my opinion, this addition is an improvement on the original method, likely reducing the risk of misclassification. Without using the ambiguous determination, Kelley (1979) reported 95% accuracy (correctly assigned sex), Lovell (1989) 83%, and Ubelaker and Volk (2002) 88.4% when using Phenice's traits. Adding this third determination of ambiguous would probably improve the accuracy further as has been shown for other traits (c.f. Walker, 2005). Each trait was scored for right and left (when applicable) and all scores were then added and divided by the number of traits to get an average. This average was then used as for estimation of sex.

A more debated but very commonly used trait relates to the greater sciatic notch for which some different methodologies have been developed, ranging from very open definitions to stricter scores (e.g. Buikstra & Ubelaker, 1994; Bruzek, 2002; review in Walker, 2005). Of importance for archaeological material in particular are the findings of Walker (2005) in a recent test of the accuracy of sex estimation having been assigned according to the shape of the greater sciatic notch (*sensu* Buikstra & Ubelaker 1994:18) and emphasizing the possibility for significant population differences. Walker argues that these population differences could be related to, for example, temperature and/or vitamin D deficiency. A recent study testing this trait on modern populations, Bruzek (2002:163) gave a comparably low score of just 70% accuracy for sex estimation, compared to Walker (2005) who reached 80%.

In the same site as the greater sciatic notch there is another trait that can be used for sex estimation, the arc composé or composite arch (Genoves, 1959). There are several somewhat revised drawings and descriptions in Steckel et al. (2006) and Bruzek (2002) describing this trait. I have used the drawing in Bruzek (2002:161) as a reference. This trait is missing from Buikstra and Ubelaker's (1994) selection of sex traits in the pelvis. Bruzek (2002:163) notes that the character is of a secondary significance, with correct classification varying from 30–92%. It is more correctly diagnosed for females, and is thus most useful in combination with other traits. I have used the composite arch in sex estimations as a trait of secondary importance, only if other pelvic traits were also present.

The posterior pelvis has recently attracted new attention, as Brown (2015) suggests would be appropriate, with methods producing highly accurate classification scores for individual traits and combinations (Novak et al., 2012; Wescott, 2015). Wescott (2015) details a specially devised methodology for scoring auricular surface projection that proved successful and will hopefully be evaluated soon in independent studies. However, in my opinion, the most interesting innovation presented by Wescott was the introduction of an entirely new type of trait: a nonbinary/only positive trait. When there is a positive expression (an elevation) of this trait (the surface projection), the sex is female, but a lack of expression (no elevation) means the sex is either male or female. Focusing on finding these types of traits could help to add more traits to the "toolkit" which is still reliant on binary traits identified more than 40 years ago. Traits involving more taphonomically robust morphology (such as the auricular portion) would also be a welcome addition for those working with archaeological material.

Bruzek (2002), mentioned above, formulated a specific scoring methodology using the criteria defined by others but with modified scoring systems for the traits, including both posterior and anterior characters and fragmented materials for a calculation of a weighted assessment. This approach is interesting but so far, to my knowledge, has not been tested in any large study of material of known sex.

In this study, I have chosen to rely on methods for sexing that are widely used and tested by independent publications. The anterior pelvis, when preserved, was primarily given more weight in the estimation of sex than those of the posterior pelvis. The criteria described by Phenice (1969), but as detailed and scored by Buikstra and Ubelaker (1994), were considered most reliable: the subpubic angle, subpubic concavity, ventral arc, and medial aspect of ramus. The greater sciatic notch, and with a secondary weight, the preauricular sulcus, were also diagnosed according to guidelines detailed in Buikstra and Ubelaker (1994) for all individuals where the bones were preserved.

4.1.1.2 Skull

Estimating sex from the skull can arguably be more difficult than from the pelvis as the characters used are related to size and muscular use, unlike the pelvis which is used for reproduction. The muscular expression can vary with age and also between populations with differences potentially influenced by cultural factors (specific diet or other use of muscles). Recently, Moore explicitly recommended that skulls should only be used in sex estimation when the skull is of a person aged 20–55 years old (Moore, 2013:97). Female cranial morphology can become increasingly masculine when older, after menopause, and young males may have less developed traits (Walker, 1995; Moore, 2013:97), probably due to entering the growth spurt and puberty somewhat later than females. I have estimated the sex of individuals aged from approximately 14 years and above, but I have taken Moore's recommendations into account so that a final assessment is not made without also considering age. These traits (considered alone or in combination with one another) have been tested for accuracy in sex determination yielding between 80–90% accuracy (Williams et al., 2006; Walker, 2008). I have used the Ascadi and Nemeskeri traits as reported and scored in Buikstra and Ubelaker (1994).

4.1.2 Age estimation

Traditionally in osteological investigations the question of demography and age distribution is imperative and therefore age estimation is given close attention. In this study, since age of death was not a criterion for selection of the material and demography is not discussed, specific ageing is of lesser importance. The biases in age estimations are multiple and the virtual obsession with extracting biological age (note, not chronological) from skeletal remains comes not only from a great interest in demographics but is also fueled by forensic osteology (c.f. contributions and discussions in Latham & Finnegan 2010).

Estimations of biological age on skeletal remains depend either on stages of development and/or degradation. Ageing is thus intertwined also with cultural phenomenon, such as physical activity and/or diet. Recently, it was argued that body size in humans, both stature and weight, is correlated with ageing (Meritt, 2015). Low body mass may function as protection against skeletal ageing whilst conversely, larger mass could accelerate ageing. However, the biological processes are very different. In individuals of low body fat, the rates in bone turnover are lower, and the biological ageing process itself is thus slowed down. In obese indivuals the bone turnover is comparably faster and they also have an intensified joint degeneration (due to increased mechanical load), resulting in accelerated skeletal ageing. The differences between the extremes are thus amplified and therefore potentially significant (c.f. Merritt, 2015).

The age of sub adults, and to some extent adults, can be estimated from the degree of bone development (appearance and fusion) but also dental development (formation and eruption). The methods are fairly accurate and straightforward compared to other age-estimation methods for adults. In this study, I have used dental development (Gustafson & Koch, 1974, as described in Hillson, 1996:135) and epiphyseal development (Schaefer et al., 2009). I have not used measurements of bones since the lower age limit of seven years in this study allows prioritizing these other methods.

Age estimations can be made on the basis of a wide variety of skeletal elements and methods, using histology, radiography, and visual estimations based on morphology of joints, skull sutures, or dental attrition (c.f. review in Uhl, 2013; Finnegan & Latham, 2010; Buikstra & Ubelaker, 1994). Despite not being the most recommended or accurate, the methods used most frequently appear to be those requiring the least amount of equipment (c.f. review in Falys & Lewis, 2011). Composite models, usually relying on scoring multiple visual traits, do not simply give an age but correct the result in comparison to modelled age distribution of a chosen population. This is referred to as Bayesian modelling, or so-called transition analysis (Boldsen et al., 2002, c.f. Millard & Gowland, 2002; Müller et al., 2002). However, these methods are rarely applied in publications other than methodological reviews (c.f. Falys & Lewis,

2011) which have increased greatly in recent years (e.g. Godde & Hens, 2015; Koeningsberg, 2015). Other statistical approaches are also proposed (e.g. Anderson et al., 2010).

Falys and Lewis (2011) end their review on the use of age estimations in journal articles by calling for greater comparability between studies by appealing for consistence in the techniques used and the ways they are used. They critique the use of dental wear (being significantly culturally determined) as well as cranial sutures for more specific estimations (similarly the review in Uhl, 2013). I have chosen to base my adult age estimations on a selection of morphological aspects, i.e. a visual estimation. The methods used relate to the pelvis and ribs and their application in osteology in a primarily archaeological context is detailed below. The methods chosen were selected to be able to catch the full age span, avoiding the misclassification of the age of older individuals. The methods of Suchey-Brooks (Suchey, 1988), Buckberry and Chamberlain (2002), and Kunos et al. (1999) were used in descending order of preference.

The Suchey-Brooks method for estimating age based on the pubic symphysis is a development of the Todd method (Suchey 1988; Brooks & Suchey 1990) and is considered highly reliable. It is widely tested, often in tandem with other ageing methods (c.f. Hens et al., 2008; Merritt, 2014; Rissech et al., 2012; San Millán et al., 2013). Hoppa (2000), and later others, followed in critiquing the bias of population differences, especially for females. The major limitation of Hoppa's work is that it ends with older-aged individuals being categorized simply as '60+', thus underestimating older individuals in calculations of age distribution. Still, it is considered more precise than most methods where younger individuals are concerned (Hens et al., 2008; San Millán et al., 2013).

Buckberry and Chamberlain's (2002) retake on the Lovejoy et al. (1985) method of ageing the auricular surface has been tested multiple times (c.f. Falys et al., 2006; Mulhern & Jones, 2005; Wittwer-Backofen et al., 2008) and recently received more positive reviews than earlier on both historical and forensic collections (Hens & Belcastro, 2012; Meritt, 2013; Moraitis et al., 2014; Rissech et al., 2012; San Millán et al., 2013; and Godde & Hens, 2015, in combination with Bayesian transition analysis). Indeed, this method

Primary age group	Years of age	Secondary group, crossing one or more age groups
Child	6-12	
Juvenile	13-19	
	13-35	Juvenile-young
Young	20-35	
	20-59	Young-mature
Mature	36-59	
	>36	Mature-old
Old	>60	
	>20	Young-old

Table 4. The age groups used in this study.

was usually preferred over the original Lovejoy method. A number of tests point out the accuracy and utility in this method for identifying older individuals (those marked '60+') and therefore recommend it regardless of their other results (e.g. Falys et al., 2006; Hens and Belcastro, 2012; Mulhern & Jones, 2005; San Millán et al., 2013). However, recent studies are a lot more positive than in the initial test, as mentioned above.

The Iscan et al. (1984) method for estimating age using the fourth rib is of limited applicability in archaeological contexts as ribs are often fragmented and the morphology allowing the determination of rib number is in the opposite part of the rib (the vertebral end) to that used in ageing (the sternal end). However, despite this, this method is still used in some instances (c.f. review in Falys & Lewis 2011; test and review in Meritt, 2013). A different methodology, relying on the first rib, was presented by Kunos et al. some time ago (1999) and was based mainly on morphology. Like the Iscan method, the age ranges allowed estimates well over 60+. So far, this method has been used sparsely (c.f. Falys and Lewis, 2011) and has returned both fairly poor results (Schmitt & Murail, 2004) and, more recently (Meritt, 2013), more satisfactory results. A new take on this method was devised by Digangi et al. (2009) which remains relatively untested (Merritt, 2013).

The methods for ageing have yielded somewhat different result. In some cases, preservation was poorer so only wide ages were applied as estimations. The individuals are primarily discussed in the age groups detailed in Table 4 throughout this study. These age groups (the primary) correspond to some of the indications given in Falys and Lewis (2011:712f and 708f). There is one group less, however, because I have treated the two age groups of young adult (20–25) and adult (20–35) as one category, except in papers IV and V where more detailed ages are used (and the groups as such were not as useful). This is because it is often possible to gain greater accuracy when including epiphyseal closure to the adult age-estimation method in young adults. This use is warranted in those papers due to the specific research questions regarding social differences and hierarchy. In the Appendix, both the age group assigned and a more detailed age (if possible) are specified for each individual included in this study.

4.1.3 A note on the use of sex and age estimations within the different papers

For the purposes of this study, age groups were mostly used (papers IV and V) but also more specific ages where relevant (c.f. Paper I where age is discussed in relation to taphonomy). In papers II and III, I have not given any information at all on age distribution since it was not of relevance to the research questions asked (i.e. where the population level discussion was fully sufficient). In Paper III, age (and sex) is a potential bias as diet is only discussed on the population level and in relation to chronology. For some populations, statistical approaches have shown correlation with changing diet at an older age and/or between the sexes (e.g. Fuller et al., 2006; Pearson & Meskell, 2015; Prowse et al., 2005). Age is here considered to result in less bias because the tissue sampled covers a long period of life (especially heavy compact bone with a probable long turnover), and primarily adulthood in these individuals. The precision available in order to divide the sample into age groups can thus mean that the overlap in diet, spanning perhaps as far back as 20 years or more, makes the ages less relevant for comparison. The age at death could possibly also relate to the diet (poor diet, earlier demise) potentially causing yet another difficulty if not investigating intra-individual dietary change. However, the criteria for selection used here aimed to reduce bias as far as possible with respect to age and sex distribution, thus making the dietary development in relation to chronology less of a problem (i.e. the same problems apply for all periods). Although tooth enamel can be worn down in older individuals, I could still include them in this study due to the use of the premolars for sampling enameldespite using tooth enamel as a selection criterion. I also selected material regardless of sex which is appropriate since I am attempting to study the general population's development of diet. These two factors, age and sex, are further investigated in Chapter 5 with relation to the isotope results to a further extent than was possible in the papers. All data is available in the Appendix for each individual.

Pathology 4.1.4

In general, I took note of all types of pathological bone or enamel resorption or formation, classifying it according to specific conditions when possible using standard paleopathology literature such as Ortner (2003), Aufderheide et al. (1998:9), Roberts and Manchester (2007), and Waldron (2008). In cases where the pathological findings were of specific relevance to the interpretation of taphonomy or violence, I describe these cases in the papers, or in more detail here in relation to the general discussion of the specific cases. Violence was in focus in Paper V, and the definition of violence used in this study refers to sharp or blunt force trauma to the skull or sharp force trauma to any bone. This is a strict definition of violence (c.f. Walker, 2001) and in bioarchaeology, skeletal trauma in general is often included, sometimes in combination with injury recidivism (e.g. Redfern, 2008; Martin et al., 2010). Moreover, I meticulously screened all bones to be sampled for isotopic analysis for metabolic disturbances (as defined in Katzenberg & Lovell, 1999; Olsen et al., 2014) as discussed further under 4.3.3.3.

4.2 Taphonomy and field osteology

The origins of the concept of taphonomy, used widely in forensic science, archaeology, osteology, geology, and paleontology, dates further back than Efremov in 1940 but he is credited as having created the specific phrase. In osteology/bioarchaeology it is rarely acknowledged that already in 1915 (Wilder & Whipple, 1917), a significant achievement in taphonomical analysis was made. Then, the position and articulation of skeletal remains were studied in a three-dimensional archaeological context (a grave was brought into the lab *en bloc*), an approach later denoted as the study of "necrodynamics" (Wilder, 1923). In archaeology, the concept of archaeothanatology (translated 'the archaeology of death'), initially called *Anthropologie de terrain*, was launched in France over 40 years ago by Duday and formally in English only in 2006, although presented by other researchers in English earlier (e.g. Roksandic, 2002). Only just over a decade ago was the specific methodology introduced in Sweden (Nilsson-Stutz, 2003) where it was employed on drawn plans of old excavations and photos rather than practiced in the excavation itself. As the methodology has become popular in English, problems have arised with translation from French and generally with anatomical definitions which is why specific terminologies were recently suggested (Knüsel, 2014). The method of *Anthropologie de terrain* is primarily concerned with movements of the bones as the body decomposes and the soft tissue disappears, which could also fall under necrodynamics as formulated by Wilder and Whipple in 1915. As far as I know, this is peculiarly never acknowledged by Duday and followers (c.f. Buikstra et al., 2003). The relation of the bones to objects or other features of the burial are also included in Duday's approach, as well as interpreting skeletal position in coherence with pathology and burns (etc.), making this a dynamic part of understanding the entire burial environment. Very often, the analysis following Duday's method is disseminated in an anecdotal and non-formalized way, accompanied by photos and drawings with measurements (e.g. Duday, 2006). Crevecoeur et al. (2015) recently proposed a detailed protocol for excavation based on photos transferred to sketches in Photoshop in order to facilitate an analysis following an *Anthropologie de terrain* approach. Here, due to commingling, anatomical representation was also a key focus. So far, to the best of my knowledge, information on post-mortem fractures of bones and their timing in comparison to the disarticulation of the body is not included in *Anthropologie de terrain*. However, since this involves mechanical forces and movement, it fits within the older concept of necrodynamics.

A major improvement, as I see it, to an *Anthropologie de terrain/necrodynamics* approach to excavation would be a smooth documentation process which preserves information on spatial internal relationships of individual bones with a more detailed integration of laboratory and field observations in one common platform.

Virtual Taphonomy: digital approaches to taphonomy 4.2.1

Digital reflexive archaeology 4.2.1.1

Digital archaeology, earlier referred to as computer archaeology, has evolved parallel to the technical advances in computers (hardware and software) since the 1970s. Today, it is an inherent part of most archaeology, whether excavation, postprocessing, analysis, or visualization. Early on, the role of computers in documenting and analysing archaeological information was regarded as objective but today the interpretation process in selecting data to be digitized is acknowledged (c.f. review in Lock, 2003, Chapter 1). The organization CAA International (Computer applications and quantitative methods in Archaeology, http://caa-international.org/) was founded by archaeologists, computer scientists, and mathematicians in the 1970s to integrate these disciplines in an interdisciplinary way. Two recent BAR volumes summarize the state of the discipline and its growing application in different sub disciplines in archaeology (Forte, 2010; Remondino & Campana, 2014). Comparing the contributions in these volumes, I argue it seems that the interdisciplinary focus is still infused within the field but due to technological advances, has started decreasing with increased specialization in subfields such as laser scanning. In field archaeology, the digital platform for interaction available in using Geographical Information Systems (GIS) has been the digital base for interdisciplinary collaboration since its introduction in archaeology, usually attributed to Zubrow et al. (1990).

Image-based 3D modelling (using Structure from Motion, SfM) has been increasing in use in the past five years for documenting and analysing archaeological excavations, and was recently integrated directly in 3D GIS. It is a methodology for documenting the archaeological context in three dimensions capturing colour as well as geometry. The slightly different methods and the reproducibility and accuracy have been investigated (e.g. Callieri et al., 2011; Dellepiane et al., 2012; Dell'Unto, 2014; De Reu et al., 2013; Doneus et al., 2011; Galeazzi, 2014; Larsson et al., 2015) and recently evaluated in a review (Optiz & Limp, 2015). This approach allows for the construction of a detailed 3D model based on a set of digital photos which in turn can be georeferenced and integrated in a GIS platform. This dynamic methodology can be applied on a landscape basis (e.g. Verhoeven et al., 2012) to archaeological sites and features (e.g. de Reu et al., 2014), buildings (e.g. Landeshi et al., 2015), rock-art (e.g. Plets et al., 2012), even very detailed reconstructions of artefacts (e.g. Koutsoudis et al., 2013), and under water (e.g. McCarthy & Benjamin, 2014). With this technical revolution has also arrived a more articulated theoretical approach of, for example, reflexive archaeology (Berggren & Hodder, 2003; Berggren et al., 2015) and recently slow archaeology (Caraher, 2015).

4.2.1.2 Digital reflexive osteology?

With regards to human skeletal remains, digital methods have been in use for as long as they have been present in archaeology. In the past ten years, the applications have expanded rapidly both in archaeological and forensic settings. They have come to include specific methods such as radiography, computed tomography (CT), scanning electron microscopy (SEM), optical laser scanning and image-based modelling, but also in databases and GIS. Digital techniques are mainly being used to analyse and visualize morphology on macro (e.g. Decker et al., 2011; Macaluso, 2011; Villa et al., 2013) and micro scales (c.f. Alunni-Perret et al., 2010; Bello & Soligo, 2008), and to view internal bone composition (c.f. Thali et al., 2003) and spatial analysis of bones in the archaeological context (discussed in detail below).

Digital archaeology and taphonomy: state of the art 4.2.1.3

The wish to integrate osteological data with archaeological fieldwork in one common platform is by no means new. Recently, a specific methodology was developed to integrate information about death (including use of *Anthropologie de terrain*) and life (demography, etc.) in a GIS-based database (Dufton & Fenwick, 2012). Images were part of this documentation and integrated in GIS with other information. It is, however, not specified how the *Anthropologie de terrain* results were integrated in the database or analysed further. The paper only details how the data derived from lab analysis (age, sex, etc.) was used in a spatial analysis.

Richard Wright has been a pioneer in working with GIS and exploring the spatial relations of human remains *in situ* within a forensic setting (c.f. Tuller et al., 2008). He developed Bodies3D, a software that uses GPS coordinates of specific bones to reconstruct the bodies as simple stick-figure geometries (Wright, 2012). This does not allow for interaction with the representations of the bodies within the depositional context but it can be used to study the relations between the different bones detected in the field. The software also made it possible to compare and separate different bodies in mass graves, to individualize them, and study their internal spatial relation. A similar approach was used in the CAD-based software Crossbones/X-bones (Isaksen et al., 2008) which included even more coordinates than Bodies3D but, in a similar manner, still created stick-figures, albeit more precisely. This tool was used in investigations of archaeological mass graves in England (Marquez-Grant & Loe, 2008; Loe et al., 2014:16). In the case of the Ridgeway Hill massacre, a 3D image-based reconstruction model was additionally created (processing a small set of digital images not intended for this purpose) purely for exhibition purposes (Ducke et al., 2008:377) as well as the separate Crossbones documentation that was then used in a CAD-application as reference to the ortophotos (Loe et al., 2014:16). This documentation was without apparent employment in a specific taphonomical analysis (Loe, 2014:130). The use of image-based modelling for studying human bones in context is being tested (Haddow et al., 2015; Optiz, 2012), but without integrating it in GIS or connecting the interpretations in lab and field in a detailed taphonomical analysis.

In conclusion, I argue that the use of digital methods in osteological contexts has so far shown little in the way of emphasizing the reflexive aspects of analysis and interpretation that these methods offer. Their importance for maintaining reflexive thinking is comparably very well established in archaeology, however.

Isotopes

4.3

Details regarding the theoretical background, osteological caveats and specific methodology employed in the dietary isotopic analysis are presented in Paper III, and for the provenance of isotopes in papers II and IV. The preparations and analyses of the dietary isotopes were performed in the Stable Isotope Laboratory Department of Geosciences and Natural Resource Management, University of Copenhagen, while the provenance samples were processed in the Department of Geosciences at the University of North Carolina ($^{87}Sr/^{86}Sr$) and the University of Arizona ($\delta^{13}C$ and $\delta^{18}O$ in enamel). The Lund University Radiocarbon Dating Laboratory performed the ^{14}C analyses.

In this section I will first present a very general explanation of the rationale behind isotope studies of skeletal tissues in archaeology today without references. In the second section, I address the detailed approaches, all steps, and methodological concerns in detail with full referencing. The purpose of this division is to give a more general background for readers that have not worked with isotope approaches before, as well as all the necessary details for those specialized in isotopes.

Why isotopes?

4.3.1

Isotope analysis for paleodiet and provenance is a continuously growing approach in archaeological studies and in the last few years has become commonplace (e.g. Pestle et al., 2014). It is based on the principle that specific isotopes are metabolized and integrated in human or animal bone and enamel. In other words, what you eat and drink on a regular basis will turn up in your skeletal tissues. Bone continuously metabolizes throughout life which means the isotopic profile will change as the intake (diet, water) profile does. Varying with the type of bone and age of the individual, a sample will allow researchers to study the isotope profile at a length of time before death. Contrarily, enamel is inert (it does not alter chemically) once formed which is why the isotope measurements of different teeth reflect different ages as teeth are formed in a given sequence in childhood. If you, as an archaeologist, want to find out whether an individual migrated from his/her place of birth sometime during their life time, samples should preferably be taken from a tooth formed in childhood but at an age when weaned to avoid the risk of results reflecting the mother's diet instead; if the person moved location, the tooth should give a different isotopic profile than the area does. The area profile (baseline) can be estimated from taking samples of other animals unlikely to migrate. If you want to study diet, similarly, the human isotope values need to be put into relation to those of animal sample values.

Isotopic analysis is largely a destructive process. Presently, most analysis includes the destruction of the actual sample investigated in the analysis, but usually not the whole tooth or bone and usually very small amounts (mg) are sufficient. There are always a series of procedures to follow to make sure the tooth/bone is not contaminated in that the chemical composition is not altered by burial environment or during storage after excavation. Some of these procedures are done early on to make sure the best material is used as the sample will often be treated both mechanically (drilling deeper into the tissue from the surface) and chemically (purifying the sample with acids). Further procedures are designed to check quality of the extracted material while purifying it as well as while analysing it. The process of retrieving isotope values during the measurement part of the analysis involes destroying the samples in the complex and sensitive machines. The performance of these machines is continuously evaluated by running standard samples to make sure accuracy and precision is at a certain level at all times. Often, subsamples from the same sample are run to control consistency in the results. As well as the documentation of all the procedures before and during analysis, this is the guarantee that samples analysed in different labs are comparable.

Once concluded to be uncontaminated, the isotope values are interpreted in line with a developing body of theory and method specialized for each isotope. As I will show below, there is a significant element of interpretation in order to "make sense" of the isotope values and translate them into a determination (or estimation, perhaps) about whether or not the person has moved since childhood, what their diet was like at a point in life, or what time in the past this person was alive. The interpretation relies on both theoretical and methodological development in the subfield of isotope studies and relates to isotope analysis in general (such as that used and studied in medicine and ecology).

Isotope values can be seen as a primary source for understanding diet and shift in residence (migration) in the sense that they stem directly from an individual human. Values are also primary in the sense that acquiring one's isotopic signal is not an "intentional" act; the prehistoric human did not decide diet based on which isotopic profile it would give him/her. There are also a lot of aspects of diet and migration that are difficult, or even impossible, to study using isotopes alone. The choice in isotopes, as well as the choice of the specific sampling site (type of tissue and formation time, etc.), is crucial for determining what can be studied. An understanding of this, as well as of which archaeological questions are appropriate and interesting to answer, is crucial. If archaeology is to take advantage of the potential and avoid the pitfalls of this primary source, two things are crucial, in my opinion: in studies, the interpretational aspect of isotopes needs to be both transparent and approachable for all archaeologists. It is my ambition to live up to that in this study.

Choice of isotopes and sampling strategies 4.3.2

Isotope analysis offers many different possibilities but has some crucial limitations too. Making a decision on which specific isotopes and tissues to sample will determine the outcome of any study. Different tissues form at different times in the skeletal development. The specific tissue composition also changes (turnover) at different paces in different elements, and at different rates depending on the age and metabolism (including disease disturbances) of an individual. Different tissues are also uniquely susceptible to diagenetic change which means that the type of risks involved in giving an erroneous isotope value are also varied.

In this study of diet and radiocarbon, the choice of tissue is bone collagen from uncremated compact cortical bone.

For radiocarbon samples, different bones were used based primarily on availability and on samples with a significant proportion of compact bone to avoid any diagenetic alteration.

In order to investigate diet, I chose to use primarily isotope analysis of bone collagen (δ^{13}C and δ^{15}N) since it allows for the centring of the study specifically around the humans. Other rewarding approaches would include archaeozoological and archaeobotanical analysis, as well as lipid analysis of ceramic vessels, but these are not human-centred approaches as they are impossible to link to a specific human. There are multiple possibilities for studying dietary input via isotopes, for example: δ^{13}C in bone apatite or enamel, δ^{34}S in bone collagen and amino acids (c.f. Makarewicz & Sealy, 2015; Richards et al., 2001; Webb et al., 2016). Pestle et al. (2014) caution the use of hydroxyapatite analysis (i.e. those from the mineral component of bone) in comparison to the more established protocols for performing and evaluating collagen analysis. The most frequently employed isotopes are δ^{13}C and δ^{15}N in bone collagen, but these are limited as they do not reflect the entire diet compared to hydroxyapatite (see discussion below). Moreover, this was the specific approach used in the two previous studies of isotopic variation on Öland allowing for a direct comparison of these results, thus contributing to the building of a larger comparable data set. Primarily, bone from the mandible was sampled, intended to reflect a long-term diet rather than merely in the run-up to death. The mandible is also diagenetically stable as it has a significant component of compact bone (details available in Paper III). This approach allows for the investigation of subsistence practice and population level patterns (rather than dietary practice shifting over the life course) and the cultural, social, and ecological interpretations possible. This corresponds to the specific aims of Paper III.

There are multiple methods available for a human-centred approach to migration including genetic analysis (from skeletal traits or DNA) and isotope analysis. Identifying the first-generation migrants' is most successfully addressed by isotope analysis as the isotope ratios can reveal an actual change in residence. There are several choices for isotope analysis of provenance. In bone collagen δ^{34}S is employed but $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ in bone apatite and enamel are most common. It is also possible to add various lead (Pb) isotopes in the enamel analysis but this uses more enamel and there are few comparable studies and thus only a limited understanding of geographical variation. In a previous study of provenance isotopes on Öland the $^{87}Sr/^{86}Sr$ variation in fauna was investigated. These isotope results could thereby be employed to get an unusually wide variety of faunal values across the island and from diverse species. Although those samples are from both earlier (the Neolithic) and later periods (present), the soil and bedrock have probably barely altered through time and should allow for comparable results for the Iron Age. For provenance isotope analysis, dental enamel was chosen due to its diagenetic advantage over bone. Dental enamel reflects a limited time in life – childhood – as enamel is inert. Potentially, this would allow for identification of individuals spending their early childhood in an environment presenting different isotopic values than are local to those of Öland. Instead of the commonly used first and second molars, the premolars were chosen for sampling. The first molar is a frequent target in provenance isotopic studies since it forms early on in childhood and, I suspect, is relatively easily identified by osteologically untrained scientists. This tooth was not sampled in this study for a number of reasons. The first is that the first molar, if the crown is not very worn down, holds metric and morphological information which is of interest to osteologists but which is very difficult to document sufficiently with photos or any other media before sampling. As sampling the enamel is destructive, this will lead to a significant loss of the specimen's scientific value (this also applies for the later erupting second and third molars). The premolar is a simpler tooth and its morphology and metrics are of little interest both historically and currently. Even the root of the premolar is comparatively simpler so that it is easier to sample without destroying alveolar bone. Moreover, the first molar also wears down quite quickly in adult age which means individuals of an older age are easily discriminated against in sampling as they have no enamel left or the tooth is lost *in vitram* due to caries entering the exposed root. This is also a problem since there are only four first molars in the dentition. There are eight premolars meaning there are theoretically twice as many teeth to choose from and they are generally less worn in older individuals allowing for their inclusion in the research sample. This sampling strategy corresponds to the specific aims of papers II and IV where more details are also recounted regarding the sampling. Both $^{86}/^{87}$Sr and δ^{18}O isotopes are used in Paper IV and only $^{86}/^{87}$Sr in Paper II. The crowns on the premolars are completed between the ages of five and nine according to the Gustafson and Koch chart (as presented in Hillson 1996:135) and by five to six according to Smith (1991, based on the Moorrees, Fanning, and Hunt [1963] methodology). The sampled individuals have at least one fully formed crown (clearly mature enamel) from one premolar with very few exceptions (four individuals, see Appendix and Paper IV for details). Only individuals aged seven years and older were sampled.

The use of laser ablation on human teeth, which allows for investigation of changes in residence via intra-tooth variation in $^{86/87}$Sr during the enamel formation, is only recently beginning to be explored (c.f. methodological experiments in Lewis et al., 2014; Willmes et al., 2016). So far, only single individuals have been investigated by such an approach (e.g. Richards et al., 2008) and so results are not yet applicable on a population level. Since cremations leave very few possibilities for studying migration and diet through chemical analysis, only unburned human remains were selected for this study. In 2015, the possibility to use ^{87}Sr/^{86}Sr for cremated bone was acknowledged in the scientific community and is gaining in popularity (Harvig et al., 2014; Snoeck et al., 2015, 2016). However, this was not an option for this study which was planned before this opportunity had appeared.

In this study, a decision not to investigate intra-tissue variation was taken, so that isotopic results would not be compared for potential changes in subsistence or residence. A single value per isotope per individual is sufficient to address the current research questions about diet and migration posed here. However, as earlier studies demonstrated, such an approach could no doubt be a rewarding pursuit to gain a deeper understanding of these phenomena and of the specific results and patterns detected and detailed in this study.

As well as the specific selected isotopes and sampled materials, as mentioned above, a range of other isotopes/methodologies could also have been employed. To avoid limiting the sample size (i.e. the population), only the most commonly employed isotope approaches where chosen. In addition to having a lower cost than many other methods, they are well used in archaeology and the results and methods of interpretation explored are therefore relevant beyond Öland. The isotopic results from this study thus add to both the body of knowledge on the Iron Age and the study of diet and migration through isotopic analysis in archaeology in general.

The population-based approach used in this specific study is unusual and often the selection of sampled individuals is focused on deviants (see, for example, Eckhardt et al., 2014, and discussion in Paper II). In this respect, this specific study and strategy for isotopic sampling furthers the understanding of the use of isotopes for archaeology in general. The focus on biographies and choosing the most "interesting" individuals (special graves, pathology or similar) has here given way to finding variation in the masses. This approach is aimed at investigating how a human-centred archaeology can add new insight if looking at the population *en masse* rather than on specific individuals.

The skeleton as material: diagenesis 4.3.3

Most of the diagenetic changes to bone occur in the initial phases of the breakdown which is why this environment is key for preservation of organic bone components. Burial/depositional practice thus plays a bigger role in bone diagenesis in comparison with the length of time the bone has been deposited (c.f. discussion in Weiner, 2010:110f). Bone collagen is especially susceptible to diagenetic changes; it both degrades and can be contaminated. Degradation is less likely to be a problem in the environment of northern Europe than contamination of the collagen is (c.f. discussion in Jørkov, 2007:50f; van Klinken, 1999). Microbial attack (see review in Hedges, 2002) and chemical degradation affect collagen and can alter isotopic values (Nielsen-Marsh & Hedges, 2000). Protocols for dealing with these problems include rigorous mechanical and chemical preparation of bone samples, as well as tools for evaluating collagen quality (c.f. review in Jørkov et al., 2010; methods outlined in DeNiro, 1985; Nehlich & Richards, 2009; Van Klinken, 1999). Pestle et al. (2014) offer an interesting discussion on laboratory procedures in bone isotope analysis and inter-lab differences and quality control.

Being a highly-mineralized tissue, although not completely resistant to diagenesis as is sometimes stated, enamel is more resilient to diagenesis than bone (Lee-Thorp, 2002; Weiner, 2010:130f). Protocols for avoiding diagenetically altered samples for $^{87}Sr/^{86}Sr$, $\delta^{18}O$ and $\delta^{13}C$ analysis are detailed in, for example, Grupe et al. (1997), Sjögren et al. (2009), and Frei and Price (2012) (review in Bentley, 2006).

4.3.4 Interpreting diet from $\delta^{13}C$ and $\delta^{15}N$ in bone collagen

Recently, the methodologies available for interpreting isotopic results, particularly $\delta^{13}C$ and $\delta^{15}N$, and "translating" them into diets have developed significantly (as will be discussed in detail below). Another great advance is that simultaneously, the awareness of the significance of context has increased. The emphasis on the importance of comparing human values to animal proxies that are contemporary and geographically and ecologically comparable is increasing (c.f. Bogaard & Outram, 2013; Doppler et al., 2010; Grupe et al., 2013; Makarewicz & Sealy 2015). The methods currently used to compare the human and animal (and sometimes botanical) isotope values can be summarized by three different approaches: (1) the biplot, (2) linear mixing models, and (3) Bayesian mixing models. Only one of these has been chosen to interpret the results of this study, as presented here and in Paper III: the biplot approach. The biplot approach (1) is the oldest of the three and is basically an eyeballing of the human isotope values in relation to values from selected animals and/or plants. It is generally the raw data (the isotope values, or a mean/average per species) that is plotted in the diagram. The mixing models (2, 3) define the contribution of the dietary inputs by comparing their values in relation to human values using statistical approaches. Here, usually only the results of these calculations are presented and discussed. The major difference between these approaches is in the visual presentation of data (for 1) or data after analysis of data (for 2, 3), and is thus transparency.

Some important caveats of linear mixing models in general deserve to be highlighted. (i) The main food source(s) needs to be included in the analysis. Excluding a significant source will bias the calculated proportions of the other sources and may result in inconsistency between the observed isotopic values and the possible solutions from the selected sources. (ii) By default, all sources are considered equally as likely to contribute to the diet. This makes the prior estimations of the importance of dietary resources impossible to integrate with the calculations. The partitioning model outlined by Phillips and Gregg (2003) is one option for a linear mixing model and it is widely used in ecology. Usually, only three or four sources are employed in studies of human diet often resulting in a pooling of different species. In Grupe et al. (2011), for example, domesticates are pooled and in Bocherens et al. (2006), both wild and domestic ruminants were pooled. Few exceptions use more sources (Newsome et al., 2004, seven sources). Moreover, complexity is further limited due to the use of only mean values for the sources (animals, plants) and because the variation between individual species is not taken into account. On the contrary, in Bayesian analysis, this variety (not only mean values but also variances and error terms) and a larger number of sources can be taken into account (Parnell et al., 2010). Furthermore, an informative prior (cf. 4.3.3.1) can be added, such as written sources detailing the proportions of different dietary sources (c.f. Arcini et al., 2014). In ecology, mixing models have been in use longer than in archaeology, and Bayesian mixing is currently acknowledged there as a powerful interpretive tool (Philips et al., 2014; Semmens et al., 2009). Indeed, the use of Bayesian mixing has increased in archaeology in the past few years (e.g. Arcini et al., 2014; Bernal et al., 2016; Fernandes et al., 2014, 2015).

In my opinion, for mixing models to be relevant to ancient human diets there needs to be sufficient complexity in the specific food web. Bayesian mixing satisfies this requirement more than linear mixing. But, so far, mainly ideal scenarios – those investigating opposing extremes in the food webs, such as herbivores vs carnivores, or marine vs terrestrial animals – are being pursued in archaeology (e.g. Bernal et al., 2016; Fernandes et al., 2015). The proportion of different domestic animals in the human diet is rarely pursued when using mixing models as the species are usually too similar in isotope profile to differentiate between to a sufficient extent (one exception is Bocherens et al., 2006). Devising a relevant informative prior for the Bayesian analysis could further enhance the interpretation of diet as well, but besides written sources (which are also biased, of course), it is complicated to quantify the dietary sources comparatively due to taphonomy. Different plant and animal remains (bones, shells, etc.) preserve differently in different environments, and some animals (fish, birds, etc.) are almost always underrepresented because of this, making a proper specific quantification very complicated, if not impossible.

When dealing with a diet which appears to depend on domesticates (usually with similar isotope values for more than one species) for Iron Age Öland, the precision given by the mathematical models (mixing, whether Bayesian or linear) for each species can be misleading as there is not sufficient support for such precision in the base data. I have therefore chosen to use only the basic biplot approach for interpreting diet. Moreover, I consider the greater transparency in the biplot approach an asset. This is also, still, the most popular method for presenting dietary isotope results and is therefore easily accessed and understood by a wider, scientific, archaeological community.

4.3.4.1 Fractionation

Before applying any of the approaches to the interpretation of the $\delta^{13}C$ and $\delta^{15}N$ values, the results first need to be considered as a result of diet-tissue fractionation of the isotopes, or TLE (Trophic Level Effect; c.f. Schwarcz & Schoeninger, 2011:731). Metabolism discriminates these isotopes differentially explaining why there is an offset between the isotopic signals of different tissues. Experimental studies have given some benchmarks for how to estimate the offset between animal bone isotope values and human bone values that are commonly agreed upon in the field but with some variations and interesting recent developments.

A fractionation of +3‰ for $\delta^{15}N$ (Minagwa & Wada, 1984; Ambrose & Norr, 1993) is often used, although the variation is described to be between 1–6‰ (reviews Makarewicz & Sealy, 2015; Mörseburg et al., 2015). Today, many studies are using levels close to double of this at 5–6‰ (Craig et al., 2013). The difference in interpretation of probable dietary input is of great magnitude from the low (3‰) to high (6‰) TLE (see discussions in Hakenbeck, 2013; Hedges & Reynard, 2007; O'Connell et al., 2012). Almost a decade has passed since Hedges and Reynard (2007) recommended using a higher TLE, preferably 5‰, and support for this has since been shown by, for example, O'Connell et al.'s (2012) study of controlled human diet. Moreover, the much-cited definition of Hedges and Reynard of a 3–5‰ TLE for humans (often translated to 4‰ as a mean in other studies) was recently upgraded to 3–6 ‰ (Reynard & Tuross, 2015). As there remains some ambiguity around what specific TLE is acceptable to use, I have chosen to interpret my isotope values using both the 3‰ and 5‰ levels and compare their results (see Paper III for further discussion). The fractionation of $\delta^{13}C$ is not similarly debated and in most studies, is rounded off to +1‰ (De Niro & Epstein, 1978; Fuller et al., 2006), although sometimes also considered as an interval of 0.8–1.3‰ (Bocherens & Drucker, 2003). Compared to the $\delta^{15}N$ TLE, this is a very small variation of decimals in comparison with the doubling of the lowest value. I will use the +1‰ definition for $\delta^{13}C$ in interpreting my samples here and in Paper III.

Proxies

4.3.4.2

The isotopic signatures of the proxies, that is, the animals and/or plants expected to be part of the human diet, need to be determined. This is an often-underestimated part of the interpretation of the isotope results. Recently, it has been emphasized that only isotope values from local, contemporary animals and plants should be used as proxies to human values (Bogaard & Outram, 2013; Grupe et al., 2013; Makarewicz & Sealy, 2015). Müldner and Richards (2007:684) found chronological differences in cattle $\delta^{15}N$-

values, probably explainable due to changes in animal husbandry practice. Locally, if different grazing options were possible, and if marshlands or beaches were available for grazing, this would give different isotope values in animals of the same species (Balasse et al., 2005; Britton et al., 2008; McManus et al., 2013, Müldner et al., 2014). The practice of animal husbandry and the climate can both vary not only geographically but also temporally, which needs to be taken into consideration to as great an extent as possible. As well as using isotope data from local and contemporary food sources, the choice of animals, for example, should be informed and include relevant species. So far, only one study of Iron Age Scandinavia has included samples of domestic fowl, despite its inclusion in the zooarchaeological assemblages of Haithabu (Doppler et al., 2010). The taphonomical loss of the fragile bones probably leads to an underestimation of the significance of chickens and this was recently argued to be a factor for an Iron Age assemblage on Öland in particular (c.f. Vretemark & Sten, 2008). When choosing sources for comparing the human values to in this study, I consulted local, contemporary archaeozoological assemblages to discern which species would be likely to play a significant role in the human diet. These species were then sampled from Iron Age assemblages and/or graves on Öland and processed for isotopic analysis at the same time as the human samples were analysed. The sampled species most likely to be part of the diet were fish, chickens, cattle, sheep, and pigs. Furthermore, I sampled the potential top predators: dogs, cats and seals. These are likely to be on a similar level in the food chain as humans and also serve as a comparison to the other animal species and the wider food web of which the humans were a part.

The earlier dietary isotopic studies of Öland (Eriksson et al., 2008; Howcroft et al., 2012), which included human samples, mostly used local animal proxies of diverse species in their interpretations of diet. These animals were not contemporary, however; most were Neolithic or even Mesolithic which is why I chose not to use these proxies in addition to my animal samples (see details in Paper III).

Pathology 4.3.4.3

A factor very rarely specifically reported in isotope studies is whether or not the sampled bones were screened for pathology. It is established that pathological conditions resulting in catabolism can alter the $\delta^{15}N$ values in the specific bone and also the $\delta^{13}C$. In particular, osteomyelitis, healing fractures, and periostitis have been documented to correlate with changes in isotopic values, and it is recommended not to use bones with these changes when investigating diet (Katzenberg & Lovell, 1999; Olsen et al., 2014). Additionally, long-term metabolic disturbances which have occurred over years, such as celiac disease (Scorrano et al., 2014), appear to affect bone collagen isotopes. Metabolic disturbances like rickets/osteomalacia are, however, usually occurring episodically and would not have a significant effect (Olsen et al., 2014) unless sampled in individuals with quick bone turnover (children; c.f. Beaumont & Montgomery, 2016). Short-term metabolic disturbances are established as changing isotope signals most significantly, but so far, this is only recorded in tissues of short turnover, such as hair, but not in bone collagen (D'Ortenzio et al., 2015; Fuller et al., 2005, 2006; Mekota et al., 2006; Olsen et al., 2014).

The human samples selected from Iron Age graves in the earlier studies on Öland could include samples of individuals presenting extensive metabolic disturbances, possibly concurrent with the period in life investigated by the isotopic analysis (Howcroft et al., 2012:217; Ingvarsson-Sundström, 2006). The earlier study (Eriksson et al., 2008) does not describe whether pathology was present on the bones sampled or in general in the population. The potential bias is therefore not possible to estimate for either of these samples, although it could be suspected as significant for the younger individuals in the later study.

Interpreting provenance from $^{87}Sr/^{86}Sr$ 4.3.5

Isotopic provenancing using Strontium ($^{87}Sr/^{86}Sr$) in enamel or bone should reflect the $^{87}Sr/^{86}Sr$ ingested by the living person/animal as $^{87}Sr/^{86}Sr$ replaces Calcium (Ca) in the tissue. This assumption has been considered true for the almost 30 years of its presence in archaeology (Ericson, 1985; c.f. reviews in Bentley, 2006; Pollard, 2011). Setting a baseline by estimating a particular area's range in bioavailable $^{87}Sr/^{86}Sr$, is often detailed in the background section of bioarchaeological papers, before the results. In a way, this is puzzling. There is no universal or simple way of setting a baseline. This is a process of interpretation itself, and is of great significance for the overall results. In archaeology, there are a few different practices currently more or less accepted by the greater scientific community. One of the less common ones is the use of the distribution of human samples under the assumption that this is what would be expected to be a normal distribution when excluding outliers (Irrgeher et al., 2012; Slovak & Paytan, 2011; Wright, 2005). This could be a valid approach as long as it can be assumed that the majority of the humans are locals. However, if we cannot predict the presence of a large proportion of locals, such an approach is inappropriate.

The $^{87}Sr/^{86}Sr$ profile of freshwater rivers and groundwater would be expected to be similar in prehistory to today's values of these bodies of water, unless significant changes occurred in the climate. This approach to map $^{87}Sr/^{86}Sr$ variation of large areas (c.f. Frei & Frei; 2011) has been employed by researchers in archaeology (e.g. Killgrove, 2010; Montgomery et al., 2007; Price et al., 2013). Similarly, samples of soil and bedrock measurements of geological $^{87}Sr/^{86}Sr$ availability are often used to differentiate potential regions of origin, although their exact translation to bioavailable $^{87}Sr/^{86}Sr$ is frequently recognized to be slightly offset (Price et al., 2002). Most studies use soil, and/or water or plants along with animal samples in their discussions on $^{87}Sr/^{86}Sr$ baselines (Evans et al., 2010; Frei and Frei, 2011; Grupe et al., 2011).

Most researchers today seem to agree that measuring animal values is a good indication of bioavailable $^{87}Sr/^{86}Sr$ in the environment (Bentley, 2006; Price et al., 2002). The reliability of using animal values for the baseline for humans can be questioned. Firstly, measures need to be taken to evaluate whether or not the animal diet was significantly marine-based (which would infer the seawater $^{87}Sr/^{86}Sr$ levels) and, by extension, how similar such a diet was to that of humans. Secondly, the possibility of migration in the animals needs to be discussed and animals least likely to migrate should preferably be those sampled. I would argue that fulfilling these two parameters is virtually impossible in many cases. The available archaeological animals with teeth, and thus with more diagenetic-resistant material enamel, and which could have a similar diet to humans, are mainly dogs and pigs. However, the question of mobility is definitely crucial as these are small, easily transported animals; they could even have been transported by boat, as would be necessary in Iron Age Öland. The companion aspect of dogs also makes them possible, even likely, migrants. The grazing animals (cows and sheep) would have a different diet to humans and could potentially also have migrated. Small rodents are less likely to migrate due to their small habitats, and they have a potentially very different diet to humans. Most studies in $^{87}Sr/^{86}Sr$ which use animals as baselines advocate focusing upon these small animals as they are least likely to migrate. Many studies also collect modern snails from specific areas of interest to extract the $^{87}Sr/^{86}Sr$ composition in the shell to use as a proxy for that area's $^{87}Sr/^{86}Sr$ profile. Modern techniques for fertilizing the soil or later additions of new soil could potentially bias these results based in modern fauna or flora which is why they are usually employed in tandem with archaeological samples. Most researchers prefer to take out obvious outlier values (outside of the mean and two standard deviations), claiming them to be migratory animals (e.g. Fornander et al., 2011; compare to Fornander et al., 2015). Using the mean and two standard deviations of all values is a frequent approach to bioavailable $^{87}Sr/^{86}Sr$ baselines (Bentley et al., 2004; Grupe et al., 1997; Price et al., 2002; Turner et al., 2009), especially recently, when larger sample sizes are starting to become more frequent (e.g. Waterman et al., 2014 [n=29]; Gregoricka, 2013 [n=106]). In some cases, where faunal samples are unavailable, the human samples have been used to create a baseline (e.g. Tung & Knudson, 2011) also using the mean and two standard deviations. This approach assumes the majority of the population is local – a relevant assumption for humans in certain circumstances, but which of course begs the question of why the migration is then investigated at all. When constructing a baseline, especially using this statistical approach, the point at which the decimal place is active is of significance. The precision for reporting $^{87}Sr/^{86}Sr$ values was recently recommended to be only to the fourth decimal (Knudson et al., 2016).

For Öland, estimations of baseline for $^{87}Sr/^{86}Sr$ to be used for interpreting values from Neolithic humans have been published in Fornander et al., 2011 and 2015. The most recent estimate of the baseline for Öland is determined to be 0.7102–0.7158 (2015). Since these two publications differ slightly in reported faunal values, I use the values reported in the 2011 study to discuss a new baseline and will also take into account the animal samples from this study.

4.3.6 Interpreting provenance from $\delta^{18}O$

The $\delta^{18}O$ values measured here are in VPDB (carbonate). In order to interpret them as indicating provenance, these are usually compared to archaeological values and/or modern $\delta^{18}O$ values in drinking water. One common approach is to convert VPDB ($\delta^{18}O_{carb}$) values to ($\delta^{18}O_{phos}$) SMOW using equations, as in Coplen (1988). To allow comparison of $\delta^{18}O_{phos}$ SMOW to drinking water values ($\delta^{18}O$ VSMOW), equations in, for example, Daux et al. (2008) or Levinson et al. (1987) can be used (discussion in Chenery et al., 2012). These recalculations of the original values ($\delta^{18}O_{carb}$ VPDB) thus mean adding levels of interpretations (by choice of equations) before arriving at the new values. These new values are then, in turn, interpreted in relation to modern drinking water values. These are frequently used as a more or less direct translation to archaeological case studies, despite the fact that these reflect the current climate (c.f. Burgman, 1987, for Swedish values). From the compiled climate data in Davis et al. (2003), for example, it is evident that climate does change in the region, including in Öland (northeast Europe) throughout the Iron Age.

It is common to interpret human $\delta^{18}O_{phos}$ SMOW values directly to those of modern drinking water and to give quite narrow definitions of baselines (e.g. 0.5–1‰ in England, Evans et al., 2012). It is also common to view the human sample variation alone, whether comparing to water or not (e.g. Evans et al., 2006, 2012; Oras et al., 2016; Price et al., 2016). As well as the different climate in Iron Age Öland as a possible explanation of the potentially different $\delta^{18}O$ water values, there is also a bias in the anthropogenic factor. Humans do not necessarily use the surface water in the way that animals do; humans use wells and springs, they filter the water (c.f. Lee-Thorp, 2002; Pestle et al., 2014) and manipulate it in other ways, like boiling or brewing it (Daux et al., 2008; Brettle et al., 2012), to make it safe to drink or because of cultural preferences. These anthropogenic biases might shift in time, as well as by climate, and could thus alter the "bioavailable" δ^{18}O.

Comparing human δ^{18}O to animal samples is also very complicated. Different animals acquire water both through drinking it – sometimes from places unsuitable for human consumption – and through food, mainly by eating leaves and plants (review in Lee-Thorp, 2002). Consequently, their values, depending on species, are very difficult to compare to human values. Contrary to ^{87}Sr/^{86}Sr studies, using archaeological fauna for constructing a δ^{18}O baseline is very unusual. One exception is Bentley and Knipper (2005) who use pigs. The choice of pigs is relevant in that, like humans, they too are omnivores and often live close to humans, even being fed their refuse. However, due to different enamel formation (shorter time-span compared to human samples), the samples of pigs, and other animals, risk showing seasonal δ^{18}O effects, especially in northern Europe. I chose not to include faunal samples of δ^{18}O because of these reasons.

The third option, comparing other archaeological human samples (more or less contemporary), is also not without problems. For example, it is likely that at least some humans would be migrants, resulting in a skewing of the mean value in a population. Moreover, comparing human samples is a problem even within a contemporary static population, and an intrapopulation level variation of ± 1.7–2.3‰ (Levinson et al., 1987) has been reported. This variation may be explained by cultural, personal, or social group differences in the preparation of food and liquid. This variation means that interpopulation differences could potentially be obscured by intrapopulation differences (see, for example, discussion in Brettell et al., 2012).

In this study, I will define a δ^{18}O baseline comparatively with other Scandinavian archaeological human samples. I will set this baseline (widely defined to take a potential intrapopulation variation into account) using only the $\delta^{18}O_{VPDB}$ values (not using the recalculations to SMOW). In order to facilitate comparisons with this study in future, the carbonate values $\delta^{18}O_{VPDB}$ are also given as phosphate values, $\delta^{18}O_{SMOV}$ and $\delta^{18}O_{VSMOW}$, in Paper IV. However, I will not use modern drinking water values to decide the baseline, despite their availability, for a location close to Öland (Smedby in Småland; -10.5 ± 2.31 ‰ $\delta^{18}O_{VSMOW}$, Burgman, 1987:580). Those values are based on modern precipitation and are thus potentially entirely, and at least partially, different in climate to the Iron Age on Öland. Moreover, such a comparison means transforming the original $\delta^{18}O_{VPDB}$ values through multiple steps of calculations to appropriate SMOW values before even opening a discussion. This, no doubt, paves the way for potential biases on multiple levels. Therefore, I will show the distribution of the modern precipitation values in relation to my samples (recalculated) for transparency but I will not use it to discuss a baseline.

Single isotope baselines, mainly of $^{87}Sr/^{86}Sr$, are becoming increasingly common in provenance studies (e.g. Knudson & Buikstra, 2007; Mbeki et al., 2017; Schweissing & Grupe, 2003; Waterman et al., 2014). A combined bi-isotopic baseline based on $^{87}Sr/^{86}Sr$ and including $\delta^{18}O$ is similar to the approach chosen in this study is used less frequently (c.f. Bentley& Knipper, 2005; Bäckström et al., 2016; Evans et al., 2006; Oras et al., 2016; Price et al., 2016). Quite recently, a bi-isotopic approach where lead is added to $^{87}Sr/^{86}Sr$ started gaining in popularity again (c.f. Chenery et al., 2014; Valentine et al., 2015; Shaw et al., 2016; Sharpe et al., 2016) once the earlier difficulties of using lead had been acknowledged and dealt with (see Pollard, 2011). In the present study, both a single $^{87}Sr/^{86}Sr$ baseline (in Paper II) and a combined $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ baseline (in Paper IV) will be investigated and the results from each approach compared here in detail.

4.3.7 Interpreting ^{14}C: dealing with the reservoir effect and calibration

The methodology for measuring ^{12}C to ^{14}C for dating archaeological material has been well established in archaeology for more than 50 years. Since the 1970s, when it first started to be used in Sweden, the methodology has greatly improved, particularly where collagen in human bone is concerned. I have chosen to use only ^{14}C dates available from Öland which were performed after 1980. Since the level of carbon in the atmosphere has not been constant throughout time, values obtained must be calibrated to match actual calendric years in order to be comparable to other archaeological data that is dated by typology to calendric years. In calibrating ^{14}C values, there are several options for software. Two of the most common are OxCal and CalPal: OxCal uses the IntCal-calibration curve and CalPal uses the CalPal- calibration curve. CalPal is based only on ice-cores while OxCal uses dendrochronological data. The latest version of CalPal (CalPal-2007Hulu) has been directly compared to the more frequently used Oxcal (specifically IntCal 04; see Reimer et al., 2004 for details). Since then, IntCal has been updated (the IntCal13 version in Oxcal 4.2), but this has made very little difference to the calibration, and only for the very earliest part before 2300 cal BP (i.e. up to 350 BC), in the range of the Scandinavian Iron Age (Reimer et al., 2013:1881). There is very little difference between the two calibration methods when looking at data from the Scandinavian Iron Age, but I have chosen to implement the CalPal-version on my data. The results of the ^{14}C dates from this study and earlier studies are available as calibrated and uncalibrated in the Appendix and Paper III.

Another much more complex issue with radiocarbon dating is that of the reservoir effect. Humans with a diet incorporating a significant proportion of either marine or freshwater resources could have a secondary shift in ^{14}C values accordingly. In order to be able to take a potential reservoir effect into account, the diet must be estimated for the same individual (Philipsen, 2013; Van der Sluis et al., 2015). Today, studying diet with this type of accuracy on an individual level is virtually only theoretically possible by also analysing both a $\delta^{13}C$ and $\delta^{15}N$, as I do in this study. However, the stable isotope diet is an interpretation, as discussed above, resulting in further uncertainty. In Paper III, ^{14}C results are discussed with typological chronology and diet isotope results are discussed on an individual level in order to address the potential bias introduced by the reservoir effect.

4.4 Social organization and hierarchy

4.4.1 Contextualizing artefacts and archaeological contexts with human remains

It is often argued that studying artefacts and grave form allows inferences to be made concerning the social status and identity of the society burying an individual, or the individual him or herself while alive. Comparisons of funerary practice (focus on artefacts and/or grave form) in periods of the Iron Age in South Scandinavia have inspired many to discuss societal organization and hierarchy on temporal and geographical levels (reviews in Björk, 2005; Ekengren, 2009; Naum, 2008; Svanberg, 2003).

Within the context of immigration in the Late Iron Age on another Baltic island (Bornholm), Naum argues for the significance of funerary rituals and the specific treatment of objects (c.f. Naum, 2008:188) to commemorate the deceased individual's migration. She also poses the idea that immigrants buried by locals would be buried according to the local traditions (187) and are thus impossible to identify with such an approach. Her discussion of the use and arrangement of artefacts, and arrangement of the body (193) is the closest she gets to practicing a human-centred archaeology; like so many other scholars (e.g. Svanberg, 2003), she is confined to relying on archaeological methods of sex determination (i.e. using artefacts) for the remains when many burials lack osteological analysis (e.g. Naum, 2008:101).

The study of aspects of artefacts and the physical grave space, as well as grave fields, has a tradition as long as archaeology itself (c.f. Carr, 1995). The grave offers a limited space and event to study, and its elaboration in terms of different artefacts and construction is considered imbued with meaning. Human remains have not been at the centre of these studies until recently. Dealing with variations in the many different aspects of artefacts and grave forms (etc.) can be a complex and rewarding endeavour (such as in South Scandinavia: Björk, 2005; Ekengren, 2009; Räf, 2001; Svanberg, 2003). This follows a long and international tradition where the material aspect of burials has been given the spotlight at the expense of the human remains, as argued by osteologists (e.g. Gowland & Knüsel, 2006b; Duday, 2006). The artefacts, like human remains, can be studied on many levels:

- as actual physical objects within the grave and their relation to the body (e.g. Ekengren, 2009:56);
- characteristics of the artefacts, such as quality (e.g. Fabech, 1991, 1999), wear, origin, function, transforming meanings during the "lifetime" of the object, etc. (e.g. Ekengren, 2009);
- variations in object assemblages, which artefacts are paired or not (e.g. Björk, 2005:104);
- number of artefacts (e.g. Headager, 1992, used for Early Iron Age in South Scandinavia in Björk, 2005).

Grave forms are often studied on many levels such as: type (cremation, inhumation or other), elaborate architecture where present (coffin, cist, etc.), orientation, and spatial organization. In addition to the aspects of artefact and grave form, these are central in interpretations regarding manipulation, whether as part of the burial rite or due to simple looting of valuables (e.g. Klevnäs, 2016). If the information is available in the documentation, a valuable observation to include is whether the human remains are disarticulated or otherwise manipulated (see discussion under 4.2).

Although it may seem paradoxical that artefacts or grave forms often receive more attention than the physical person in the grave, in archaeology this can be explained by two things, in my opinion. The first is that the archaeologists are concerned with the artefacts and grave architecture as is their expertise, and enlisting another expert (an osteologist) to study the bones is deprioritized due to the costs. Secondly, when the body is studied by specialized osteologists, it is mostly with regards to aspects of life and biographies – as in the "archaeology of already dead people" (Robb, 2013:442) – rather than in an archaeology of death and taphonomy (or even *mortographies*), for example. The archaeologists who are studying the artefacts and graves are mostly doing so with regards to specific meaning in the funerary context or to the society burying their deceased. This leaves a very small common ground if the osteologist only studies the living person and not the idea of the body as being an "object" in the grave.

If the characteristics of the dead body – its spatial properties and affinity as a biological entity and structural element of the grave as studied by skeletal remains – were included in research, this would increase the common ground for archaeology and osteology and help create the cornerstone for a true archaeology of death and funeral (as suggested by several researchers, see discussions in Knüsel, 2010; Lorentz, 2015; Robb, 2013). However, I would prefer to call this *mortographies* (c.f. 2.2.1) rather than, for example, *funerary taphonomy* (c.f. Knüsel & Robb, 2016).

As this study is human centred (in contrast to much mortuary archaeology), the artefacts and grave form (or other context) are only investigated in direct relation to the specific human remains included in the study. Aspects of artefacts (date/typology, provenance, etc.) are based on information of the grave/context described in *Ölands järnåldersgravfält I–IV.* There, the graves were regarded throughout as a reflection of societal organization (as detailed earlier in 2.3). Here, the artefacts and archaeological context will be discussed specifically in relation to both death and life. Expressions of social stratification through burial practice may be very complex, and possibly may shift through time. I will discuss social stratification by positives only, i.e. high social status in relation to occurrence of specific types of artefacts (following definitions of high-status burials for Öland initiated in discussions in Hagberg, 1967:107f; Beskow-Sjöberg, 1987:388f; Rasch, 1991:474, 477). Looting/manipulation of the burials, as well as commingling from reburials (Rasch, 1991:510; 1994) is very frequent on Öland. It also appears that in some periods of the Iron Age, graves tended to contain fewer artefacts than at other times. A specific number of artefacts, or a lack of artefacts, is therefore a potentially very risky indicator of low social status. There are also many important types of artefacts that could hold great socioeconomic value that would decompose entirely (for example, fabric, exclusive plant material, foods such as eggs), leaving a very "rich burial" to appear empty. The location of the archaeological context could be relevant for identifying individuals of low social status, if interpreted in conjunction with the human remains (such as a prone position, tied extremities). The definitions and detailed discussions of high and/or low status individuals are specified in papers IV and V and follow the previous archaeological definitions to allow contextualization of the new results. On some occasions, the provenance of specific artefacts has been determined in *Ölands järnåldersgravfält I–IV* which could be relevant in comparison to the person's provenance, here determined by isotope analysis. This is discussed in detail in Paper IV.

Although animal bones are not artefacts *per se*, when found in graves they often represent artefacts (a fur, a piece of meat, etc.). Occasionally, an entire animal (a dog, for example) could be interred with the human. The occurrence of animals in Iron Age graves on Öland has been investigated by Räf (2001). Here, only animals which are unlikely to be local are highlighted as indicators of high status (a bearskin, for example). A discussion on animal symbolism, such as Erika Räf's, is very interesting but complex to integrate with a discussion on social status. With the exception of something like a bearskin, it is extremely difficult to determine whether an animal was put in the grave due to being economically valuable during that period (such as an early cat or chicken, a special type of dog, a horse, etc.) or for a more spiritual/symbolic purpose, as has been concluded in relation to Early Iron Age Öland (Räf, 2001). This question has been discussed in relation to Scandinavia generally (review and discussion in Jennbert, 2011) and is thought to be unrelated to social status.

An old tradition, especially practiced on Iron Age graves in Scandinavia, is to use artefacts for an archaeological sex determination. This was practiced extensively in *Ölands järnåldersgravfält I–IV* due to few osteological analyses and a proportion of cremation burials. Since this refers to social gender rather than biological sex (estimated with osteological methods on skeletal remains), I have only referred to biological sex, not social gender, when discussing the human remains. Social gender established using artefacts would be interesting to compare, but such a comparison is not in line with the specific research questions investigated in the papers and is therefore not elaborated on here.

4.4.2 Violence and social organization

Violence, conflict, and warfare is an area that has been engaging bioarchaeologists from the very beginning, and in recent years, publications about these topics have increased greatly (e.g. see review in Martin & Harrod, 2015; Stojanowski & Duncan, 2015). Generally, archaeologists have shown great interest in using the study of violence, primarily warfare, as a method for investigating societal changes (e.g. Ralph, 2013). Defining skeletal violence is not straightforward in the archaeological literature when "skeletal trauma" is often used without further definition (e.g. Vandkilde, 2015). Skeletal trauma can have many etiologies other than interpersonal violence making assumptions about definition problematic. In my definition of interpersonal violence, I follow a generally accepted, albeit strict, rule in osteology. Violence is only interpreted (i) for trauma affecting the skull, or (ii) when sharp force trauma to any part of the body is visible. Generally in osteology, isotopes are rarely integrated when investigating violence, and when they are, it is only on an individual-case basis. However, this makes it hard to contextualize the isotope results of a case if investigating levels of population variation; are the isotopes even relevant to the violence, or are the values "normal" in that they are also common in people without skeletal violence? This is why the population level approach to isotope variation is useful here, especially as practiced in Paper V.

Weapon injuries are a form of "meeting ground" for bioarchaeology and forensic anthropology where both are equally at home with creating biographies, as well as focusing on the specific moment of injury, the weapon used, etc. However, in bioarchaeology, the type of burial (or other) is crucial in contextualizing the trauma comparatively to the rest of the population as a whole, particularly so in cases of lethal violence (e.g. Harrod, 2013).

The frequent equivalence of warfare and violence is problematic (for a recent bioarchaeological review of violence and warfare, see Knüsel & Smith, 2014b). This equivalence probably originates in archaeology since here the arguments are based primarily on artefacts and settlements, and written or iconographic sources which, by definition, are focused on specialized warfare and warriors. This is a problem since the idea of "warriors" as practitioners of violence need not apply for all periods (argued in, for example, Schulting, 2008). If used in other contexts, the historical and modern way of considering aggression in war as desirable while, on the other hand, treating violence as a punishable offence, is argued to be socially learned and not "nature" (c.f. Nordstrom, 1998). In my opinion, we are at serious risk of trivializing the past societal structure by implying that violence is equal to warfare, regardless of time period. In recent social theory, it is argued that violence is a form of renegotiation of social roles, which is more or less sanctioned by society, depending on its context and victims, and occurs similarly in war as well as "at home" (Nordstrom, 1998; Scheper-Hughes & Bourgois, 2004). However, very often, the violence occurring outside of warfare is less socially acceptable unless regulated. This might be achieved through a justice system of some sort, for example, or through adherence to a hierarchical structure, with status being determined by gender, age, sex, or some other criteria. If we consider violence independent of warfare, and approach it in all types of archaeological contexts to contextualize the victims (and types of violence), this allows an investigation of violence as being indicative of social organization or as a form of cultural expression on a more general level. Skeletal remains are therefore a primary source for investigating violence unlike most other archaeological sources.

4.4.3

Approaching variation: quantification, modelling, and network analysis

When dealing with archaeological data which is often complex and biased, both deductive and inductive reasoning can be useful approaches. Inductive reasoning – testing a specific hypothesis – can be applied in many forms to archaeological data. Bayesian inference is one of these forms, where a prior understanding is used to model (and remodel) the hypothesis based on the data at hand. A positive result means that the scenario implied in the Bayesian modelling is possible, but not that it is the only appropriate explanation. The validity of the results depends on the information going into defining the model parameters, i.e. the prior knowledge. Deductive reasoning can be used in more explorative approaches such as the use of graph theory to organize the data in networks. This approach is useful where the prior expectation is less solid or specific hypotheses are less clearly defined thus working as a means of exploration of variation.

I will employ two specific approaches to variation in my dataset: (i) Bayesian modelling to investigate immigration patterns to Öland, and (ii) a simplistic version of network analysis in order to view social hierarchy, organization and violence on Öland in an approach centred on human remains. Both approaches have been in use in archaeology for some time and have recently been quickly increasing in popularity (especially during 2015, as detailed below) and are therefore timely to explore here, for an interdisciplinary approach.

4.4.3.1 Bayesian inference: knowing is believing?

Bayes' theorem consists of three major elements: the posterior, likelihood, and prior. The posterior is formed from the combination of a prior (existing knowledge about parameters) and likelihood (the model data). The prior can thus affect the outcome of the analysis, a major difference from classical (frequentist) statistics. The use of prior information is what makes it so philosophically different from the frequentist statistics that have dominated the Anglo-Saxon field of statistics in the past 100 years (reviews in Efron, 2013; Cowgill, 2015; Buck & Meson, 2015). The use of prior information is a matter of some controversy. Bayes' theorem has been in use since the late eighteenth century for finding hidden information in complex data sets and is today applied to a great variety of data in different branches of science. Before today's current hype, Bayesian approaches had experienced two hypes and two crashes, resulting in an abandonment of the concept (Efron, 2013). This is testament to elements of controversy regarding its uses and its inherent stability and relevance as it continues to resurface, despite these crashes.

Today, many researchers within mathematics and a wide variety of other fields have seen the success in the use of Bayesian modelling to solve a range of difficult problems and tease information from very complicated data sets.

Efron (2013), Cowgill (2015), and Buck and Meson (2015) from the field of statistics are all very positive on the use of a Bayesian approach, but only when using informative priors. They all call for caution in choosing priors and using only those that are truly based on solid information. Additionally, all discourage using uninformative priors, those inferences not based on any experience. Cowgill, and Buck and Meson, are propagating the use of Bayesian modelling (with strong informative priors) in archaeology and regret that so far, it has been used mainly for radiocarbon chronologies despite its great potential for many other research questions.

Kruschke (2015) recently released an updated manual which is very useful for the aspiring Bayesians of any field, and which is also suitable for archaeologists as a starting point. However, in order to be a true Bayesian, care should be given to incorporate not only the mathematics and specific software but also the philosophy behind the mathematics (c.f. discussions in Buck & Meson, 2015; Cowgill, 2015). The frequent, and sometimes uninformed, use of Bayes' theorem in radiocarbon chronologies in archaeology has attracted criticism. In the literature, a focus on technical details, such as the use of different software for computations, has been allowed to take precedence over discussions concerning the very intellectual basis of the model, for example, whether it should be applied to some of the problems in the first place (c.f. discussions and review in Buck & Meson, 2015). Bayes' theorem has been used in osteology in such diverse areas as paleopathology (e.g. Byers & Roberts, 2003), age estimation (e.g. Boldsen et al., 2002), and recently in determining the identity of Richard III's remains (King et al., 2014). In isotopic analysis, outside of radiocarbon, Bayes' theorem has also been applied to studies of diet (c.f. 4.3.4). This trend of Bayesian inference within archaeology in general could be a way of integrating the subfields – a way of "speaking" a common language.

In this thesis, I will employ Bayesian modelling, using data selected on the basis of the gravity model for mobility as a base for the prior. Currently, Bayesian modelling has not been applied to $^{87}Sr/^{86}Sr$ isotopes for, in my view, two reasons: (i) the difficulty in devising a sound prior predicting human mobility and (ii) the fact that sampling is usually selective in migration studies, aiming to pinpoint deviants rather than discuss the phenomenon of mobility and immigration on a population level. Quite recently, the gravity model was rediscovered after a long pause (Hodder & Orton, 1976; Renfrew, 1977) in conjunction with the explorations of GIS and/or network theory (e.g. Conolly & Lake 2006; Rivers et al., 2013). Nevertheless, it is still unusual in an archaeological context. The gravity model was recently used explicitly to model human mobility and migration in an archipelago setting (Leppard, 2015). This study developed an ecological approach based on the gravity model which was suitable for archaeological application and which could potentially be of relevance to islands in general. In my opinion, an island setting is especially promising for the gravity model as the mode of communication is given – maritime transportation – making it possible to estimate distances to centres of gravity with relative ease compared to different modes and routes of land transportation.

4.4.3.2 Graph theory, networks and social network analysis: seeing is believing?

In some respects, network theory and graph theory have a similar story to that of Bayes' theorem. They go back centuries but their use in archaeology is similarly recent. The method of network visualization graphs is based in graph theory and has been used by pioneer thinkers such as John Snow and Florence Nightingale (c.f. Rodighiero, 2015). The approach allowed them to devise and detail their theories on human disease and find a pattern among multiple variables. The role of visualization in successfully conveying these theories to those in political power and the public cannot be overestimated.

Network analysis can be applied to virtually any field of science relating to humans. Its flexibility to study social relations and physical phenomena, as well as the possibility it provides of connecting these to geography, is of particular relevance to archaeology. Studying networks is, in essence, the studying of relationships between nodes, helping researchers to gain deeper insights into each of the nodes. A node can be virtually anything that is engaged in a network with other nodes (an action or activity, a quality, a person, an object, a geographical area or an animal), and which is connected by relationships (edges) (Collar et al., 2015). The process of abstraction that goes into defining nodes in a network is a conceptual process calling the researcher to make very specific definitions of concepts (labelled as a network model by Collar et al., 2015). Visualization and network theory is not a model per se, but a tool for data exploration. Similar to Bayesian modelling, the definition of nodes (defined with some degree of abstraction as a guide) determines the outcome of a network analysis. However, the study of nodes might reveal several possibilities and complexities, making the question "is this specific connection relevant?" not so straight forward to answer.

Bordoni (2015) has supplied a current review of the recent use of network theory and social network analysis in archaeology. The most common use has been investigating connections related to geographical space, whether to investigate physical movement of people and/or objects (for example, in trade: Graham, 2009; Sindbæck, 2007; multiple contributions in Knappet, 2013), and/or cultural connections (e.g. Ashby et al., 2015; Sindbæck, 2007). In particular, graph theory and its use in archaeology for network analysis was recently acknowledged and advocated by Nakoinz & Knitter (2016), although like many of the works mentioned above, mainly focused on the use for geographical analysis (roads and transportation). Hodder and Mohl (2015) have taken the theoretical approach of entanglement and paired it with network theory and graphs. In their version, a node can be an object, material, action/activity, human, or any more-or-less defined space for a complex visualization giving an overview otherwise extremely challenging to describe as efficiently and dynamically in text.

Much of the use of network analysis in archaeology has focused on islands (early works such as Broodbank, 2000; Hage & Haray, 1991, 1996; Leppard, 2015). I am convinced this is no coincidence but a direct result of islands being the very embodiment of a node (or gravity centre, such as in Leppard, 2015). An island is clearly defined by the sea-land dichotomy and the communication-isolation dichotomy of the sea. Humans, whether considered agents or objects, are suitable to study as nodes which has taken a significant expression in social theory and social network analysis (SNA) (c.f. Bandyopadhyay et al., 2010). The graph resulting from the visual projection of nodes and edges visually allows – even invites – the researcher and readers to make interpretations by association and makes it possible to see the problem from a new viewpoint; it allows a new dimension for exploration. The social network graphs are also commonly referred to as sociograms (e.g. Carolan, 2014). In *Signs Theory*, Rodighiero (2015:4f) claims that the process of visualizing data in networks can reveal a deeper meaning than is otherwise accessible. It is an explorative method widely applicable to different types of data. It acts to define aspects of data as phenomena and, by association, allows for a rethink of the definition of a phenomenon. In my opinion, this is also an effect of the process of designing the nodes in the visualization, forcing you to be confronted with your definitions of concepts. When projected and visualized in a network, these definitions may acquire new dimensions showing greater complexity than is allowed for in a yes/no hypothesis. The strength with using a network approach is that it allows, even requires, consideration of *how* and *why* relationships matter.

In this thesis, through a human-centred approach, I will use network analysis to combine various parameters which are difficult to quantify uniformly (isotope results, and archaeological and osteological parameters) in order to study social hierarchy and violence on Öland. Network analysis is dynamic in that it involves defining nodes and thus provokes questions on frequently undefined concepts (for example, questions concerning what aspects of a grave can be significant and why). Another dynamic aspect is that it allows the scoring of a feature only when present which could suit the type of incomplete and biased data that archaeology largely deals with. In other words, it takes the positives (actual occurrences) into account and highlights them in relation to one another without automatically attributing the negatives with the opposite significance. An example: just because high-status burials are assumed to contain certain artefacts does not mean a burial lacking such artefacts is of lower social status due to, among other things, taphonomy. Indeed, a most valuable fabric can be completely dissolved over time. Moreover, in Öland's case, manipulation/looting is most likely a taphonomical factor of great significance for explaining a lack of artefacts. Furthermore, studying variation and simply noting whether the characters of the deposition (burial or other context) are normative or whether they deviate (non-normative) in some specific respect can help to shed preconceptions of what such deviations indicate. A deviant or non-normative burial/disposal does not necessarily have negative connotations in terms of social standing of the buried individual, as aptly argued in detail by Weiss-Krejci (2013), but it is often assumed that this is the case. Using network analysis these aspects can be investigated more transparently as this shows the full variation.

4.5

The human-centred archaeology and Iron Age Öland

All of the methods detailed in the sections above are established in archaeological context and some are frequently practiced. I have selected them to represent a human-centred approach because their results are possible to tie to specific individuals that lived and died, rather than generic periods, populations, or cultures. Furthermore, the human remains are primary sources, in many senses unsurpassed, compared to all other archaeological remains with regards to understanding society. As an osteologist, my insight into the different aspects of the human skeletal remains gives an informed starting point from which to study these primary sources. My insight into the methods chosen from different disciplines and the research collaborations with three other experts allow me to take an interdisciplinary approach.

Human isotope values are a primary source for investigating human diet, reflecting the diet of one specific individual unlike the more generic assemblages of animal bones, paleobotanical remains, settlement patterns, artefacts, and so on which represent diet for a population. Additionally, these secondary sources are susceptible to biases; representativity can be a problem, for example, as some materials are less well preserved and their state can depend on how humans deposited the material. Bird and fish bones are more poorly preserved than the more robust bones of many mammals and are thus less likely to be proportionally preserved, collected during excavation, or identified in an osteological analysis. This is a bias based on the physical properties of the material. In other words, it is purely a biological factor. Cultural choices lead to the selective treatment of the physical remains: which animals or plants were eaten and when, how they were prepared, and how the bones were deposited. Such factors can also result in biased assemblages. Similarly, various human choices have resulted in differences in preservation of material and thus biases in the archaeological record: how humans chose to build enclosures for animals, how they prepared fields for crops, which materials were used for objects to process or store these resources, and so on. Human remains are not under the same level of bias because the isotope levels do not determine which animals were part of the human diet; humans didn't select their foods based on their bone robusticity or where the refuse was deposited. This is why I regard them as a more primary source for diet investigation. Having said this, the isotopes do have other biases. It is unclear, for example, to what extent they reflect the entire diet or just the protein proportion of the diet. Still, they do give information on a specific individual and are therefore an inherently primary source.

Migration and mobility can be studied using multiple archaeological sources from approaches comparing material qualities as well as presentation of objects or construction of objects or structures. Plant and animal remains can also be investigated in a way that is similar to that of human remains using isotopes and DNA. Plants, animals and objects can show how they moved, but they do not prove that humans moved or migrated along the same route. Only the isotope analysis of human remains can prove whether a human migrated from one place (a place of childhood residence) to the place where they were buried or otherwise deposited. The primary source for investigating migration today, then, is isotope analysis, with all other sources being secondary.

Human skeletal remains are a primary source for studying social organization in multiple respects. Violence can leave marks upon the skeleton and the social behaviour that is expressed in the use of violence can thus be studied. Weapons, iconography, and written sources can also be informative on violence but are secondary compared to actual injuries to individuals. Other aspects of social interactions can also be linked to the skeletal remains, and the social and cultural aspects of burial practice can be discussed in relation to characteristics of the individual, such as age, sex, migration, and diet.

The detailed study of taphonomy can also add to the understanding of what specifically happened to the human remains and the environment in which they were found, that is, the archaeological context. The movement, mechanical impacts, and manipulation of the skeletal remains are a primary source of information about the formation of the archaeological context due to their physical properties. This information can be related to aspects of burial practice, as well as the artefacts integrated in the context. This primary source can thus not only further the understanding of a particular individual's death but can also further the understanding of the social organization which resulted in the individual's violent treatment. Here, the taphonomical analysis is mainly performed in the case study of Paper I where I could acquire sufficient documentation. There are a few cases where photographs were useful to discuss a specific body position or element position (discussed in Paper V), but this is far from an optimal approach in my opinion.

CHAPTER 5

The human-centred approach “in action”

I WILL USE THIS CHAPTER to present the results as they relate to the four major themes (taphonomy, diet, migration and social organization, c.f. 1.4). The main focus here is to give an overview of the basic results of the papers but primarily in a way that provides a deeper understanding by adding them together. However, I will also account for the results of the human-centred archaeology as seen “in action” in the papers.

5.1 Taphonomy

Virtual Taphonomy was a methodology named and developed in Paper I. It is based on image-based modelling (IBM), a method practiced for a few years in archaeological excavations and recently integrated in 3DGIS (Three-Dimensional Geographic Information System). The IBM provided high accuracy and high levels of detail as demonstrated with examples in Paper I, where the position of gnaw marks on a bone could be identified on a 3D model, for example. The IBM also proved to be a very time-efficient method in the excavation, like when documenting archaeological contexts in general (c.f. Dell'Unto, 2014). The possibility to integrate field and post-processing results in 3DGIS via the 3D model and the database function was highly beneficial to the overall interpretation of taphonomy. Other osteological post-processing results (such as age, sex, etc.) were not considered as relevant to address in a spatial environment in this specific case study and were therefore not included in the database. The *Virtual Taphonomy* approach made it possible to integrate osteological and archaeological interpretations in a common platform (i.e. in 3DGIS). The combination of results meant that new information could be accessed and the osteology could be integrated with the archaeological interpretation. While Paper I mainly had a methodological focus, the interpretation of the results achieved specifically by that approach will be elaborated on below.

5.1.1 The reflexive approach to the context of the individuals in Sandby borg: the use of *mortographies*

In Paper I, the two individuals (ID 1108 [Individual 1 in the paper]; ID 1109 [Individual 2 in the paper]) found in a house within a fort reveal the potential of *mortographies*. The specific events relating to their death and up to their recovery were the focus of the study, or, in other words, their *mortographies* were at the centre of this research. Taphonomy was studied in the field, in the lab, and in 3DGIS allowing a reflexive interpretation. The paper's main focus was to detail and demonstrate the *Virtual Taphonomy* approach rather than to make more elaborate archaeological interpretations. I concluded from the taphonomical analysis in Paper I that the bodies started to decompose in an open space without scavenger access—the house—and that it would have needed to be more or less closed off from large predators, both airborne and terrestrial. The house later collapsed over the bodies while they were still partly articulated, probably quite soon in the process. An exact time line would be very difficult to establish considering the complexity of the house's microclimate and the lack of information on season, etc. The collapse of the house could have been caused by one violent event or a sequence and here, again, the spatial context was very helpful for analysing the different taphonomical aspects. The extreme torsion of the spine of Individual 2 allowed for hypothesizing in terms of the direction and great severity of the force which might have caused it. This hypothesis correlates well to another taphonomical aspect, the fracture loading points (defined in Paper I) on the bones. In total, this suggests application of great force, possibly in a single event, and I interpret this event to be the probable caving in of the roof; a gradual collapse of elements of the house would be less likely to have caused the specific movement of, and mechanical impact on, the decomposing human remains. This begs one important question in relation to the interpretation of the site. Why would the roof (and/or other architectural elements of significant weight) suddenly collapse? Would it not take many years for well-kept and well-built houses to collapse? Would it not be a gradual process allowing access bit by bit to the still articulated remains for animals? Based on these thoughts, I speculate that someone came to the site, found the partly decomposing bodies, and decided to collapse the roof (probably collapsing structural beams by fire or mechanical impact) to bury them under the wreck. Considering the advanced, but not complete, state of decay indicated by the spinal articulation, handling the bodies would be challenging. The probably significant odour and loss of structural integrity of the soft tissues would be problematic in order to be able to move the bodies to bury or burn them. If it is true, as currently hypothesized, that many more people were killed and left in the houses of the fort (c.f. Victor 2015), then the number of bodies would also have been a confounding factor. Furthermore, Fallgren and Lindquist (2016) have argued that the deposits of elaborate and rare jewellery should not be considered hidden, and/or left in haste (as Victor [2015] argues, for example), but were deposited in this and other houses since that was what tradition dictated. This is interesting in relation to a conscious decision to demolish the house while still leaving the jewellery inside in its proper place along with the bodies. In order to investigate the hypothesis proposed here, more would have to be excavated, with taphonomical aspects of skeletons, objects, and architectural elements analysed jointly and the *Virtual Taphonomy* approach practiced in the excavation. Currently, this can only be suggested as a hypothesis.

The practice of leaving bodies in houses that are then collapsed over them is not unheard of in Iron Age Scandinavia, and in two cases they appear undisturbed similar to Individuals 1 and 2 in Paper I. Both examples are burned human remains over which the house had collapsed/been collapsed after the fire. The first case, Nørre Tranders, Denmark, is much earlier, dating to the first century BC and concerned an entire burned house including a byre. Both humans and animals were found inside the house and it is interpreted as a small domestic household where they were overcome by the fire and died trying to get out or saving the animals (Harvig et al., 2015). The second case, house 21 in Uppåkra, Sweden, is determined to be from around the fifth century and three individuals were found inside a collapsed, burned house. One of the individuals could be determined as an adult male in prone position, one was a young individual lying supine, and the last one was more fragmented and heavily burned. The individuals were probably dead before their bodies started to burn, and at some point after the fire, new houses were built over the burned house (Magnell, 2008; Lenntorp, 2008, Larsson, 2011; Larsson & Söderberg, 2012). For Uppåkra, the disarticulated human bones found in occupational layers have been interpreted as, among other possibilities, victims of a massacre event as the bones show sharp force trauma from weapons (Magnell et al., 2013:110). It is possible the house in Uppåkra could be something similar to the case in Paper I—demolished to bury the bodies after initial decomposition. In both cases, although the element of fire is an important difference, the bodies appear “buried” by the house collapsing over them with people probably aware that they were still inside.

There is a further example of relevance here, on the deposition of human remains in a battlefield context in Iron Age Denmark, in Alken Enge. In the wetland site of Alken Enge, the human remains were recently interpreted as those of people who died in battle and were exposed to animal scavenging and dismembering and partial defleshing in a fresh state (Mollerup et al., 2016). Thus, the practice of leaving bodies unburied for some time, as in Sandby borg, is similar to this situation. However, in this study’s case, it is likely that the house shielded the bodies from scavenging while they were still fresh and most attractive for scavengers.

5.1.1.1 An example of a reflexive taphonomy also for the archaeological context

The paved walkway (singular flat, white limestones circa 23 x 50 x 5 cm) placed in a straight row tracing the midline of the house, as mentioned in Paper I, was a structural element identified only in postprocessing in GIS while working with the 3D models (Fig. 13). This was due to excavation occurring in small, multiple, sequential, non-connected trenches excavated during different campaigns which could only be viewed as a unit in 3DGIS. In the GIS, due to Individual 2 lying partly over the walkway, the *Virtual Taphonomy* analysis could determine that the decompression of the original floor level of the house was in fact at least 7.7 cm. In the very midline of the house there was a height difference of 7.7 cm (measured in the 3DGIS) between the top of the walkway stone, where the left arm was lying on top, and where the left hand was found right next to, but much lower than, the stone. The decompression was slightly less prominent, closer to the walls of the house and further from the midline, with a 7.3 cm difference between the right foot metatarsals and the corresponding tarsals lying elevated on a small stone at the same level as the walkway.

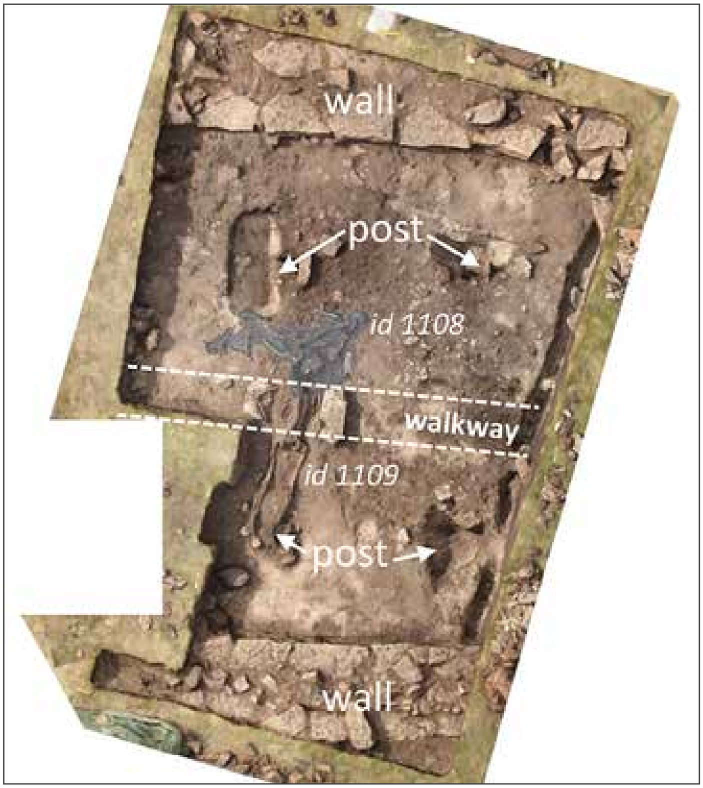
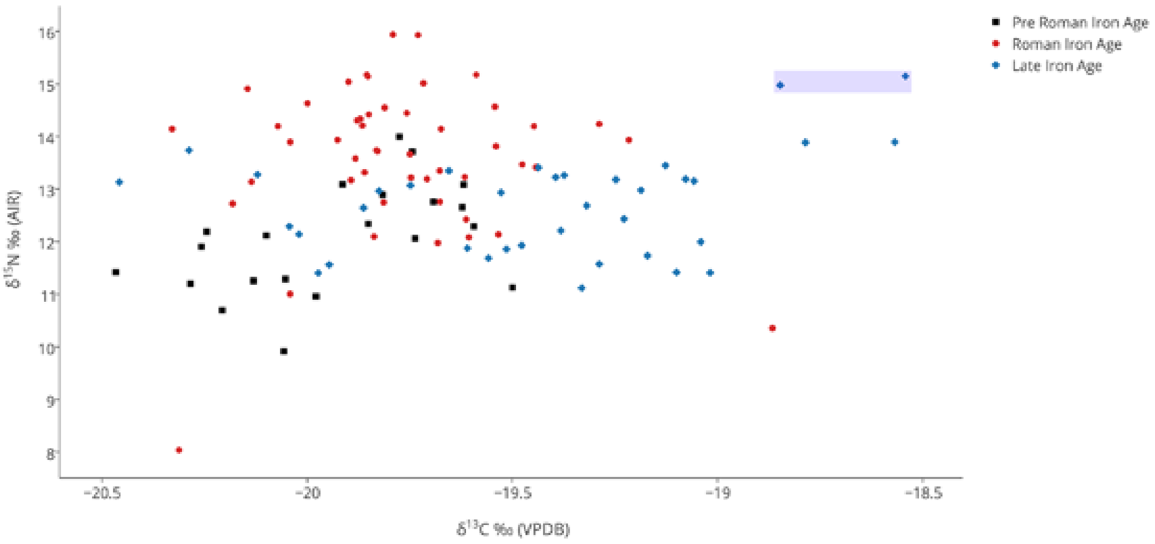


Fig 13. The extent of the walkway, excavated non-single context (i.e. from 2011–2013) is shown here. The image is of the merged 3D models in GIS (mainly 2013 with 2012 [darker colour] imposed on it). Modified after image by Nicoló Dell'Unto, Lund University, and used with kind permission.

5.1.2 From *mortographies* to biographies: Who were the two men in house 40?

While Paper I only dealt with the *mortographies* of the two men, something could be added about the life of these individuals, their biographies. In fact, this could be relevant to their death and the scenario that led to them being found in a house. Their biographies can be found in part in papers III, IV, and V as ID 1108 (Individual 1) and ID 1109 (Individual 2). Here, I will present the osteological and isotopic results in greater detail, while relating them to the entire Iron Age sample.

The two men in house 40 were similar in age, 17–19 and 19–22 years old, and are likely to have been local to Öland (in the sense detailed in Paper IV) or from an area of similar geology and climate, such as along the Baltic Sea coast, perhaps from areas not yet investigated for $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ in detail. Their childhood diets (measured in enamel) appear marine-based or C4-based, and both are in the higher end of the $\delta^{13}C$ spectrum but the slightly older individual (ID



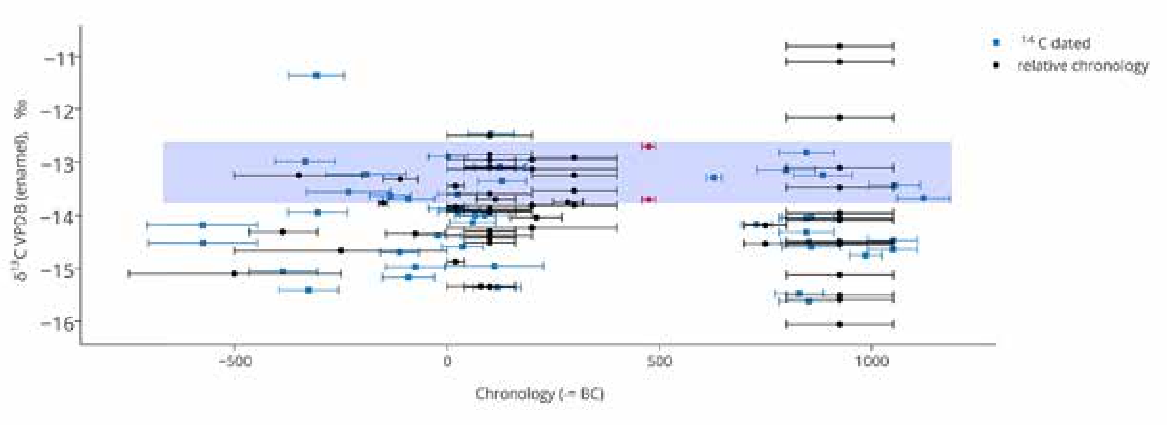


Fig. 14. The diet samples from bone collagen (adult diet) divided by relative chronology (as discussed in Paper III) with the two men from Sandby borg (ID 1108, 1109) indicated by a blue shaded area. Their diets are clearly different from all of the earlier individuals in Öland (Pre Roman and Roman Iron Age) and from most from the Late Iron Age (AD 400–1050) as well. The higher δ¹³C indicates a more marine-based diet than most other individuals. There are two animal samples from Sandby borg included in this study. ID 1247, a dog had -17.6‰ δ¹³C and 12.6‰ δ¹⁵N which is similar to the humans although with a lower δ¹⁵N indicating it was possibly fed refuse, therefore less protein than the humans. ID 1246 was cattle with -21.6‰ δ¹³C and 6.1 ‰ δ¹⁵N, which is very similar to other cattle samples from Öland. See Table 6 for details.

Fig. 15. All childhood diet samples (δ¹³C from tooth enamel) from Öland with the two men from Sandby borg (ID 1108, 1109, marked in red). This shows that the two men had a slightly different childhood diet from each other. Their difference in diet, and the specific δ¹³C levels that include them both, is very common (see light blue area) both in the earlier and later individuals on Öland. The mean value of the date is marked as a square or circle and the whiskers indicate the standard deviation for ¹⁴C dates and the range for relative chronology.

1108) had a very high value. There are, however, several even higher values in Öland so they are not unique. Their diet in the years before death (analysed in bone collagen, not enamel) is very similar, and it is possible this could indicate they were living together. It is also interesting that their diet before death shows, for Öland, an unusually heavy influence of marine-sourced fish. In fact, they clearly stand apart from all other samples from Öland (Fig. 14). Their lifestyle seems very different from both earlier and later individuals in Öland. What is curious, however, is that despite this, their childhood diet is more or less the same as that of both the earlier and later individuals (Fig. 15). It is possible that the marine-reliant diet of the two men (both in childhood and as teenagers) is a result of living in the fort, situated literally on the seafront. However, Ljungkvist and Fallgren (2016) argue that the fort was regularly partially flooded by the sea, making constant habitation throughout the year unlikely, similar to other forts inland which were flooded by wetlands instead of the sea.

As reported in Paper I, both individuals suffered peri-mortem sharp force trauma. Individual 1108 had injuries from sharp weapons in the skull (Fig. 16), the right scapula (Fig. 17) and additionally a fracture to a tooth (Fig. 18) that could be from the time of death, slightly before or after. Individual 1109 had a sharp force trauma (SFT) through a right rib (Fig. 19). Alongside the isotope results and the peri-mortem traumas, their skeletons also revealed that both had minor healing traumas at the time of death. One had a healing rib fracture (ID 1108) somewhere in the half of the rib ending with the costosternal articulation, i.e. his chest. The other had a healing injury penetrating through to the bone on the outer—in the sense farthest from the thumb—and lateral side of the fifth metacarpal on the right hand (ID 1109; Fig. 20). These injuries could have many causes of accidental nature, but considering the individuals were both killed in a violent attack, it is possible they sustained these injuries training for, or participating in, a fight recently before their deaths. The healing injury on the right hand of Individual 2 could be a result of protecting himself from an attack, or from an attack to his hand while holding a weapon, for example. The healing rib of Individual 1108 could have been broken as that man was pushed against

Fig. 16. Close ups (microscope) of the SFT margins (kerf walls) in a fragment of the left temporal (squamosal portion). The skull trauma/s are described and analysed in more detail in Wilhelmson et al. (forthcoming). ID 1108. Photo: Helene Wilhelmson.

Fig. 17. (At least) three different sharp force traumas to the right scapula. Id 1108. Photos: Helene Wilhelmson.

Fig. 18. Possible peri-mortem trauma in the mandibular left canine. Image taken during the en bloc excavation of the skull (right), canine in the centre of the image (left). ID 1108. Photos Helene Wilhelmson.

Fig. 19. The sharp force trauma in the right rib (in microscope) is a straight transversal cut through the body. The superior surface is facing the camera (left) demonstrating the almost 90-degree angle. The margin shows minor flaking consistent with great force and/or contact with the weapon handle, for example (right image, the posterior surface is facing the camera). Photos Helene Wilhelmson.

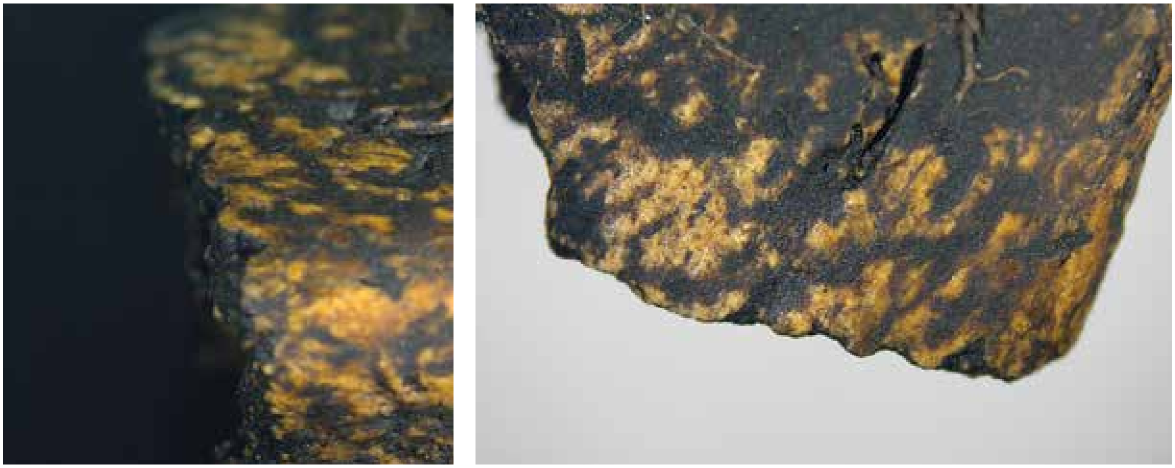


Fig. 20. The healed trauma in the fifth metacarpal of ID 1109, photo (left) and x-ray (right). Photo: Helene Wilhelmson. The x-ray image was acquired in the Radiology Department in Malmö University Hospital (MAS) and digitally processed in the software Sectra Bildvisare IDS7 2013 by Helene Wilhelmson.

something, trampled, beaten, or some similar action of significant force. All in all, it is plausible that these two men were experienced and possibly specialised fighters. They could even have been consuming a specialised diet, at least in comparison to earlier and later individuals in Öland. It is also striking that both exhibit healing injuries as if they could have recently participated in fighting, leaving them potentially weakened at the time of the attack. In my opinion, this points towards retribution as a possible motive for the violent attack on Sandby borg.

5.2 Diet

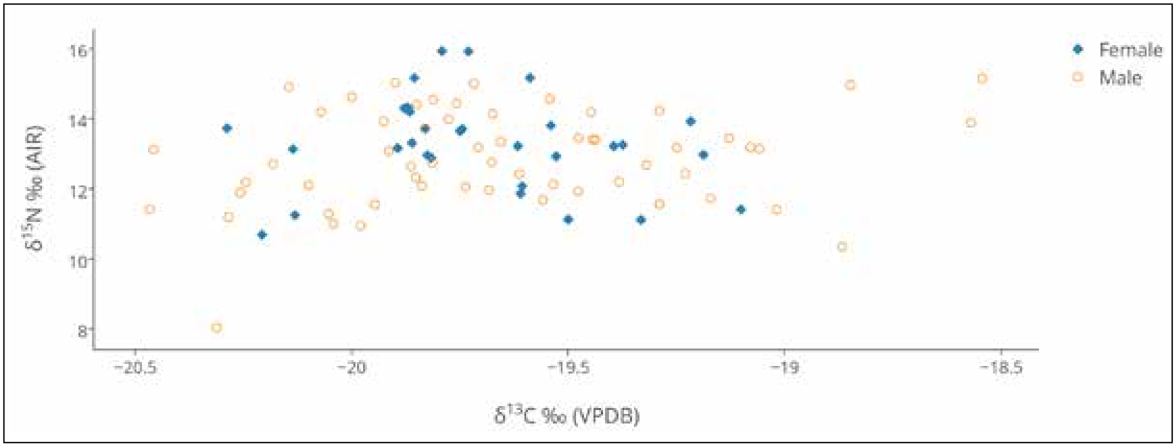
The isotope analysis of the dietary-indicating isotopes in bone ($\delta^{13}C$ and $\delta^{15}N$) and enamel ($\delta^{13}C$) are discussed here. The bone values reflect diet in the years prior to death (i.e. adult diet) and the enamel values show childhood diet. As the interpretation of the specific ^{13}C values also differs depending on the tissue sampled, these interpretations of diet are discussed separately. However, all the results are explored to form a basis for a discussion of (i) how diet changed (or not) during the Iron Age, and (ii) what isotopes can tell us (or not) about the diet(s) on Öland. First, I will discuss the variation in isotopes and the chronological development of adult and childhood diets. Secondly, I will discuss the interpretation of adult diet from $\delta^{13}C$ and $\delta^{15}N$ values and other archaeological sources. The isotope values are shown and interpreted in biplots.

5.2.1 Adult diet: the $\delta^{13}C$ and $\delta^{15}N$ variation in bone collagen

There is a significant difference in diet when taking chronology into account, as detailed in Paper III. The dietary shifts in one case also appear to transcend the relative chronology (archaeological periods). Here, the focus is on the (not very informative) conclusions from comparing male and female diets, as well as diets in different ages of death. These results do not present any indication of covariance of diet with either age of death or sex, thus indicating a more "equal" diet. The factors explaining dietary variation are more likely to be found in chronology, and possibly in aspects of social status other than gender or age differences. The practice of grave reopening and re-use, especially in the Roman period, makes it difficult to probe this (status) as a factor.

5.2.1.1 Female and male diet

There is no clear difference in diet between males and females (Fig. 21). Chronology is more likely to be a significant factor (Fig. 22) in dietary variation than sex. Since the isotope



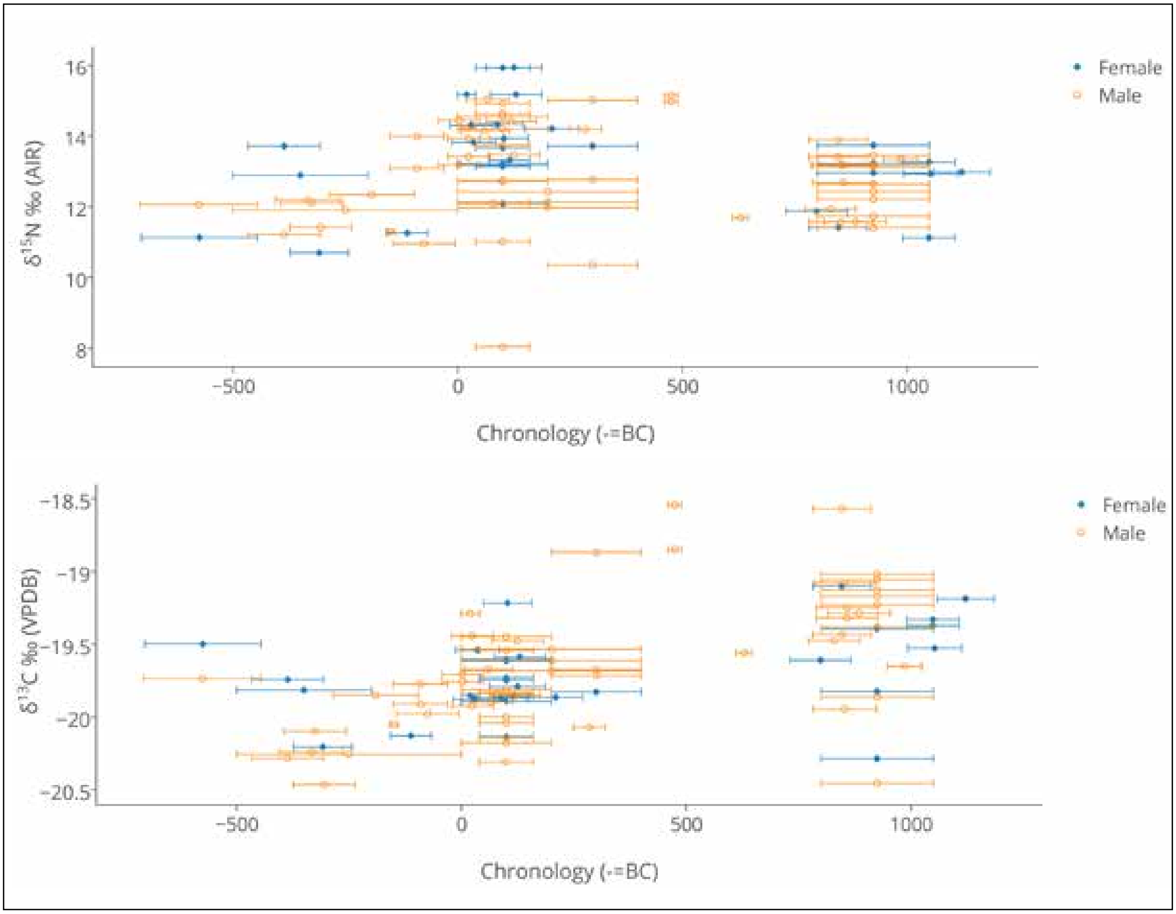
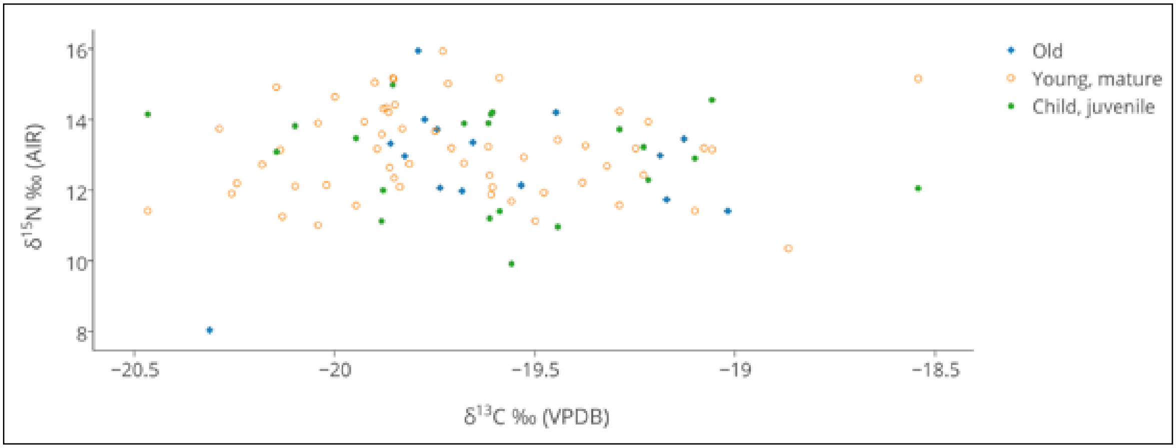


Fig. 21 (top). The distribution of δ^{13}C values and δ^{15}N values in males and females in the entire sample.

Fig. 22 (bottom). The variation in δ^{13}C and δ^{15}N (bone collagen) in males and females with respect to detailed chronology. The mean value of the date is marked as a square or circle and the whiskers indicate the standard deviation for ^{14}C dates and the range for relative chronology.



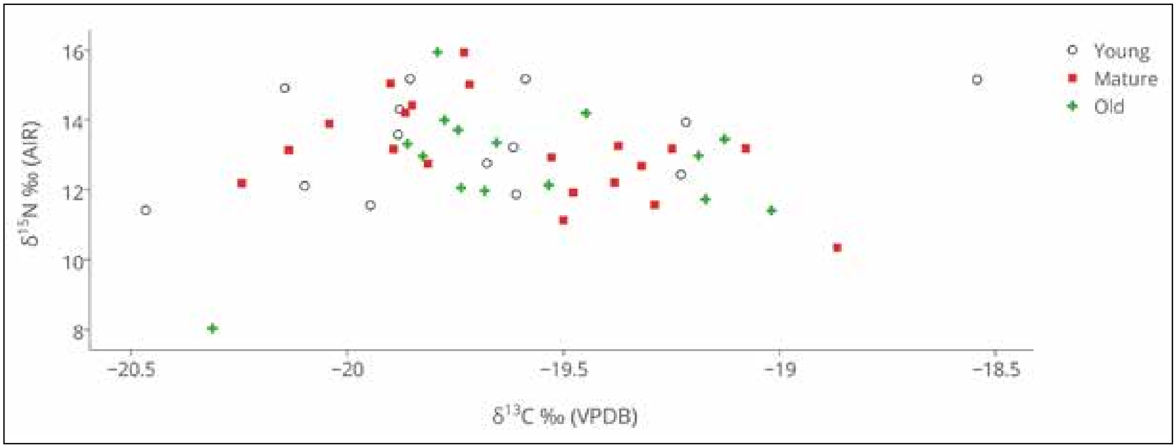


Fig. 23 (top): The δ^{13}C and δ^{15}N values are plotted against the age groups. The age groups are divided to compare mainly those youngest to those oldest and pooling the middle group of adults. These isotope values are reflecting diet during the last years (decades likely, see discussion 4.3.3) of these individuals' lives.

Fig. 24 (bottom): The δ^{13}C and δ^{15}N plotted only for the adults divided by more specific age groups. Young (20–35 years), mature (36–59 years) and old adult (60+ years).

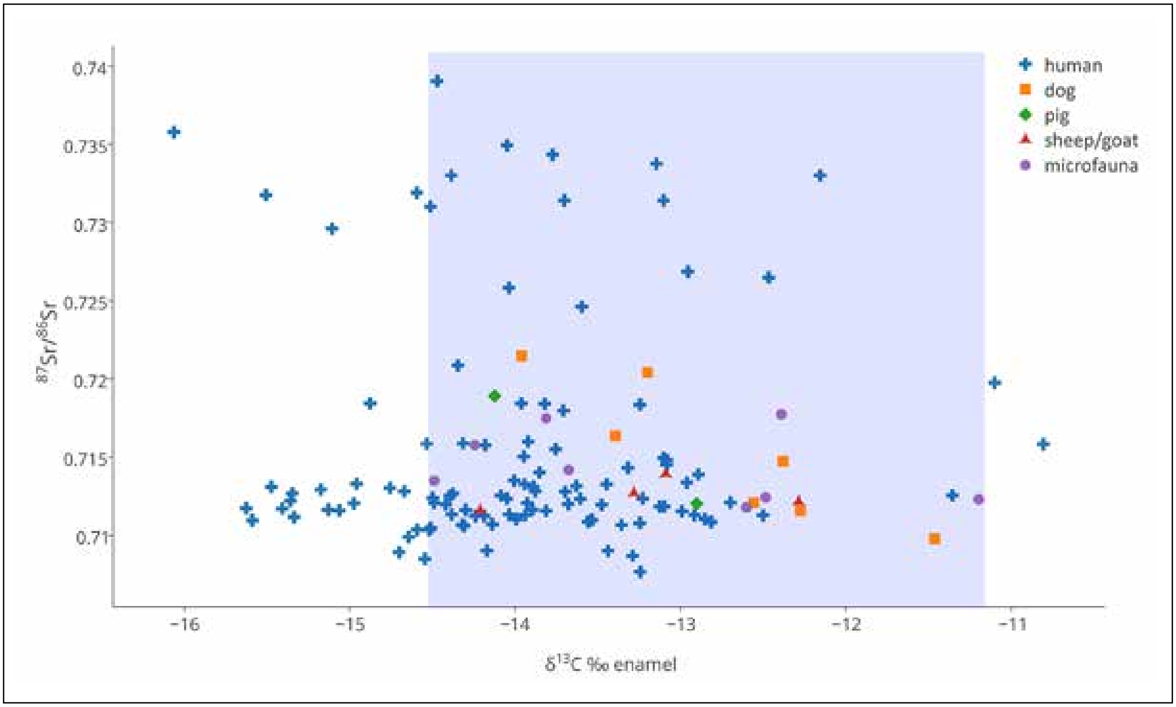
values only cover some aspects of diet, it is quite possible there were differences in male and female diet but that these remain invisible when using isotopes as the only dataset.

Age and diet

5.2.1.2

The diet does not appear directly connected to age of death judging from the division in the different age groups (Fig. 23) or between the groups with a more specific age span in the adults (Fig. 24). This could be explained in two ways: (i) that age was not a factor in diet in a way visible in isotope signals, or (ii) the difference in diet occurred in an age span partially transcending two age groups. As the diet and chronology seem closely linked (as argued in Paper III), there is another possibility as well: that if differences were present between the age groups, these are now obscured by the lack of more detailed chronology.

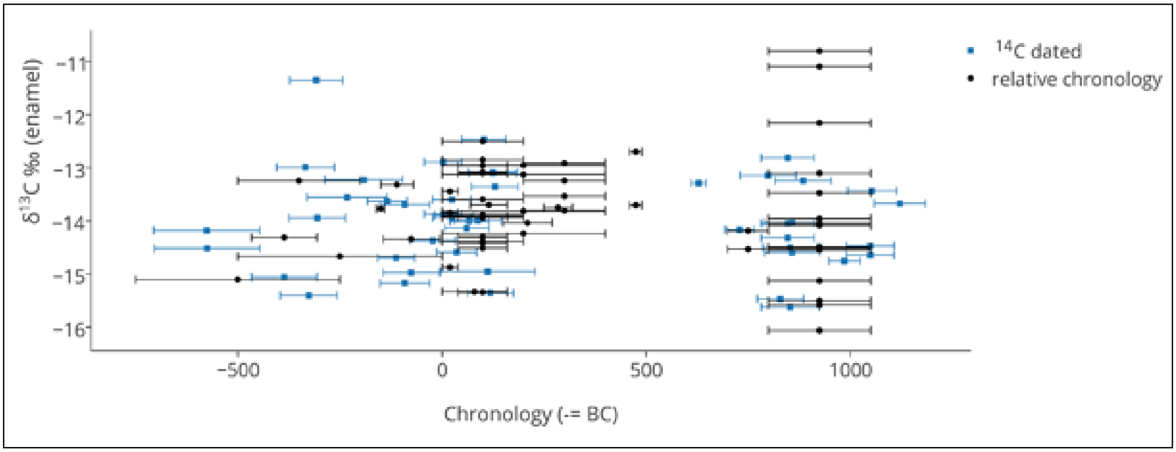
Fig. 25. The $\delta^{13}C$ values in enamel plotted against $^{87}Sr/^{86}Sr$. This allows to visualize the animal and human variation in $\delta^{13}C$ values. The variation in $\delta^{13}C$ values covered by the animals is indicated as a blue area. Note that a significant proportion of the humans have a greater variation than the animals.



5.2.2 Childhood diet: the isotope variation in δ^{13}C in enamel

The values from δ^{13}C in enamel are different from those in bone and they cannot be directly compared. In this case, the two types of tissues sampled additionally represent two different ages in life where the bone reflects diet approximately 10–20 years before death while enamel reflects only the childhood diet (approximately 5–9 years). Some animal samples of δ^{13}C in enamel are available for comparison with the human samples but since these were chosen primarily to be suitable proxies for the ^{87}Sr/^{86}Sr values they are not suitable to use in order to interpret the human values to a specific diet (Fig. 25). The animals cover the same range of δ^{13}C in enamel as the human samples. However, a proportion of the humans are more depleted in δ^{13}C, indicating a more terrestrial diet than any of the animals. For example, it should be noted that cattle, likely an important part of diet in the form of meat and/or milk products, are completely missing as a comparison for δ^{13}C. The childhood diet is therefore not discussed in the same way as the adult diet (measured in bone collagen), where more animal proxies were available. However, the chronology can also be compared to these human samples (Fig. 26). There is a wider range of δ^{13}C in enamel in the Late Iron Age, which, interestingly, is a trend also detectable in the δ^{13}C for bone collagen. In the Late Iron Age, both childhood and adult diets appear more individual than in the Early Iron Age on Öland.

Fig. 26. The δ^{13}C variation in enamel, childhood diet, in the humans compared to chronology. Note that there is a larger span in childhood diet (δ^{13}C values) from AD 800 onwards. The mean value of the date is marked as a square or circle and the whiskers indicate the standard deviation for ^{14}C dates and the range for relative chronology.



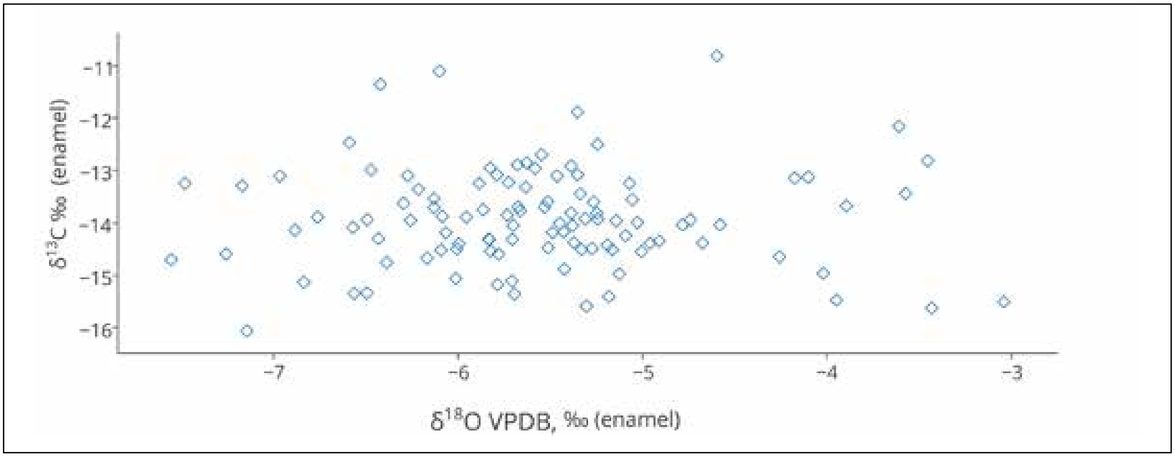


Fig. 27. The variation in $\delta^{13}C$ values compared to $\delta^{18}O$ for the population, n= 106 (three samples of the original 109 could not produce material sufficient for $\delta^{13}C$ and $\delta^{18}O$ analysis, only for $^{87}Sr/^{86}Sr$).

It should also be noted that $\delta^{13}C$ values can be less negative in warmer climates (see discussion in Bentley & Knipper, 2005:632f) which could be relevant as some individuals are clearly migrants. The $\delta^{18}O$ values that are less negative are those more likely to be found further to the south, thus reflecting a warmer climate (compare to the discussion of $\delta^{18}O$ values and geographical provenance in Paper IV). Those with the highest $\delta^{18}O$ values, over 4, however, do not have a particularly high $\delta^{13}C$ so this is probably a minor bias (Fig. 27).

5.2.2.1 Variation in $\delta^{13}C$ in enamel and bone: comparing adulthood and childhood

When comparing apatite $\delta^{13}C$ to collagen $\delta^{13}C$, these values do not translate directly, as mentioned earlier. The spacing (distance) of these values, if in the same bone (both sampling the apatite and collagen in the bone), can be compared to explore differences in protein access (e.g. Fernandes, 2015; Yoder et al., 2012). This could also be explored for bone collagen and tooth apatite (enamel) (e.g. Sjögren & Price, 2015) but with the caveat that these reflect diet at two different ages. The spacing will therefore not be used here to make inferences on dietary patterns and proportion of non-protein dietary input. However, they can be used as a phenomenon alone to compare childhood and adult $\delta^{13}C$ variation which will be explored below.

The collagen vs apatite variation (Fig. 28) and spacing give some interesting results. There is an overall trend in reduced spacing over time (Fig. 29). Moreover, there are

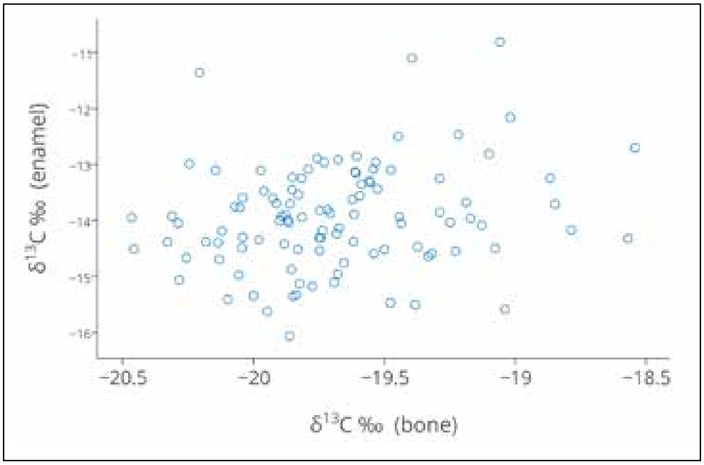
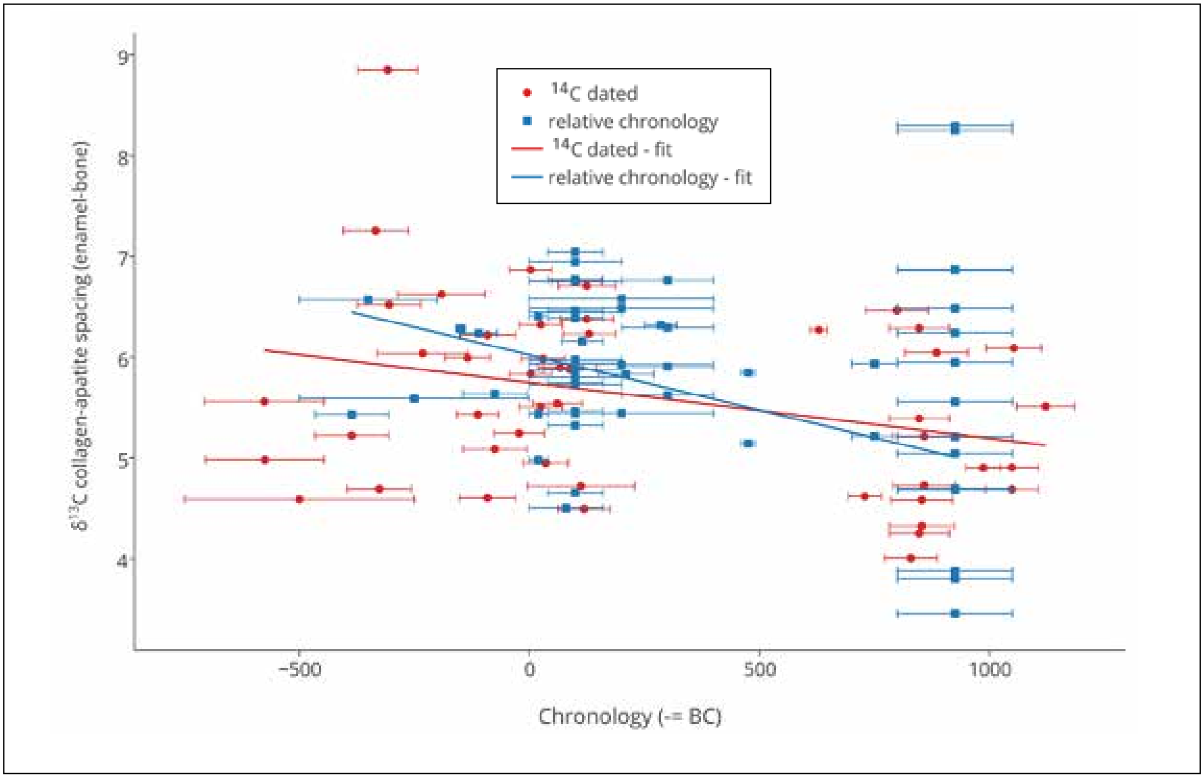


Fig. 28: A comparison of δ^{13}C variation in both bone (adult values) and enamel (childhood values). Note that these cannot be directly comparable as values, see discussion below, n=106.

some individuals who stand out as deviant in both periods (Fig. 30A). One group in the Viking Age form a cluster with spacing values of 4.3 or less (Fig. 29, Table 5). There are also three individuals with very large spacing. These three individuals are those with the lowest δ^{13}C values in the enamel in the entire sample and they had a comparably large marine component (or C4 plants) in their diets as children (ID 1016, ID 1046, ID 1052). These individuals probably changed diet during their life time, going from a more marine-/C4-based diet to a more terrestrial-based diet more "typical" of Öland. Interestingly, two of the individuals are local (ID 1046, ID 1052) and one is non-local. The locals are men of 19 and approximately 20 years of age. One interpretation could be that their strong offset reflects a more temporary dietary change (having a fast bone collagen turnover at a young age). However, their collagen values are within the norm for the periods; it is only the enamel δ^{13}C value that is deviant. The third individual is an old, non-local female (ID 1016, ^{87}Sr/^{86}Sr 0.7198). It is a possibility that all three individuals are migrants considering the deviant childhood diets in comparison with everyone else, even different from all but one of the ^{87}Sr/^{86}Sr and δ^{18}O non-local individuals. The ^{87}Sr/^{86}Sr for the two young men corresponds to Öland but could also correspond to other areas around the Baltic Sea. Considering their marine-based (or possibly C4 plant-based) childhood diet, a coastal origin would be likely.

The group with smaller spacing values, those of 4.3 and lower (Table 5), have two things in common: they are all Viking Age and all non-locals. It is unlikely they are from


9
8
7
6
5
4
δ13C collagen-apatite spacing (enamel-bone)
-500
0
500
1000
Chronology (-= BC)
14C dated
relative chronology
14C dated - fit
relative chronology - fit

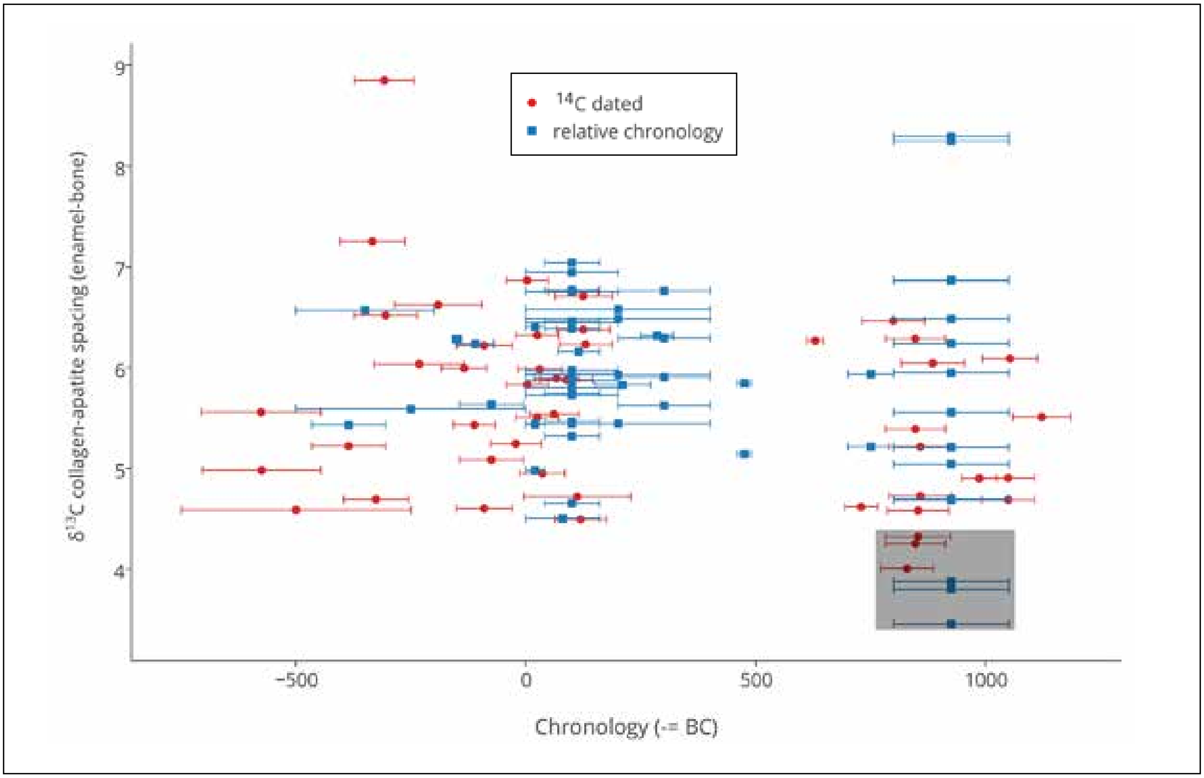
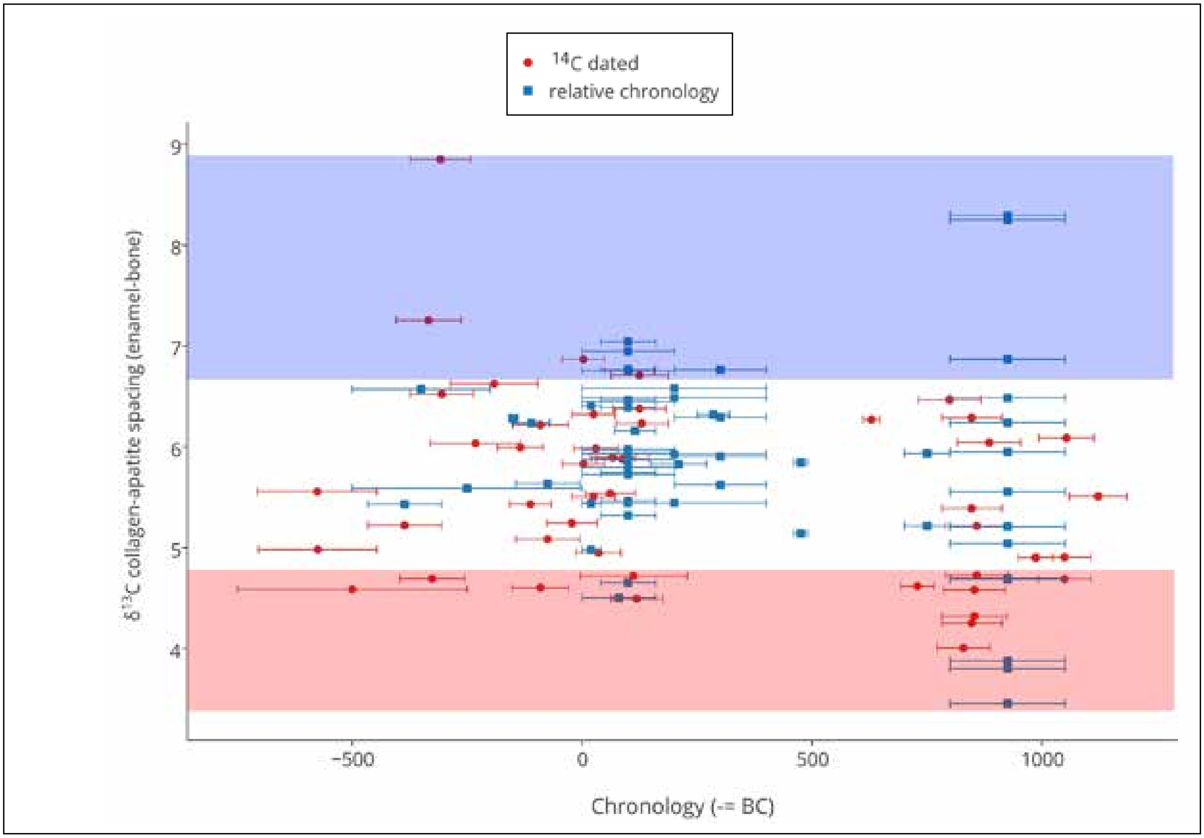

9
8
7
6
5
4
δ13C collagen-apatite spacing (enamel-bone)
-500
0
500
1000
Chronology (-= BC)
14C dated
relative chronology

Fig. 29 (pevious page). The δ^{13}C spacing values (bone enamel value subtracted from the bone collagen value) and chronology. The individuals with a ^{14}C are shown separately to those with a typological date. A linear fit within each group still shows a similar temporal trend-decreasing spacing. The decrease in spacing is difficult to interpret but could mean the change in diet from childhood to adulthood was a smaller change in the Later Iron Age than it was earlier. The mean value of the date is marked as a square or circle and the whiskers indicate the standard deviation for ^{14}C dates and the range for relative chronology.

Fig. 30 (below). The same chart as in Fig. 29 appears in both (A) and (B). (A) Here, the statistically defined interesting values are indicated, and all deviant individuals (i.e. those outside of the mean and two standard deviations) are shaded (light blue and red areas in the graph). Note the number of deviants is somewhat larger in the Late Iron Age. (B) shows the outlier group discussed indicated by a grey shaded area (details in Table 4).

Table 5: The group with smallest enamel-bone collagen spacing in δ^{13}C. Note: all individuals here are defined as non-locals in Paper IV.

ID	**δ^{13}C enamel, ‰**	**δ^{13}C bone collagen, ‰**	**Spacing, ‰**	**^{87}Sr/^{86}Sr**	**δ^{18} O VPDB, ‰**	**Age groups**	**Sex**
1045	-16.0	-19.0	3.5	0.710953	-3.6	Old	male
1038	-16.1	-19.9	3.8	0.735774	-5.3	Mature	female
1012	-15.5	-19.4	3.9	0.731773	-7.1	Young/ mature	male
1008	-15.5	-19.5	4.0	0.713082	-3.5	Young/ mature	female
1060	-14.3	-18.6	4.3	0.71068	-7.0	Child (11-12y)	Undeter-mined
1004	-15.6	-20.0	4.3	0.711715	-4.0	Juvenile/ Young	Undeter-mined



the same region as they have varying $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values. Instead they are likely to be from various different areas. These individuals span from 11 to over 60 years old and include both males and females. These individuals share a childhood diet which was the least reliant upon marine-based/C4-based resources across the entire sample, but contrarily, their bone collagen $\delta^{13}C$ is not as different from the other values. The only exception was found in one individual, the 11–12-year-old (ID 1060), whose diet was significantly reliant upon marine resources in evidence from bone collagen but on non-marine-based resources judging from the $\delta^{13}C$ in enamel. The shift in diet is most likely related to the migration (ending in Öland) rather than to age, although it is, admittedly, unusually marine-reliant for Öland.

Interpreting adult diet 5.2.3

Animal samples 5.2.3.1

Animal isotope values are vital as a tool of comparison to the human samples when interpreting diet. In today's standards, the animal values should be contemporary, local (c.f. discussion in Makarewicz & Sealy, 2015) and relevant, taking into consideration the previous knowledge of diet and animal use from zooarchaeological assemblages, as just one example. This approach facilitates the discussion of diet on a regional scale while taking into consideration temporal changes in ecology and animal subsistence practices. The available animal samples from earlier studies in Öland failed to meet all these criteria which is why new samples had to be selected for this study. In comparison to other previous studies (details in Paper III), it was clear that the Iron Age animals from Öland were, in fact, slightly different from other contemporary samples of the same species. This was particularly apparent with regards to the major domesticates, most likely reflecting differences in ecology and animal husbandry between the regions. However, it is the difference in values for the very same species in Öland dated to the Iron Age (this study) in comparison with the earlier samples (Neolithic or Bronze Age, published in Eriksson et al.,

2008) that is most interesting. In Paper III it was concluded that these differences in the animal values probably reflect:

(i) a more specialized animal husbandry in the Iron Age than earlier, with clear differences between species of grazers like sheep/goat and cattle;

(ii) a more intense use of land for grazing in the Iron Age which resulted in higher δ^{15}N-values for the animals. This could be from manuring or the more systematic use of kelp as fodder, for example.

The animals sampled from the Iron Age form a food web, including top predators as well as animals further down the food chain (Table 6), and the values make sense as a food chain also when including the human values. The number of animal samples from this study is today relatively small, but is still larger than many earlier Swedish studies (as detailed in Paper III). More animals and a greater chronological span would no doubt add value to the interpretation of the human diet. For example, chickens showed great variety and, according to archaeozoological assemblages (Vretemark & Sten 2008), could be a highly-underestimated source of food considering both meat and eggs could be harvested and the animal is relatively simple to care for. Chickens were not considered in the Eriksson et al. (2008) study of Öland, and could, in comparison to their human values, be a most relevant resource.

5.2.4 Chronology and dietary development

The variation in isotope values is indicative of two dietary shifts on Öland during the span of the Iron Age.

The first shift was established sometime in the last two centuries BC according to ^{14}C and the more detailed typology. This new diet included sources with higher δ^{15}N in the protein component and more negative δ^{13}C. I interpret this in Paper III as reflecting the introduction of a more intense and organized animal husbandry probably corresponding to the introduction of the field partitioning system which is a characteristic feature of the Öland landscape. This was a protein-rich diet.

The second shift cannot be chronologically pinpointed due to lack of data (cremation burials instead of inhuma-

TABLE 6: The animal samples from bone collagen from this study, for details see Paper III and Appendix.

ID	SPECIES	SITE (SHM)	SUBPERIOD	δ^{13}C VPDB, ‰	δ^{15}N AIR, ‰
1223	Cattle	27362	Early Iron Age	-22.0	6.7
1225	Cattle	28361	Roman Iron Age-Vendel period	-21.7	6.2
1246	Cattle	Sandby borg	Migration period	-21.6	6.1
1244	Sheep/goat	23280	Late Roman period	-21.5	8.6
1235	Sheep/goat	27702	Early Roman period	-21.4	8.0
1230	Cattle	27362	Early Iron Age	-21.3	5.4
1204	Cattle	27702	Early Roman period	-21.3	5.6
1245	Pig	27362	Early Iron Age	-21.0	9.4
1241	Chicken	23280	Late Roman period	-20.9	11.2
1216	Sheep/goat	27362	Early Iron Age	-20.9	8.2
1224	Sheep/goat	27362	Early Iron Age	-20.5	8.9
1238	Sheep/goat	10302	Iron Age	-20.3	7.1
1214	Pig	31597	Iron Age	-19.7	9.7
1242	Pig	10302	Iron Age	-19.5	8.0
1205	Chicken	25570	Iron Age	-16.0	11.3
1213	Flounder	31597	Iron Age	-13.3	8.3
1211	Pike	27362	Early Iron Age	-11.8	10.8
1231	Cat	31597	Iron Age	-17.8	11.9
1201	Dog	12142	Early Roman, per IV	-18.1	12.3
1202	Dog	22231	Vendel period	-19.8	12.1
1237	Dog	27702	Early Roman IA	-20.0	11.3
1239	Dog	10302	Iron Age	-15.9	12.5
1247	Dog	Sandby borg	Migration period	-17.6	12.6
1222	Horse	28549	Viking Age	-21.6	7.1
1217	Seal	27362	Early-middle Iron Age	-15.7	14.0

tions) but it occurs sometime in the middle Iron Age (AD 200–700). It is possible this shift occurs during the ecological collapse of the Alvar lime barren sometime in the Roman Iron Age (AD 0–400) as suggested by Enckell et al. (1979). They interpret the archaeological and archaeobotanical evidence in the Alvar as indicating that even more marginal lands were taken for grazing during this period. This would fit well with the interpretation from the isotopes of a highly animal-based diet. After the middle Iron Age, from approximately AD 400, the carbon values reflect an overall greater variation in individual diets. A generally lower δ^{15}N indicates less protein in the diet than before. The collapse of the Alvar, and perhaps other lands as well, could have forced the people living on Öland to decrease their reliance on high δ^{15}N protein sources. Adopting to a more diverse, and possibly a less vulnerable, subsistence would make sense in the face of ecological change and/or climate change. This could potentially coincide not only with the Alvar collapse but also with the so-called climatic event called the Fimbul Winter in Scandinavia (Gräslund, 2008; Gräslund & Price, 2012; Löwenborg, 2012; Tvauri, 2014), which has been suggested to be a temporary, but very abrupt, drop in temperature. This is argued to have started in AD 536 and taking great effect in central Sweden (Löwenborg, 2012) and the eastern Baltic areas (Tvauri, 2014). The effects of the Fimbul Winter event upon Öland specifically are, so far, not investigated in detail but it is possible that this was a major event experienced there too. As the timing of the change in diet found in this study cannot be pinpointed to anything more specific than AD 200–800, this cannot answer whether the Fimbul Winter was the cause of the change in diet, but it is an interesting hypothesis. In the wake of a climate crisis, a change from a highly-specialized diet to a more diverse one makes sense. A further possibility to explain the more individually diverse diet is that the society in the Later Iron Age was more diverse in subsistence resulting from a large immigration (c.f. 5.3.2.1). It could also potentially indicate a repopulation of the island following such a crisis, which is also a hypothesis this study will have to leave uninvestigated.

The dietary development, as traced in isotope variation on Öland, revealed what appear to be three different diets.

The interpretation of the specific diet from the isotope values is heavily influenced by the choice of the factor of δ^{15}N TLE (Trophic Level Effect), i.e. how big the offset is expected to be between human bone and animal bone isotope values. This is a choice with quite some leverage, and could lead to virtually opposing interpretations of diet. In Paper III, I chose to compare two commonly used TLE values, 3‰ and 5‰, to see which made more sense in relation to the other archaeological evidence regarding human diet. The higher (5‰) level was concluded to be most relevant and likely to explain the diet and the changes occurring in the human values throughout the Iron Age. This, along with the new animal samples, resulted in a very different interpretation of Iron Age diet than in the two earlier studies from Öland (Eriksson et al., 2008; Howcroft et al., 2012), despite having very similar human isotope values.

In the Pre Roman Iron Age, at least leading up to the final centuries BC, the diet is interpreted as based on domesticates with a potentially greater consumption of cattle than sheep or pigs implied by the lower δ^{15}N levels. Then, there is a shift to a diet with higher δ^{15}N levels which I argue could be explained by an increase in sheep husbandry and an overall intensification of land use for domesticates. The introduction of the partitioning system, indicating an intense use of the landscape, could correspond to a diet with higher δ^{15}N and more meat/milk. Another possibility could be that this increase in general δ^{15}N corresponds to the introduction of chickens. The great variation in chicken isotope values, as well as the limited availability of samples, makes it difficult to prove this hypothesis, however. The animal bone assemblages are somewhat ambiguous as the chicken bones are likely to be underrepresented being more fragile than large mammal bones. The bone assemblages do support the use of chickens in Öland during the Early and middle Iron Age, but the scale is unclear. It is interesting, though, that the increase in δ^{15}N occurs at a time when chickens are believed to have been first introduced in South Scandinavia, in the Pre Roman period (Johansson, 2004; Berggren & Celin, 2004:180ff), while from the middle Iron Age, geese and, later, ducks also appear (Boessneck & von Den Driesch, 1979; Ericson & Tyrberg, 2004:43f). It is not just chickens that were introduced; many other changes in subsistence practice appear to take place in Scandinavia at this time, including new crop technology (manuring, new crops), as well as the introduction of new domesticates (Welinder, Pedersen & Widgren, 2004).

This second shift in diet resulted in generally lower $\delta^{15}N$ values and more diverse $\delta^{13}C$ values. I have interpreted this as reflective of a more diverse diet where people were not relying so heavily on one type of subsistence as they had done earlier, and were less reliant on animal protein. Their diet includes lower $\delta^{15}N$ resources than found in earlier diets. This could mean cattle (with considerably lower $\delta^{15}N$) grew in importance compared to the other domesticates. The diversity in $\delta^{13}C$, however, suggests that animal protein came from more diverse sources, probably from more marine-sourced fish. In addition, a decrease in the proportion of protein generally, suggested by lower $\delta^{15}N$ values and due to more cultivation and less pastures than before, could help explain the distinct variations in diet.

The Öland values from this study and a few of the earlier studies (Erickson et al., 2008; Howcroft et al., 2012; see Paper III for details) with more detailed chronologies are not very different from values from earlier contemporary studies in Scandinavia (Fig. 31A-D). Smörkullen and eastern Denmark include samples from the Early Iron Age, primarily the Roman Iron Age but also possibly Pre Roman Iron Age in Smörkullen. They correspond best to the Pre Roman Iron Age samples from Öland but are still significantly lower in both $\delta^{13}C$ and $\delta^{15}N$ (Fig. 31A). The datasets from Birka and Haithabu, both Late Iron Age trading centres and Baltic harbors, are most similar to those of Öland, and the great diversity in Birka in $\delta^{13}C$ corresponds especially well to Late Iron Age Öland (Fig. 31C). The proportion of reliance on animal husbandry compared to crops probably varied across the different environments, and the comparison to eastern Denmark and Smörkullen with Roman Iron Age Öland appears to have a generally higher $\delta^{15}N$ level, which I would interpret as indicative of a higher reliance on animals than cereals in Öland. However, the values in Roman Iron Age Öland fit very well to Birka in particular, despite the large time difference of around 500 years (Fig. 31D). The samples from Birka are mainly from individuals of a probable high status, living in a pre-urban environment

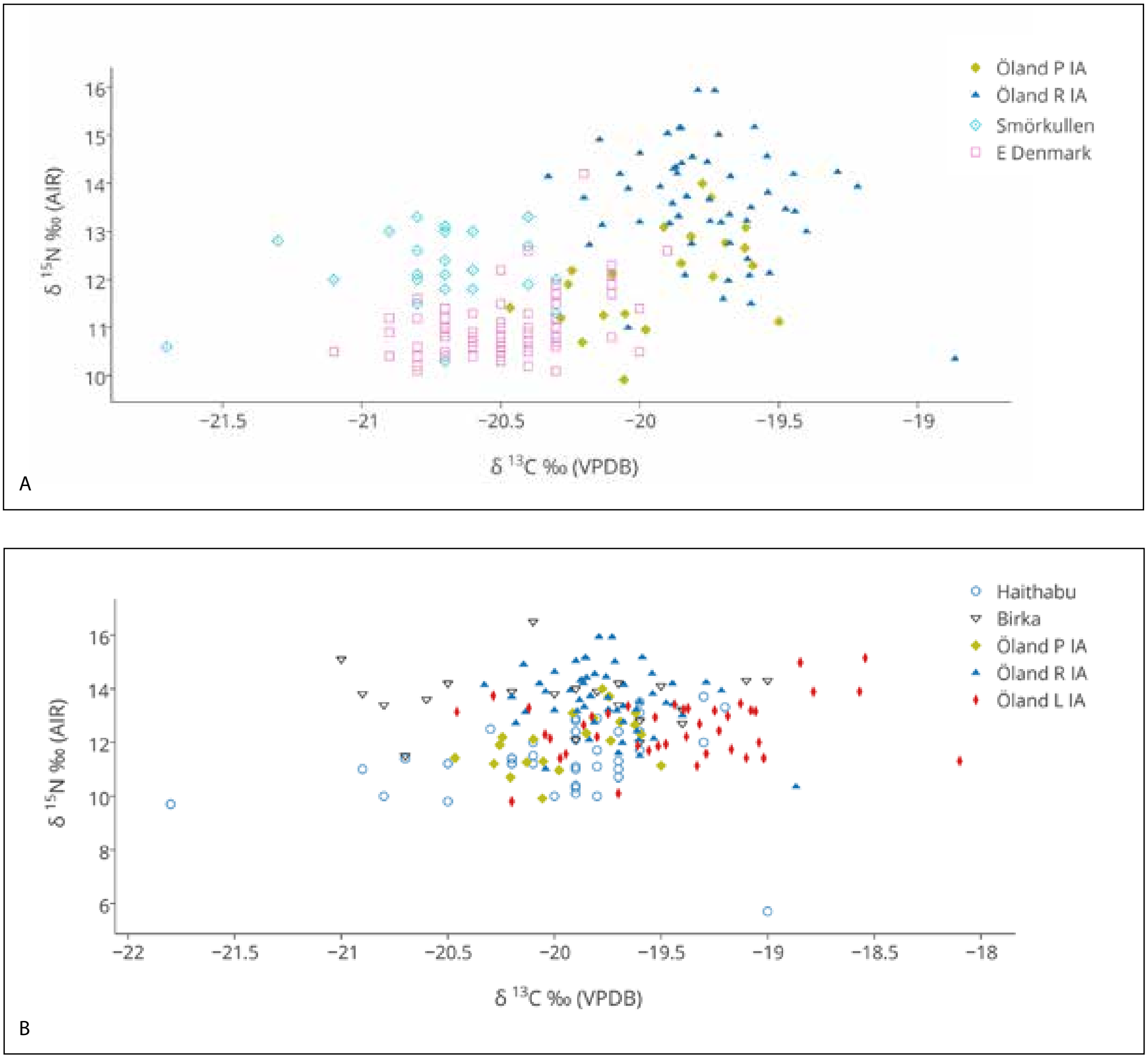
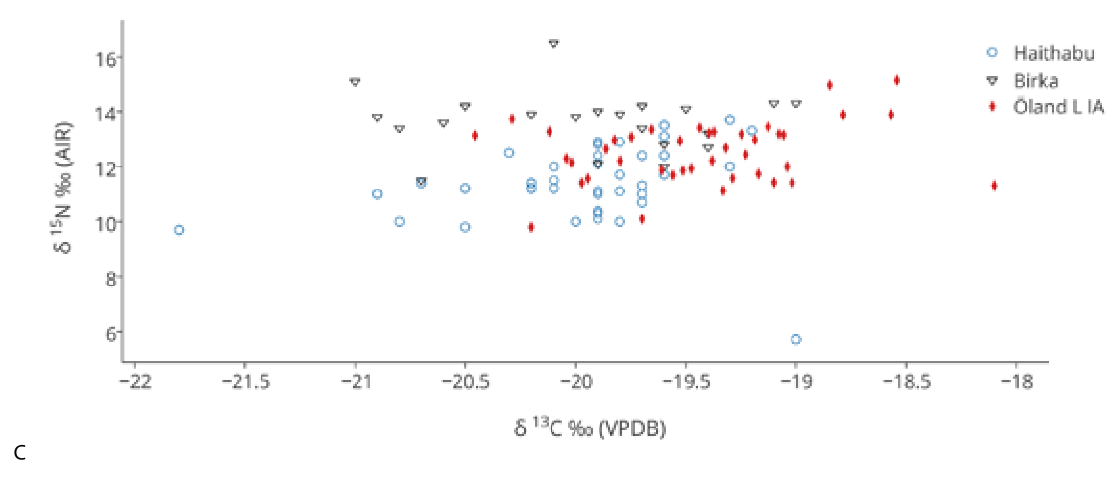
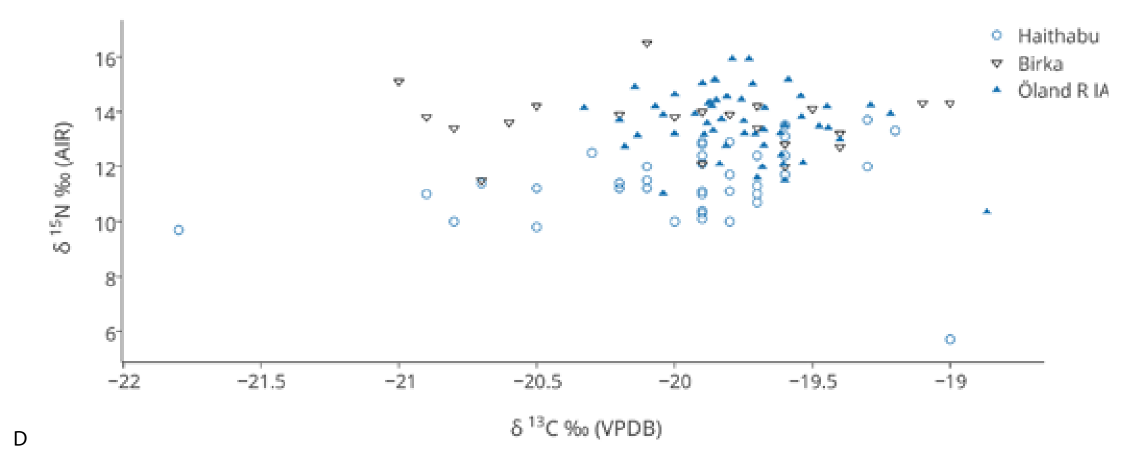


Fig. 31A-D. A shows the δ^{13}C and δ^{15}N distribution in the bone collagen samples from this study (n=107) compared to samples from A: Smörkullen and eastern Denmark (both Early Iron Age) and B, C, D: Birka and Haithabu (both Late Iron Age, mainly Viking Age). Data from Birka from Linderholm et al. 2008 (n= 22) Late Iron Age/Viking Age; Haithabu from Becker and Grupe 2012 (n=40) Late Iron Age/Viking Age; Smörkullen from Lindberg, 2009 (n= 25) Early Iron Age; Jørkov, 2007 (n=76), Roman Iron Age. To the Öland data set the few securely dated samples (see discussion in Paper III) are added from Eriksson et al. (2008; n=7) and Howcroft et al. (2012; n=3). The selected samples from the other studies are not including children under seven years of age and only bone samples (not dentine). P IA (Pre Roman Iron Age), R IA (Roman Iron Age), L IA (Late Iron Age).



δ ¹⁵N ‰ (AIR)
16
14
12
10
8
6
−22
−21.5
−21
−20.5
−20
−19.5
−19
−18.5
−18
δ ¹³C ‰ (VPDB)
Haithabu
Birka
Öland L IA
C



δ ¹⁵N ‰ (AIR)
16
14
12
10
8
6
−22
−21.5
−21
−20.5
−20
−19.5
−19
δ ¹³C ‰ (VPDB)
Haithabu
Birka
Öland R IA
D

(Linderholm et al., 2008). It is likely such people had access to much animal protein. However, in my opinion, it is very risky to compare the human values from the different contemporary sites like I have just done, even though this is something seen very often in isotope studies. To do this could be very misleading as the animals making up a significant part of the human diet across the different sites in fact have different isotope values (c.f. discussion in Paper III), probably reflective of different practices of animal husbandry or local ecology at each site. In other words, if a human was to eat, say, a sheep, theoretically this would result in a different isotopic signal in the human if the sheep came from Öland than if it came from Haithabu or Birka. Thus, the differences and similarities between the contemporary, or less contemporary sites and Öland (see Figs. 31A-D) need not necessarily reflect very big differences, or similarities, in diet. The differences could result from different local ecology and subsistence practice *and a different diet* but they might only reflect local ecology or animal husbandry giving different isotope values to the same animals eaten. This puts focus on the vital interpretational aspect of dietary isotopes that is the factor of understanding local, contemporary animal isotope variation. Hopefully, more detailed future studies of animal isotope variation will aid in showing just how significant a factor this can be. It is clear that this complexity needs to be taken into account in the isotope interpretations of human diets. I have highlighted the importance of this factor in Paper III. Larger studies of animals are desirable, for Öland and in general.

5.3 Migration

The isotope results for $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ showed a great variation in the human values (Fig. 32). In order to interpret these values as representative of Öland (locals) or not (non-locals), different strategies were used in papers II and IV (discussed below). Both interpretations are based on the same basic data, however: as either single or bi-isotopic approaches.

5.3.1 Interpreting isotope baselines

5.3.1.1 $^{87}Sr/^{86}Sr$

Usually, it is the geology that is assumed to be most significant for variations in bioavailable $^{87}Sr/^{86}Sr$ which is why the variation in age (and $^{87}Sr/^{86}Sr$ proportions) of bedrock is investigated. The soil distribution, especially complex soils potentially including bedrock of different ages, could also be significant. For Öland there is remarkably little variation in bedrock but quite significant variation in soil types over the island (Fig. 33).

The distribution of the animal samples in this study and an earlier study of Öland (Fornander et al., 2011) showed no clear spatial variation that could be related to geology, as is often suggested (Fig. 34). Instead, I suggest the variation could be more relevant in relation to soil types. With the exception of the eroded coastlines, the land is more or less covered by till deposited during the last glacial event. This is a mixed soil type composed of geological material of varied ages (and therefore probably great $^{87}Sr/^{86}Sr$ variation) which could potentially account for the wide variation in animal isotope values in this, and the earlier, study. It is an interesting possibility that soil composition might have a more pronounced effect on faunal $^{87}Sr/^{86}Sr$ variation than the bedrock, routinely accounted for in isotope studies (e.g. Price et al., 2012a; Frei & Frei, 2011). It should be noted that dogs in particular had a different variation in $^{87}Sr/^{86}Sr$ compared to other species; dogs were similar to humans in this

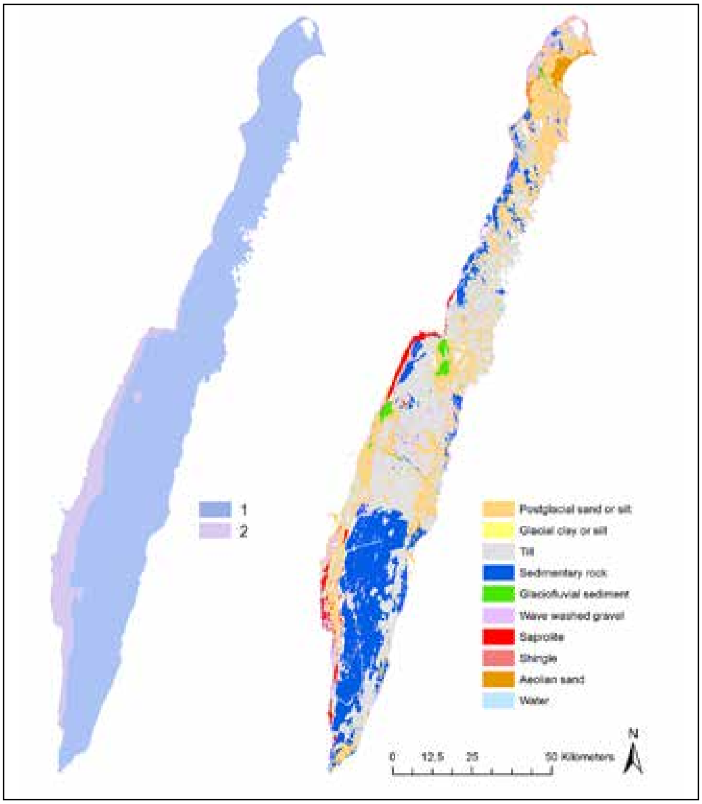
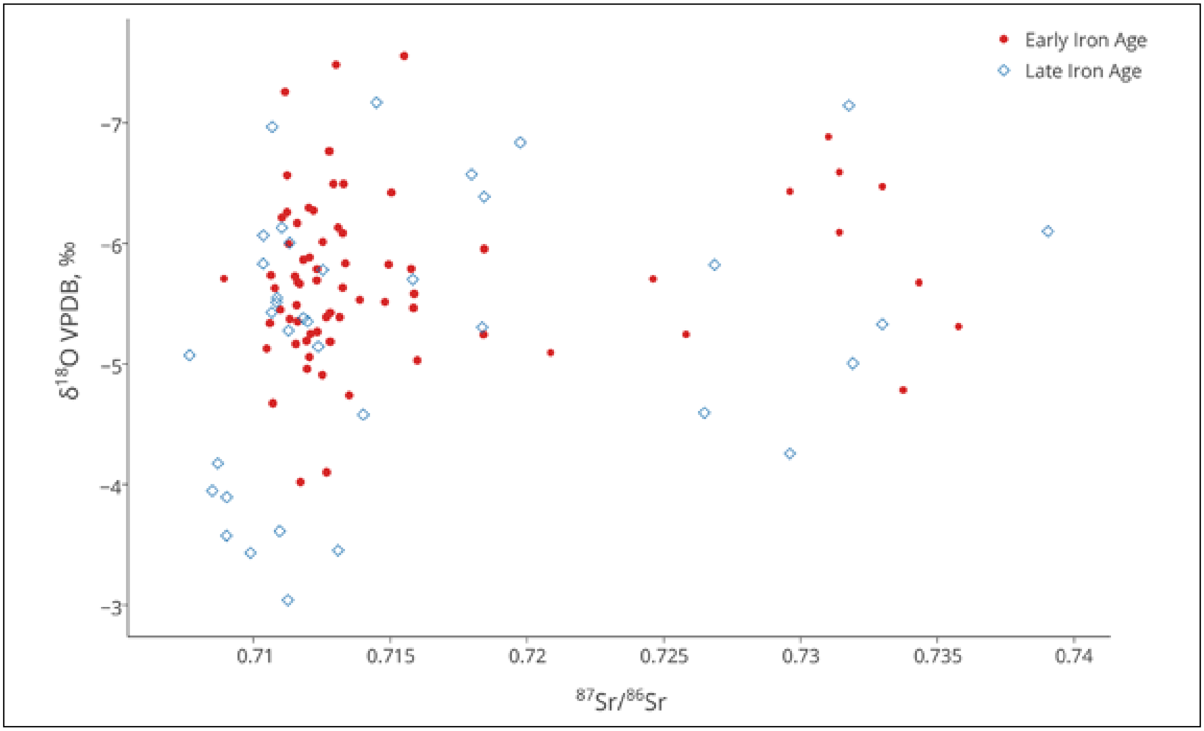


Fig. 33 (left). The variation in geology (left) and soil (right) in Öland. Legend: 1, Carbonate-rich sedimentary rock (limestone, dolomite, marble, etc.). 2, Mica-rich sedimentary rock (shale, siltstone etc.). Mainly bedded rocks in the youngest bedrock unit, age 850–34 million years. Data ©SGU. Basemap: Esri, HERE, DeKorme, MapmyIndia,© OpenStreetMap contributors and the GIS user community.

Fig. 32 (below). The variation in the human samples of $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ VPDB divided by Early Iron Age (500 BC–AD 400) and Late Iron Age (AD 400–1050).



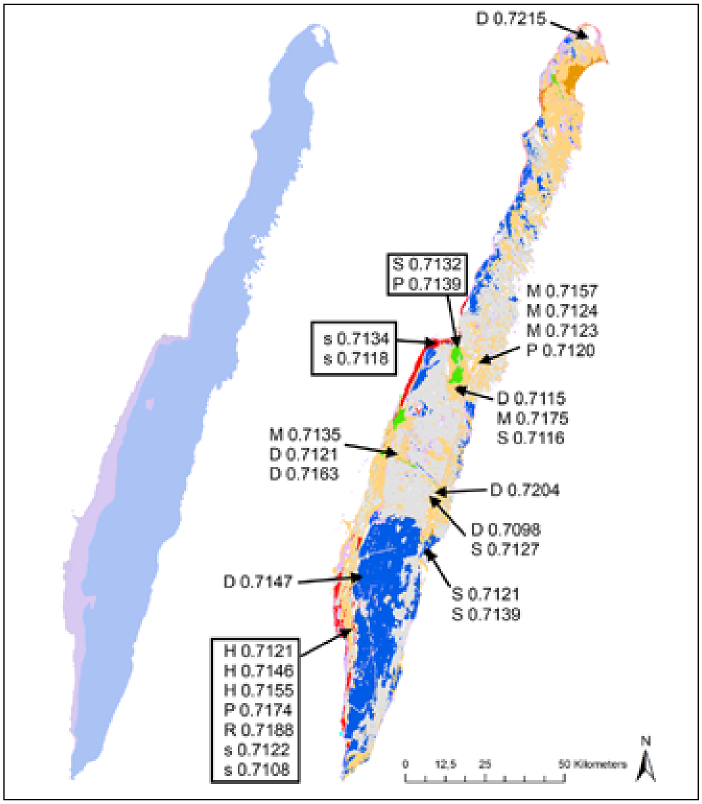


Fig. 34. The variation in animal samples $^{87}Sr/^{86}Sr$ values over the island and over different soil types and geology. For soil and bedrock legend see Fig. 33. D= dogs, S = sheep/goats, P =pigs, M = microfauna, H = hares, R = roe deer, s = modern snail. Data from Fornander et al., 2011 and this study.

respect. In my opinion, this is suggestive of the dogs migrating to a similarly high extent. I would therefore advise against using dogs in devising $^{87}Sr/^{86}Sr$ baselines, at least in the Iron Age, based on these results.

In papers II and IV, two different definitions of baselines for $^{87}Sr/^{86}Sr$ were used but still the material was exactly the same (Table 7). The reason for the different approaches was because the research questions in the two papers were different. Paper II was testing the gravity model and thus only operated with definitions of baseline on a population level, whilst Paper IV operated with definitions of baseline on an individual level, determining locals and non-locals. In my opinion, in terms of the individual level definition, allowing the fourth decimal to decide whether an individual was local or not seemed too arbitrary to be relevant. Moreover, it indicated a precision not supported in the $^{87}Sr/^{86}Sr$ data at large, where variation was found even in the third decimal place. The overall width of the baseline (even the more conservative one used in Paper IV was 0.0053) is a huge span in comparison to that of many other regions (see Paper

	Baseline	Range local $^{87}Sr/^{86}Sr$	Non- local $^{87}Sr/^{86}Sr$	Gray $^{87}Sr/^{86}Sr$, undetermined
Paper II	Locals or non-locals	0.7116-0.7164 (defining mean and 2 std as the local range, 0.7140+-0.0024)	<0.7116 or >0.7164	-
Paper IV	Locals, non-locals, undetermined	0.7109-0.7164	<0.7098 or >0.7189	0.7098-0.7109 and 0.7164-0.7189
Fornander et al. 2011, 2015	Locals or non-locals	0.7102-0.7158	<0.7102 or >0.7158	-

Table 7. The $^{87}Sr/^{86}Sr$ baselines used in the two papers compared to that devised by Fornander et al. (2011, 2015). For details regarding definitions, see the individual papers. The lower $^{87}Sr/^{86}Sr$ range for locals in Paper IV is an effect of the inclusion of the full faunal range, not just the bulk of the values (mean and two standard deviations), although still not taking the dog outliers into account.

II, Table 3 and references therein). Fornander et al. (2011) have given an estimate of the baseline for Öland as 0.7102–0.7158 based on snail shells and terrestrial mammals, and published the same baseline again in 2015. I have used the values published from the 2011 paper which are identical to those in the 2015 paper (which came out after Paper II was finished), with the exception of sheep/goats of $^{87}Sr/^{86}Sr$ 0.7188 which they curiously did not report in the 2015 paper. This is very similar to the baseline range used in Paper IV (0.7109–0.7164) for the local $^{87}Sr/^{86}Sr$ definition where these samples were also included. The Fornander et al. studies had access to a more limited dataset in terms of faunal samples (n=9 used for their baseline) and types (enamel, bone, snail shell), but these correspond very well to my faunal samples (see Paper II, Table 2) which indicates that the baseline used in Paper IV, however wide, is probably accurate.

5.3.1.2 $\delta^{18}O$ and combined baselines

Devising a baseline for $\delta^{18}O$ samples to be used in tandem with the $^{87}Sr/^{86}Sr$ results for the same samples is complicated. Faunal values cannot be used to create a baseline for $\delta^{18}O$ similar to $^{87}Sr/^{86}Sr$ and are not available. Plotting the $\delta^{18}O_{VPDB}$ values in the Early versus Late Iron Age shows differences in the distribution (Fig. 35), primarily an inclination towards less negative values in the Late Iron Age and a larger variation overall, despite the smaller sample size. This could indicate a change in the $\delta^{18}O$ profile in the Late Iron Age. It could also indicate that a larger proportion of non-local individuals is present in this period. Since the $^{87}Sr/^{86}Sr$ (c.f. Fig. 36) results have revealed that there is a great increase in non-locals in the Late Iron Age, this seems a plausible explanation for the greater variation in $\delta^{18}O$ in this period.

Setting a δ18O baseline based on the mean and two standard deviations of all values, as is common for an $^{87}Sr/^{86}Sr$ baseline, is less appropriate for these samples primarily because they are human samples. When this approach is used, it is based on the assumption that samples are from locals (only animals). Furthermore, it is already established from the corresponding $^{87}Sr/^{86}Sr$ values that the $\delta^{18}O$ samples do include a significant proportion of migrants. Moreover, this proportion is very different in the two periods and therefore it is possible, even likely, that the $\delta^{18}O$ values would also differ for the two periods. The Early Iron Age has a slightly higher mean value (-5.3‰ $\delta^{18}O$) than

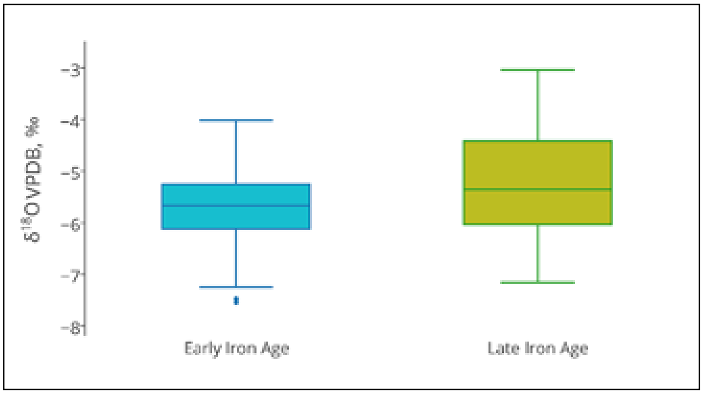
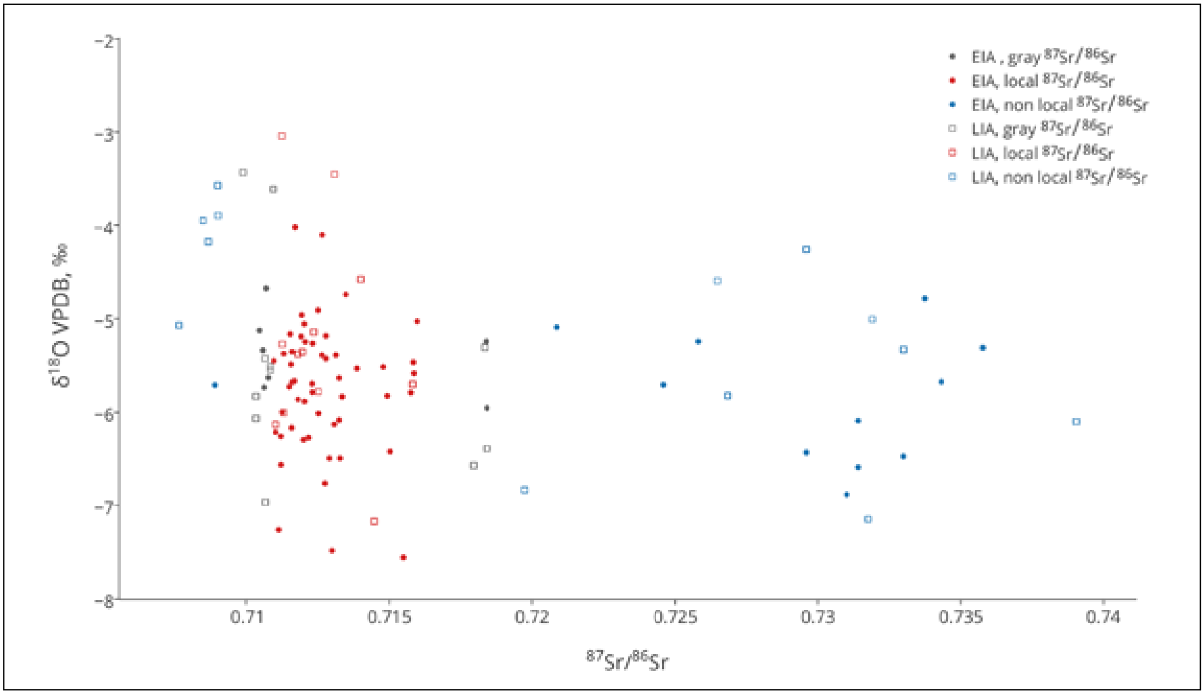


Fig. 35. The variation in $\delta^{18}O$ VPDB is compared in boxplots for the Early and Late Iron Age. The box indicates the range of 50% of the values, the horizontal line inside the box is the median and the whiskers indicate the upper (Q1) and lower quartiles (Q3) respectively. The dots are statistical outliers (i.e., values of 3 × IQR above Q3 or below Q1). Early Iron Age, n=70. Late Iron Age n=36.

Fig. 36. The variation in $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values in the Early (E IA) divided by the Late Iron Age (L IA) and with the definition of local, non-local or gray Sr-values as in Paper IV (see also Table 6).



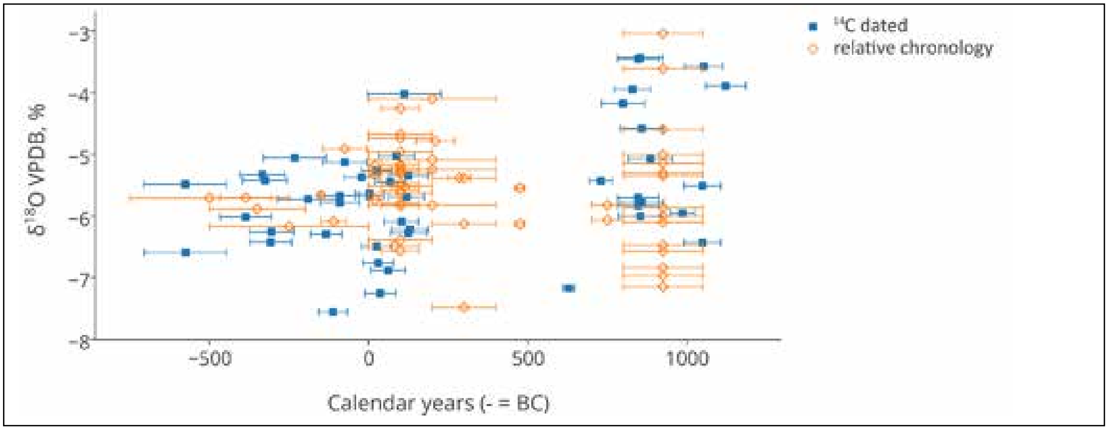
the Late Iron Age (-5.7‰ δ^{18}O). The larger standard deviation in the Early Iron Age samples, however, could seem to contradict the interpretation of a larger immigration in the Late Iron Age (±1.1‰ vs. ± 0.7‰) but this is an effect of the overall larger variation in the bulk of the δ^{18}O values in the Late Iron Age (c.f. the boxes in Fig. 35). Another, but in my opinion, less likely explanation for these differences could be that changes in the baseline of δ^{18}O between the Early and Late periods relate to climate changes. This does not explain the larger variation in values in the Late Iron Age, unless there were significant changes in climate within the period. However, the more detailed chronology detects no such trend in the Late Iron Age samples (Figs. 37 and 38).

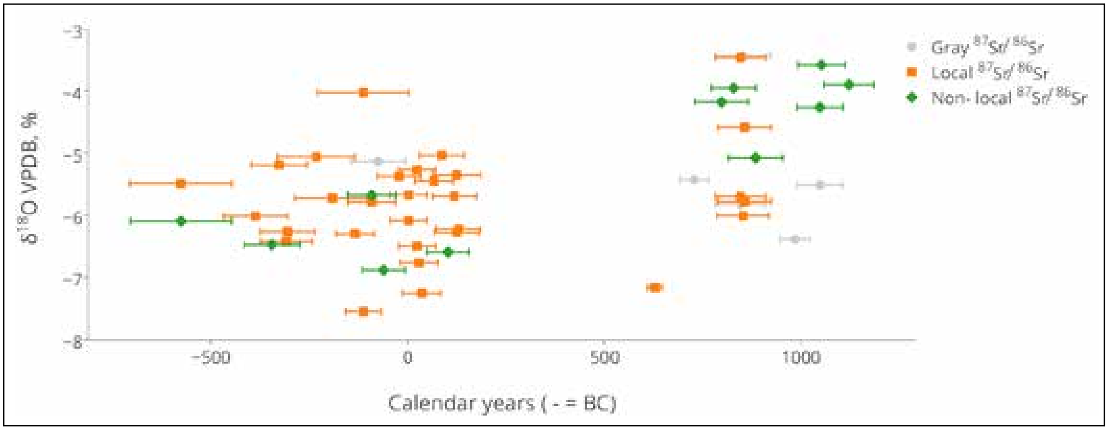
The values comparable (also from human samples) to Öland from the δ^{18}O VPDB of other sites in the region is around -5‰ (Table 8, Fig. 39). These sites span the Iron Age (primarily the Late Iron Age) and also probably include non-locals since only humans are sampled and the sites are mainly well-known trading centres. The overall profile for Iron Age Öland (δ^{18}O VPDB, -5.6 ± 0.9‰) thus presents a slightly more negative mean value than is expected by the approximation to other human samples in the region. The most distant sites, Galgedil and Trelleborg in Denmark farthest to the west, are those most dissimilar in δ^{18}O VPDB ranges to Öland. Still, there is a considerable overlap between those and the Late Iron Age samples from Öland.

In Paper IV, one baseline for Öland, for the entire Iron Age, was set to -4.5‰ – -6.5‰ δ^{18}O VPDB (Fig. 40). This definition is very similar to the mean and two standard deviations (i.e. -4.7‰ – -6.5 ‰). However, we chose to add some room in the local range and include the values right

Table 8. A comparison of δ^{18}O VPDB values from human enamel samples. The sites are found in the region around Öland similar to the regions used for the ^{87}Sr/^{86}Sr comparisons in Paper II. LIA= Late Iron Age, IA= Iron Age.

IN RELATION TO ÖLAND	SITE	LOCATION	N=	MEAN, STANDARD DEVIATION δ^{18}O VPDB, ‰	SOURCE	PERIOD
North	Birka	Sweden	29	-4.9 ± 1.2	Price et al., 2016	LIA
East	Kopparsvik	Gotland, Sweden	44	-4.7 ± 1.1	Price et al., 2016	LIA
South	Ndr. Grødbygaard	Bornholm, Denmark	36	-4.9 ± 0.6	Price et al., 2012b	LIA
South/ West	Uppåkra	Sweden	10	-5.0 ± 0.9	Price, 2013	IA
South/ West	Trelleborg	Denmark	41	-4.4 ± 0.7	Price et al., 2016	LIA
South/ West	Galgedil	Denmark	34	-4.2 ± 0.7	Price et al., 2014	LIA
	Öland	Öland, Sweden	106	-5.6 ± 0.9	This study	IA





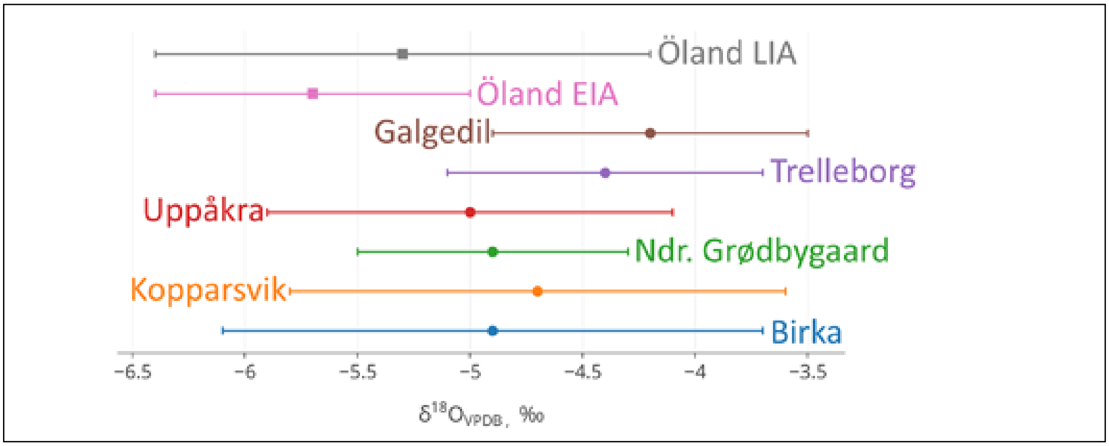


Fig. 37 (top). The full sample (n=106) of δ^{18}O VPDB with dates based on ^{14}C or relative chronology.

Fig 38 (middle). The δ^{18}O VPDB distribution is shown along with the ^{87}Sr/^{86}Sr definitions (see Table 6, Paper IV) for the ^{14}C dated samples (n=47). This shows that there is no apparent trend in the variation in δ^{18}O VPDB values over time, i.e. it is unlikely that climate changes have affected the δ^{18}O VPDB values in human enamel.

Fig. 39 (bottom). The mean (indicated with a square or circle) and two standard deviations (the error bars) for the sites with Iron Age values in the region (see Table 8 for details). All data is based on human samples and most likely includes migrant individuals of which some are probably differing in values from the actual local variation. Therefore, it is misleading to use these ranges directly as a local baseline.

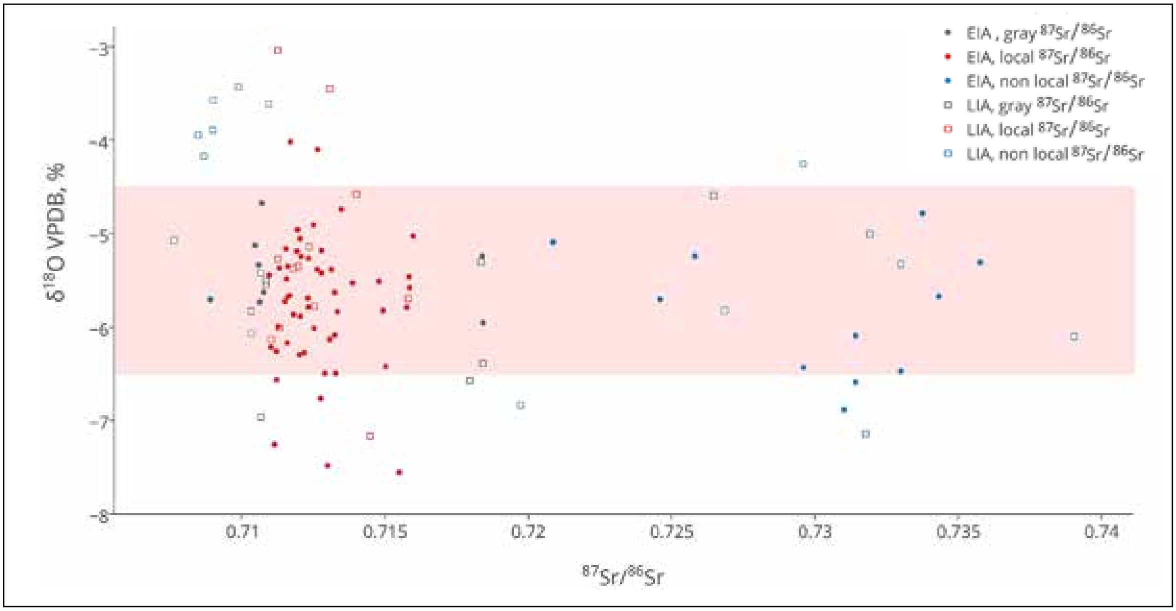
on -4.7‰– -4.5‰ (3 values) with local $^{87}Sr/^{86}Sr$ values (two local, one gray). The baseline is meant to be conservative and is primarily aimed at minimizing the risk of overestimating the proportion of non-locals from the $\delta^{18}O$ VPDB values. This definition of the baseline, a frequentistic statistical approach (mean and two standard deviations) but adjusted to take prior information (the $^{87}Sr/^{86}Sr$ distribution) into account, is similar to the basic idea of Bayesian theory. In order to be transparent, a non-statistical approach was chosen and the baseline is named "informed". This is meant to indicate that the baseline is informed in the sense that it uses a statistical basis, albeit modified to better correlate to the prior understanding of the problem (the $^{87}Sr/^{86}Sr$ definition of local) and is not just an arbitrary selection of values.

The $\delta^{18}O$ VPDB values can be recalculated and compared to modern values for precipitation as $\delta^{18}O_{phos}$ SMOW values (Fig. 41). The precipitation range is clearly skewed towards more negative values in comparison to the bulk of the samples, as well as in comparison to the "informed baseline" chosen in Paper IV. This transparently demonstrates how the modern precipitation values are probably not a suitable comparison for Iron Age human $\delta^{18}O_{phos}$ SMOW values. The reasons for this could be that the climate was different in the Iron Age in a way that made the water values different to modern ones. It could also be related to the anthrophogenic factor, where the choice of water sources and processing, such as brewing and cooking, significantly altered the water's $\delta^{18}O_{phos}$ SMOW values. Furthermore, the recalculation processes involved might also be a factor by adding further steps of data processing (c.f. Pollard et al., 2011). Adding up all these caveats for precipitation values, and the poor fit of it to the human samples, makes it unsuitable to use as a bioavailable $\delta^{18}O_{carb}$ baseline for Öland. Moreover, the precipitation range is skewed compared to the human samples at large and those with local $^{87}Sr/^{86}Sr$ values in particular. In fact, 13 samples with local $^{87}Sr/^{86}Sr$ values would also be categorized as local according to the "informed $\delta^{18}O$ baseline", but non-local from a precipitation $\delta^{18}O$ baseline. I therefore argue that, in this case, the "informed baseline" is more likely to be relevant. The difference in number of non-locals if the precipitation range would be used as a baseline (n=33) is insignif-

Fig. 40 (top). The "informed baseline" (i.e. -4.5‰ – -6.5‰ $\delta^{18}O$) marked in the plot from Fig. 36. Legend: Undetermined (gray $^{87}Sr/^{86}Sr$, local O), Local ($^{87}Sr/^{86}Sr$ and δ18O), Non-local* (just $^{87}Sr/^{86}Sr$), Non-local** (non-local δ18O, local $^{87}Sr/^{86}Sr$, Non-local*** ($^{87}Sr/^{86}Sr$ and δ18O), Non-local**** (gray $^{87}Sr/^{86}Sr$ and non-local δ18O).

Fig. 41 (middle). The calculated drinking water $\delta^{18}O$ values (phosphate, DW [=drinking water] or VSMOW) of the samples are shown with the informed baseline chosen in Paper IV (red rectangle) as well as local precipitation values (for Smedby in Burgman et al., 1987:580). The $\delta^{18}O_{carb}$ VPDB values (and baseline range) were recalculated using Coplen (1988) to $\delta^{18}O_{carb}$ VSMOW. The $\delta^{18}O_{carb}$ SMOW values were then recalculated using Daux et al. (2008, equation 6) to $\delta^{18}O_{phos}$ which is possible to compare to water values. E IA (Early Iron Age), L IA (Late Iron Age), n=106.

Fig. 42 (bottom). The ranked $^{87}Sr/^{86}Sr$ distribution. The samples are divided into three major groups: locals, non-locals, and undetermined from both $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ (VPDB) baselines devised in Paper IV. The darkest bars and the lightest blue bars are individuals added as non-locals due to the use of the $\delta^{18}O$ "informed" baseline (n=11). A single isotope approach, $^{87}Sr/^{86}Sr$, therefore clearly underestimates the proportion of non-locals in Öland. (n=109). Legend: Undetermined (gray $^{87}Sr/^{86}Sr$, local O), Local ($^{87}Sr/^{86}Sr$ and $\delta^{18}O$), Non-local* (just $^{87}Sr/^{86}Sr$), Non-local** (non-local $\delta^{18}O$, local $^{87}Sr/^{86}Sr$), Non-local*** ($^{87}Sr/^{86}Sr$ and $\delta^{18}O$), Non-local**** (gray $^{87}Sr/^{86}Sr$ and non-local $\delta^{18}O$).


EIA , gray 87Sr/86Sr
EIA, local 87Sr/86Sr
EIA, non local 87Sr/86Sr
LIA, gray 87Sr/86Sr
LIA, local 87Sr/86Sr
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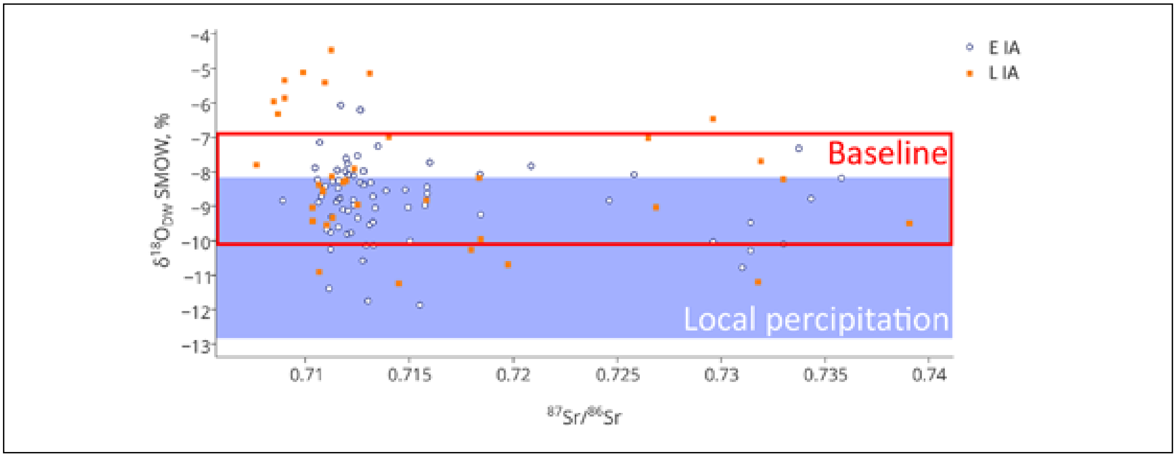
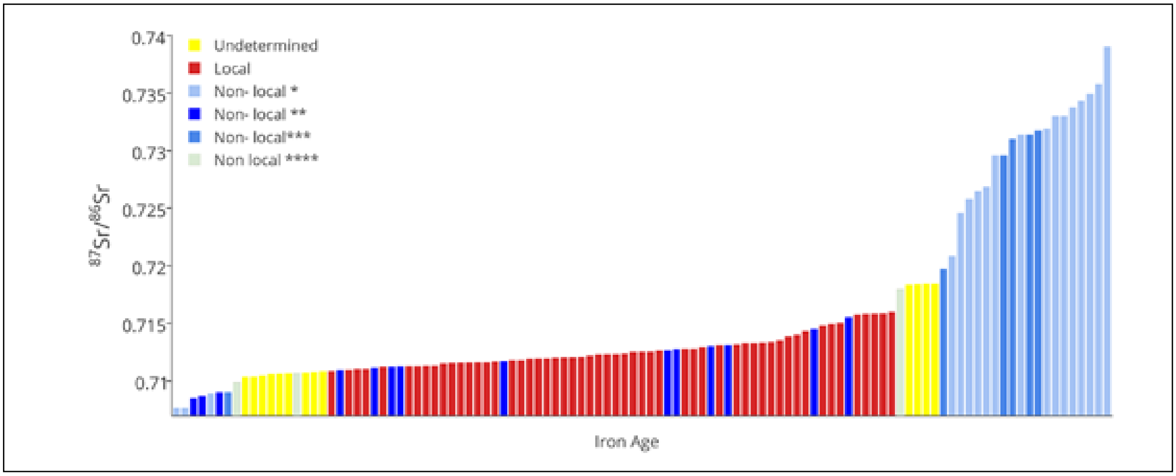
δ18O VPDB, ‰
-3
-4
-5
-6
-7
-8
0.71
0.715
0.72
0.725
0.73
0.735
0.74
87Sr/86Sr


E IA
L IA
Baseline
Local percipitation
δ18ODW SMOW, ‰
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
0.71
0.715
0.72
0.725
0.73
0.735
0.74
87Sr/86Sr


Undetermined
Local
Non- local *
Non- local **
Non- local***
Non local ****
87Sr/86Sr
0.74
0.735
0.73
0.725
0.72
0.715
0.71
Iron Age

icant in comparison to the informed baseline (n=32). This means that either way, the "informed baseline" is unlikely to be seriously overestimating the proportion of non-locals.

With the "informed baseline", a further 11 non-locals, with local $^{87}Sr/^{86}Sr$ values, could be added to the number of bi-isotopic non-locals. The different results from a single and bi-isotopic approach highlight how dynamic isotopic interpretation can be in archaeology (Fig. 42). The problems of different and/or remote areas having similar isotope baselines are apparent, as well as the lack of baseline data for great regions. Using a bi-isotopic approach, however, allows for the identification of some of these individuals and a more accurate sense of the extent of migration. It also helped to establish that migration was not purely regional.

The isotope values themselves are undebatable but the interpretation involved in translating the numbers to relevant definitions for the archaeological research questions are clearly up for debate and discussion. Both papers II and IV are examples of this. The definition of the $^{87}Sr/^{86}Sr$ baseline, such as that in Paper II, cannot be used to determine whether an individual is local or non-local. Moreover, the addition of the $\delta^{18}O$ showed the danger in using a less transparent methodology such as Bayesian modelling. The Bayesian calculations were based on flawed prior information as the $\delta^{18}O$ was proven in Paper IV to be able to intentify non-locals among those considered local in these calculations. Despite this flawed data, the calculations still genererated credible results which demonstrates that this loss in transparency can easily lead to erroneous conclusions.

Understanding migration on populational and individual levels

5.3.2

One way of understanding the pattern and impulse of human migration would be to test the theory of the gravity model which states that the inclination to migrate is dependent on distance and population density, explored in Paper II. It was possible to establish that the $^{87}Sr/^{86}Sr$ distribution in Öland was meaningful in relation to that modelled using other defined gravity centres. Moreover, this fits with the $^{87}Sr/^{86}Sr$ distribution in Öland in both the Early and Late periods of the Iron Age. There are significant uncertainties in the basic assumptions behind the calculation, primarily the precariously defined baseline used in the other areas, as well as those completely lacking baseline data which are therefore excluded from the study. Moreover, it seems from $\delta^{18}O$ that the migration included more remote areas than those taken into account in the gravity model calculations in Paper II. In Paper IV, it was evident that individuals were probably arriving from both the south/west (less negative values) and north/east (more negative values) than would fit with the regions included in Paper II. Coming from a different climate than that of Öland, these individuals had clearly remote $\delta^{18}O$ values but also occasionally had $^{87}Sr/^{86}Sr$ values that would be similar to, and could thus be interpreted as, local to Öland. This shows the danger with a single isotope approach such as that used in Paper II, where these individuals were interpreted as locals because only $^{87}Sr/^{86}Sr$ values were used.

Despite using different approaches and slightly different definitions of geological provenance, the two papers dealing with migration (papers II and IV) detected similar trends. Migration increases significantly and simultaneously with the considerable advance of maritime technology (when sails are introduced) in the Late Iron Age. This is a relevant correlation since Öland is an island and is dependent on communication by boat, but it does not necessarily imply causation. However, taking into account that the diverse immigration pattern was being not only maintained, but actually expanded to include more distant areas (from $\delta^{18}O$ values in Paper IV) in the Later Iron Age, the improvements in maritime mobility seems to be a very reasonable explanation. When investigating migration on an individual level, one big difference in mobility is revealed that is hidden when viewing the $^{87}Sr/^{86}Sr$ distribution alone without the osteological background on the individuals. The proportion of non-local females is not only very large in both periods, it increases disproportionally in the Later Iron Age. The proportion of male migrants remains at the same level in both periods. The proportion of females in the population in comparison to males is the same for both periods—approximately 30% female—despite the great increase in non-local females in the Late period. The increase

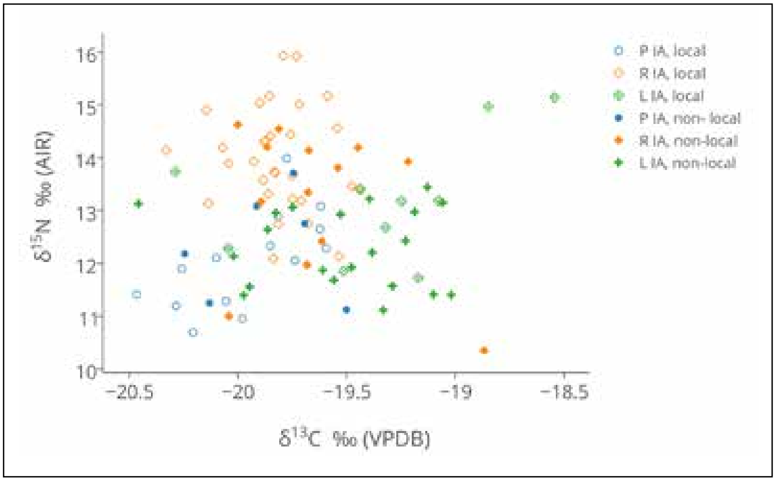


Fig. 43. Bone collagen δ^{15}N and δ^{13}C values for the sample divided into locals and non-locals as defined in Paper IV. Due to significant differences overall between the periods, Pre Roman (P IA), Roman (R IA), and Late Iron Age (L IA) are separated here. Although it should be noted that a major conclusion of Paper III was that a change in diet actually started in the Pre Roman Iron Age according to the subsample with ^{14}C dates.

in female migration is therefore unlikely to be explained as an increase in population size.

The inclusion of more bioarchaeological parameters in Paper IV also allowed for the contextualization of migration in a social setting on an individual level not addressed in Paper II. However, it was also an exercise in definition of ^{87}Sr/^{86}Sr baseline on an individual level which was very different from the earlier paper, as described above. In the Later period (AD 500–1050), the proportion of non-locals (defined from definitions of ^{87}Sr/^{86}Sr and δ^{18}O baselines in Paper IV) increased from 30% to 68%. Integration regarding burial practice is evident in both periods. In the Later period, however, there is a group of non-locals that are buried according to a different custom (west-east oriented burials) that is exclusive to them.

Migrant diet? 5.3.2.1

The adult diet differed between locals and non-locals (as defined by ^{87}Sr/^{86}Sr and δ^{18}O, see details in 5.2) in some respects (Fig. 43). Both the Roman δ^{13}C and δ^{15}N values (i.e. adult diet) were significantly different in locals compared to non-locals (δ^{13}C p 0.04188 and δ^{15}N, p 0.0341 in a two-tailed t-test). There are at least two possible explanations for these differences: (i) the non-local individuals had not been in Öland very long before they died and so their homeland diet was most prevalent in their bone collagen, or (ii) they had maintained their homeland diet despite migrating.

In the Late period, the $\delta^{15}N$ is significantly different between locals and non-locals (p 0.00536 in a two-tailed t-test). This period has the greatest variation in $\delta^{13}C$ values but the $\delta^{13}C$ variation appears to be similar in locals and non-locals alike. The specific values cannot, then, be used to determine whether an individual is local or non-local. However, it is possible that a greater proportion of non-locals, who possibly brought different food preferences and food cultures with them, could influence the dietary preferences of locals. Considering that the non-locals were such a large proportion of the population during the Late Iron Age, I do see this as an option. Also, the adaptation to a more diverse subsistence could be due to the arrival of immigrants who would bring new food preferences, methods, and technology with them.

	Child	Juvenile	Young	Mature	Old	Juvenile/Young	Young/mature	Mature/old	Adult/mature/old
years	6-12	13-19	20-35	36-59	60+	13-35	20-59	36+	20+
n	5	17	14	20	15	5	23	6	4

Table 9. The age estimation per individual as divided into the age groups (see 4.1.2). Some individuals have an estimation transcending two groups which is why they have to be included in the mixed groups and further individuals were not possible to age in more detail due to preservation of skeletal age characters.

Period	Chronological definition	Female/male/ ambiguous/unsexed
Early Iron Age	500 BC–400 AD	21/38/3/9
Late Iron Age	400–1050 AD	9/20/3/6

Table 10. Sex estimations, both “female” and “female?” are in included in the female group and the same for males. The “unsexed” category represents the youngest individuals (children and juveniles) that are not sexed due to skeletal immaturity, as well as individuals of poorer preservation (without assessable characters in the pelvis or skull). “Ambiguous” refers to those with sex characters that do not allow them to be placed in either the female or male group.

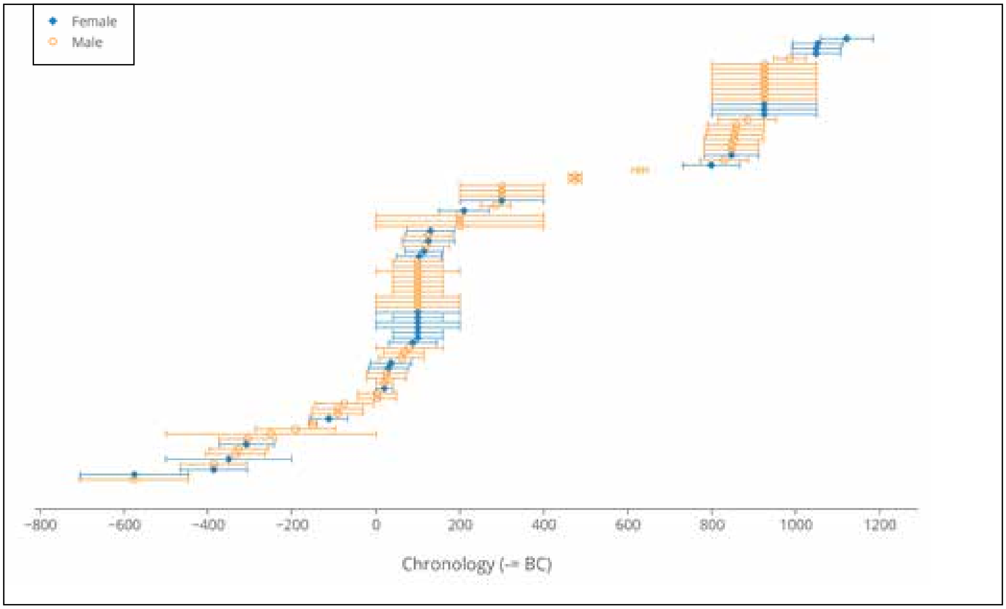


Fig. 44. The chronological distribution of the sexed individuals. This includes individuals dated by both ^{14}C and relative chronology (typology). Error bars indicate the full range of the date, and the circle or diamond the mean.

5.4 Social organization, hierarchy, and violence

Overall, in the Iron Age, there is a clear sex bias in Öland with 64% of the investigated population being male in the Early period and 69% in the Late period (Table 9). The lack of women seems to be static throughout the entire period (Fig. 44). The explanations for this low percentage of women could be cultural or geographical, or a combination of both. For example, were females more likely to be cremated due to gender, social status, or other similar factors? If so, this suggests that cremation practice was constant and consistent throughout the Iron Age. This could be questioned due to the probable occurrence of more general social changes in society during this period. In the Late period, with the exception of one female, all are non-locals (Paper IV) adding a further dimension of curiosity to the pattern. In the Late period, it is clear that women are moving to the island and yet the proportion of women in the skeletal, that is, uncremated, population does not increase. With regards to age distribution of the sample, it can be noted that most ages are represented (for chronological variation see also Figs. 22 and 23) (Table 10).

Changes in social organization could be traced using a human-centred approach. The designation of individuals as having a 'high status' due to the occurrence of specific types of artefacts (for definitions see papers IV or V) in these individuals' graves, was proved to be interesting when bioarchaeological aspects and violence in particular were taken into account. Violence appears in the most diverse contexts, from high-status burials to various non-normative contexts (see Paper V). In at least three cases, these non-normative contexts had clearly negative connotations concerning the deaths of the individuals found there: one individual (ID 1094) was a disposal/concealment rather than burial and the other two individuals were found in a house (see 5.1 for details on this case). The disposal/concealment (ID1094) is a very interesting case in many aspects. The burial was a simple pit at the far end of a grave field (possibly outside it) and the body was in a haphazard position, with spread

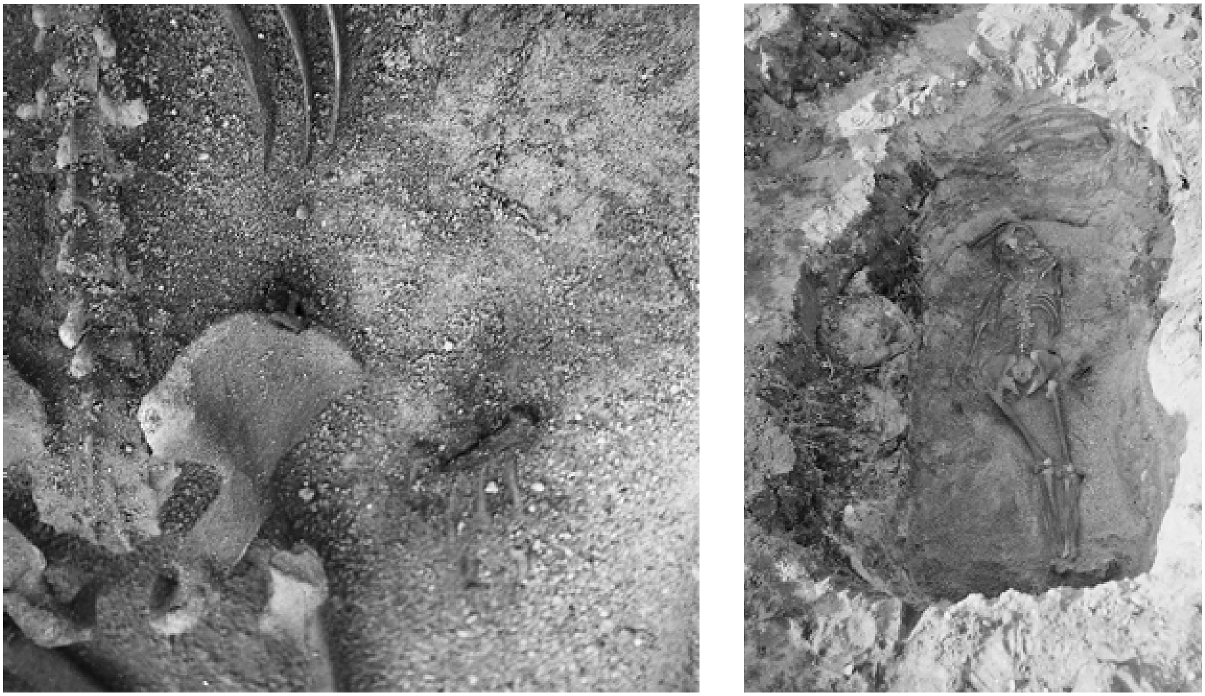


Fig. 45. Hulterstad parish, SHM 25132. These images show ID 1094 in situ. Note the prone position of the skeleton, spread arms and feet lying close together and well-articulated skeleton (suggesting a small burial space i.e. a wrapped/clothed body in a coffin, or a body placed directly in a pit). The only object, a small belt-fitting, is lying on the right hip bone (superior part of the iliac crest) with the right hand (metacarpals) close by, as seen in the detail photo. Photographs: KG Petterson, 1954, photo id 261: 186 (left), 261:187 (right). Photograph used with kind permission of ATA (Antikvarisk-topografiska arkivet), digitized by Torbjörn Linnerud.

arms and feet which appeared to be tied together (Fig. 45). The victim had multiple sharp and blunt force traumas to the skull but no other apparent skeletal injuries, such as defense wounds (Fig. 46). However, a lack of defense injuries may fit with the feet being tied together at the time of burial; if the victim was tied down before she was killed she would have had no opportunity to defend herself, thus not receiving such injuries. The extent of her injuries is only matched by a male (ID 1092) with multiple sharp and blunt force traumas inflicted at the time of death in a similar manner. Like the female, this man does not show any obvious defense injuries but, in contrast, he has a most normative, even high-status, burial. He is buried supine in a cist on top of older burials and has a sword and other objects in the grave. Although it is not possible to confirm from excavation photos (Fig. 11), nothing appeared to be unusual about his burial. These burials are more or less contemporary as well, from the Early Roman Iron Age. The woman is at least 60 years old at the time of death and the man is a mature/elderly adult. If interpreting the victim of deadly violence as a person of social power (as is the approach in Paper V), these cases are showing that older individuals –

Fig. 46. The injuries to the frontal bone of individual 1094 include a fracture (BFT, blunt force trauma) and an adjacent peri-mortem SFT (sharp force trauma). The top image shows both these injuries on the very anterior part of the skull (some 10 cm above the eyes) and the grazing SFT is just above the BFT with a piece of bone missing and radiating fractures. The bottom image shows the BFT and radiating fractures. Photos: Helene Wilhelmson.

both men and women – could have significant social power. In my opinion, the severity and great number of the woman's injuries and her likely incapacitation are indicative of excessive violence. The excessive violence thus suggests that her assailant believed her to hold great power despite a probable lack of physical strength considering her older age. Since her burial appears as more of a concealment, or at least a reckless and disrespectful abandonment considering the awkward position of the body, her death does not appear to be socially sanctioned, unlike that of the man (ID 1092). It is possible that her age is the difference here, or that women should not have been killed in this manner. The other woman (ID 1111) with traces of repeated violence (healed and unhealed) is also found in a non-normative context: a wetland deposition. However, as discussed in Paper

V, this type of context does not necessarily have to provoke negative connotations as most cases of violence were found in normative burial contexts.

When comparing violence to isotopes (local or non-local) and different osteological criteria, no clear pattern relating to social status emerged when exploring it in a network approach. However, this is still a result as it demonstrates the complexity of violence. If any trend is detectable, it is that violence was related to holding a high status rather than a low status. This could mean that the use of violence could be seen as a means to increase an individual's social status.

The one clear chronological pattern of violence is related to age and gender. Sometime around AD 200 there is a shift in victim profile. To begin with, victims of violence included both sexes and primarily mature and even elderly individuals. After AD 200, they are almost exclusively young men. The timing, although difficult to detail precisely, corresponds to extensive social changes taking place on Öland, such as a change in burial practice with cremation becoming dominant, changes in settlement patterns, and the introduction of the forts.

On the note of gender, and archaeological sexing of graves via artefacts rather than osteology, the results from Paper V add a cautionary note. Weapons occur in female graves, although not as often as with males. On the other hand, males are overrepresented throughout Öland in the uncremated human remains and throughout the Iron Age. The social hierarchy expressed in burial goods did not show any significant differences between ages of men and women. When compared to the criteria for high and low burials, locals and non-locals (defined in Paper IV) were shown to occur in similar proportions relative to their part of the entire population in both periods. However, in the Late period the non-locals were especially common in the high-status burials.

CHAPTER 6

New perspectives: rethinking old, and new questions

This chapter is divided into subsections to give an overview of the specific discussion relating to the four major themes (taphonomy, diet, migration, and social organization, see 1.3.1) and how I have interpreted the results and rethought the Iron Age on Öland accordingly. Moreover, these results have given room to discuss new questions that highlight some unanticipated advantages of the human-centred approach with regards to Öland. A synthesis of the specific advantages and limitations of the approach is also given which, together with the other discussions, is designed to relate to my overall aim of the thesis.

6.1 The new perspectives on Öland from a human-centred archaeology

This section of the discussion is divided into four subsections corresponding to the four specific goals (see 1.3.1). The overall theme of these discussions is to highlight how the different methods have been employed and developed and what new interpretations this has led to for Iron Age Öland in particular. I will argue in detail below about how and why the results from a human-centred approach call for a rethinking, not only of Iron Age Öland, but also of the use of these methods in archaeology in general.

6.1.1 Rethinking taphonomy

6.1.1.1 The use of reflexive osteology/archaeology in making *mortographies*

The idea to develop the approach presented in Paper I, the specific methodology of *Virtual Taphonomy*, was inspired by *Anthropologie de terrain/necrodynamics* as a way of integrating osteology with archaeology. This focus on taphonomy allowed for an interdisciplinary approach which manifested through the introduction of *mortographies* – accounts of the events at the time of death and after death for the individuals in the case study. The addition of already-established taphonomical criteria such as fracture patterns, allowed for a deeper integration with the archaeological context and a more detailed interpretation. However, these questions would not be possible to address without today's state-of-the-art digital methods such as the combined uses of IBM (image-based modelling) and 3DGIS, but, more importantly, without the recognition of the intellectual possibilities these methods bring. In my opinion, the major difference of this study in comparison with earlier studies was the successful collaboration with an expert in these digital methods who was also a researcher with a highly theoretical focus, rather than purely technological and methodical. The collaboration facilitated two major advances: (i) the possibility of tailoring aspects of the technical approach for the taphonomical analysis and, more significantly (ii) the integration with archaeological method and theory (reflexive archaeology) allowing an integrated analysis and interpretation of the human remains within the archaeological context.

The IBM methodology as practiced in Paper I was timesaving (compared to previous methodologies of drawing, GIS recording of individual bones, etc.) but simultaneously gave high accuracy and great detail. The integration of the osteological observations in 3DGIS enabled a third stage of analysis: the integration of lab results (such as observations of gnawing and fracture patterns) with the specific context in three dimensions. This called for a reflexive osteological analysis in the lab and led to a seamless integration of lab and field. This is different to *Anthropologie de terrain* which merely covers field observations, similar to Wilder's *necrodynamics* approach, making *en blocs* to take to the lab (Wilder & Whipple, 1917). The method has thus allowed not only integration of osteology and archaeology, but also of osteological field and lab analysis. The achievement with Paper I is more than a methodology; it allows the integration of osteology with archaeological theory and practice. Furthermore, the extension of the osteological lab analysis to include a second phase where the analysis was conducted in the archaeological context (3DGIS) gave a new reflexive element to the analysis and should therefore be seen as a form of "slow archaeology" (c.f. Caraher, 2015). Paper I has been portrayed primarily as a study emphasising the time-saving aspects of digital methods by the person that launched the concept "slow archaeology" (c.f. Caraher, 2016:430f), not as a reflexive piece. This is a positive, of course, however, I consider the major advantage of our approach to be its addition of a further reflexive phase of interpretation.

Compared to earlier digital methods used to analyse human remains, using GIS representations (stick figures) from total station measurements, or two dimensional drawings/photos, reveals technical advances that are truly significant. It was recently demonstrated that the IBM technique (SfM, Structure from Motion) used in Paper I, gives a much higher precision and accuracy than using measurements with a total station. The total station accuracy is in the scale of ±5–10 mm while the IBM gives 1–2 mm accuracy in repeatability tests on archaeological/architectural complex geometries (discussion in Sapirstein, 2016). In addition to this, laser scanning, considered the most precise method available for representing geometrical features so far, also yielded only a 1–2 mm offset with IBM in archaeological excavation (Galeazzi, 2016:167f). The laser scanner, while considered very precise in capturing geometry, does not give colour information nor a photorealistic texture as IBM does (e.g. Galeazzi, 2016). Along with the great accuracy and precision, the short time required, and very low equipment costs (compared to both laser scanner and total station), IBM could well serve to make total station or GPS measurements of archaeological features unattractive options. Therefore, the methodology outlined in Paper I is in line with other state of the art methodologies within the archaeology field, and the use of IBM and 3DGIS is likely to increase exponentially in the future.

Since the publication of Paper I, another paper details a similar endeavour where skeletal remains were documented with image-based 3D models, and/or in field measurements (bones recorded as individual geo-objects) in GIS with a taphonomic focus (Aspöck & Fera, 2015). The 3D models were created in a very similar approach to that of geo-referencing, although very few images (only 11 as a mean) were used. In Paper I, 100 photos were used to create the model of individual 2 (ID 1109) and 50 for the model of Individual 1 (ID 1108). Using only 11 images as Aspöck and Fera did would limit the accuracy of the model, probably to a significant extent, and is a curious decision as the photo acquisition (even of 100 photos) is very quick compared to using a total station, for example. Another approach was also investigated (only for one burial due to time limits) where each individual bone was measured with a total station in order to take an *Anthropologie de terrain* approach to the skeletal remains. However, considering the much smaller accuracy of the total station compared to state of the art IBM (c.f. Sapirstein, 2016, and discussion above), unfortunately, this is a definite methodological step backwards. Not only does the total station provide less accuracy and precision, it also requires a very long time in the field to complete the survey, while also relying on constant access to a comparatively expensive machine (i.e. the total station). Furthermore, the colour information is not acquired and the complex bone geometry is reduced to a simplified drawing of outlines or stick figures. The article is merely descriptive, an account of the methodologies tested. No specific results of the taphonomical analysis are presented, and any experiences of using the different approaches (measurements of each bone vs. 3D models in GIS) remain unshared. This article cites Paper I simply as a similar analysis without detailing its significant similarities, the more detailed approach taken there, or the specific results put forward in Paper I which are highly relevant in the context (the article being a methodological description). Aspöck's earlier work on burial taphonomy (excluding *Anthropologie de terrain*) has demonstrated the great relevance of human skeletal remains in an interesting discussion on grave opening versus looting of graves in central Europe (Aspöck, 2011). Hopefully Aspöck will eventually present a combination of these papers. This would be an interesting contribution, furthering the digital applications in burial taphonomy, especially if, along the line suggested in Paper I.

Zooarchaeology can be characterized by its explicit focus on taphonomy. Taphonomy is vital to any analysis and is always detailed and discussed as the field almost never deals with complete individual skeletons. This is an explicit difference to human osteological analysis/bioarchaeology, where taphonomy is often considered but is less often articulated, unless dealing with unusual contexts (wetlands, for example). This is in part due to the frequent, considerable, and very varied manipulation that animal bodies go through after death, compared to the bulk of human remains. This practice and consideration of taphonomy has resulted in some more detailed methodological approaches (c.f. Lyman 1994, and discussion in Orton, 2012). Recently, 3D modelling was methodologically explored specifically for animal bones (Macheridis, 2015) and this study focused on the potential to preserve information and reduce the negative effect of post-excavation taphonomy. The possibility to take measurements of bones in the models within 3DGIS was highlighted as an established practice in this site for human bones for some time (c.f. Knüsel et al., 2013). A common classification of taphonomical characters to be used for both animals and humans could be an interesting mutual development and a common platform could potentially be 3DGIS, with either 3D models (if that precision level is called for) or measured archaeological features/units, similar to Madgwick and Mulville (2015) only in GIS.

3D modelling is very much promoted today which has resulted in some not entirely thoughtful applications, particularly in terms of human remains, even within the scientific community. A skeleton is a common symbol or representation for a burial and is easily recognized and immediately associated with death. However, if instead of a drawing or 2D image an anatomically-correct 3D skeleton is used purely as a representation in a 3D context, the result can be very confusing. The 3D aspect is giving much more (possibly inaccurate) information and indicates a precision (possible if it was a proper IBM or laser scanned model) often unsupported in the original documentation. An unfortunate use is seen in Eerkens et al. (2016), who add 3D images without any accuracy or use, other than for purely visual effect. Similarly, Garstki et al. (2014) performed a spatial analysis where skeletons were used as representations of skeletal remains (very poorly or unpreserved), not actual human remains, when analysing the burials (the archaeological features) within the greater archaeological context (a tumulus). There, the use of 3D skeletons as representations was clearly detailed in all instances referring to those images. The study was an excellent demonstration of the practical use of 3D modelling for spatial analysis of burials on an overview level (although not in any detail since spatial information was estimated based primarily on interpretations of skeletal remains' spatial positioning from objects) for understanding excavations that predated the digital era. This also helps to demonstrate the great possibilities with using an approach like *Virtual Taphonomy* already at the time of excavation.

Very recently, in their summary of past and present directions in funerary taphonomy, Knüsel and Robb (2016) pointed out two major developments in archaeology predicted to be most influential in furthering the understanding of taphonomy in the osteoarchaeological context. The first was the use of 3D virtual reconstruction and GIS, and Paper I was specifically mentioned by them as, so far, it is the only one achieving this combination. The only objection I have to this paper is that funerary taphonomy, albeit an old and well established concept, is a limited concept by inferring that there was indeed a burial. It is ironic that they should mention Paper I as a good example given that Paper I did not detail a burial: using "funerary" in this context would thus be misleading. A concept such as *mortographies* would be more dynamic for the discussions Knüsel and Robb are asking for, as it would include any context or burial whilst excluding any effect or connotation that the word "funerary" has. Not only within osteology has Paper I been acknowledged, but also in the field of digital archaeology (e.g. Jones, 2016). In particular, it has been referred to as a promising and rare example of the analytical use of models and 3DGIS (Taylor, 2016:99, 400).

It should be noted that since Paper I was completed, the technical aspects (software capability, computer power) have developed further, now allowing for very high resolute models to be viewed directly in GIS (instead of as in MeshLab, as described in Paper I). The increasing practice of using tablets in the field (e.g. Berggren et al., 2015; Roosevelt et al., 2015) could not only produce the 3D model in 3DGIS but also make a detailed recording in the GIS platform directly while excavating the feature in real time. Creating shapefiles for bones while excavating would allow for the quick assignation of ID numbers to individuals/bones – especially important in commingled assemblages/mass graves – and also the possibility of adding taphonomic data (such as state of articulation) directly into the GIS database before removing the bone from the context.

Paper I is an attempt at supplying a methodologically improved practice for integrating the lab and the field in osteology, and archaeology and osteology in an interdisciplinary manner. However, here I would like to emphasize the theoretical implications of the *Virtual Taphonomy* approach. It is not just a methodology but also a new way of viewing and querying the archaeological record. The use of bones allows us to investigate how the archaeological context was formed and integrates the potential of bones (and bodies) as physical objects as well. On this very physical level, a human-centred archaeology can add new information and new lines of inquiry to the archaeological record in general too.

6.1.2 Rethinking diet and subsistence

6.1.2.1 Pastoralists or fishers? The effects of rethinking methodology and interpretation of isotope values

My interpretation of diet in Paper III is that it was largely dependent on domesticates throughout the Iron Age, with some temporal variations in animal use. I base this on the comparison of the animal samples, more or less contemporary, to the human remains from this study and the use of 5‰ TLE (the value of which should be considered when comparing human and animal collagen isotope values) for $\delta^{15}N$. This type of subsistence is also supported by archaeozoological and paleobotanical assemblages, the distinctive partitioning of the landscape, and the occurrence of byres. In contrast, almost identical human isotope values from Iron Age humans on Öland were interpreted very differently in the two earlier studies (Eriksson et al., 2008; Howcroft et al., 2012) as being indicative of a freshwater fish-based diet. This subsistence practice is notoriously difficult to verify in the archaeological record at large. The archaeozoological assemblages give no indication of this being the major dietary resource, at least during the timespan they cover. Moreover, these assemblages instead suggest a high reliance on domesticates, mainly sheep and cattle, but also pigs and chickens.

The rethinking of diet in Iron Age Öland that I propose is not just a very different diet compared to the two earlier studies, it is also a rethinking of dietary change and chronology. While I found indications of dietary changes during the Iron Age, the data from the earlier studies was not selected to be able to capture such trends. In fact, the Ericsson et al. (2008) study was even partly misleading in terms of reported chronology and had to be revised (relying on original sources) to be useful in comparison to the data presented in this study. However, I do not suggest freshwater fish was the main diet during any point within the Iron Age, so the reinterpretation goes even further away from the earlier studies. Neither is it in the isotope values themselves that this difference originates. There is a very strong similarity between the human isotope values in the two earlier studies and my own (as shown in Paper III). The rethinking of dietary resources and subsistence I propose is instead mainly a question of methodology. Choices of parameters used to interpret isotope values are debated and the trends have shifted in the few years separating my study and the two earlier studies on Öland. These trends were in motion at the time of the earlier studies, as I will show below, and today the debate has reached a turning point where the older methods are clearly challenged. The rethinking of the Öland diet presented here is also, in essence, a review of the interpretation process surrounding how to translate the isotope values in relation to diets today in the field at large, not just for Öland specifically.

The two earlier studies did not use contemporary animal samples or include the most relevant species (leaving out chickens which are suggested to be important from archaeozoological assemblages), limiting the interpretational possibilities of the human values. The isotope values of the Iron Age animals sampled in this study were different from the animal values in the earlier study (Eriksson et al., 2008), as shown in Paper III. The second, and most significant, difference to the earlier studies is that I chose to use the higher TLE for δ^{15}N values. The use of 5‰ TLE instead of the older 3‰, as shown in Paper III, completely changes which animals can be considered as an explanation for the human δ^{15}N levels. Before, with a lower TLE, fish were most likely to be responsible for the highest δ^{15}N values in humans but with the new higher TLE, sheep, pigs and chickens are now more likely candidates than fish.

The interpretation of high δ^{15}N levels in humans as being representative of a diet heavily based on freshwater fish is not accepted without question in archaeological contexts. Already 10 years ago, Reynard and Hedges (2007:1244) called for hesitation regarding the very frequent freshwater fish consumption apparently indicated by the isotope values. In particular, the proportionally small effect that freshwater fish have on protein levels along with the fact of the low representation of freshwater fish in archaeozoological assemblages in relation to other species, should be taken as a cautionary note. They suggest high δ^{15}N levels can be better understood by a higher TLE (such as 5‰), a view later shared by O'Connell et al. (2012). Moreover, they offer another possibility for high δ^{15}N levels in humans: "It can be concluded that high trophic levels can be sustained under pastoralism (with milk supplying by far the most protein)" (Reynard & Hedges, 2007:1248). Pastoralism considered the archaeozoological assemblages and landscape partitioning (etc.) as a very likely fit with Iron Age Öland. The use of chickens for eggs and meat could further raise this level and could potentially be relevant for Öland as indicated in archaeozoological assemblages. I would therefore argue that the population on Öland were largely pastoralists, not freshwater fishers. However, like I have reinterpreted the isotope values of the earlier studies in terms of diet, future studies could well provide different interpretations as the understanding of isotope variation develops further. Having more animal samples for comparison and more archaeobotanical and archaeozoological analysis of new materials in the future could help further the understanding of diet and subsistence on Öland throughout the duration of the entire Iron Age.

A recently published study addressing the lack of a reservoir effect in a population where this effect was expected to present significantly due to consumption of freshwater fish (Svyatko et al., 2016) is of interest in relation to my interpretation of the diet and reservoir effect on Öland. The arguments for a diet based on freshwater fish were mainly related to isotopic values (bone collagen), i.e. in the interpretation of high $\delta^{15}N$ values and midrange $\delta^{13}C$ values. The logic was that such a diet should produce a measurable reservoir effect (offset in human ^{14}C in relation to other dated contemporary material) which is what the team set out to test, with all the caveats of such an approach in mind. To their surprise, despite a very thoroughly constructed study of an almost optimal scenario, the researchers could find no such reservoir effect in the human samples. In my opinion, this is because such human diet isotope values would instead, if interpreted with the higher TLE as I have done here for Öland, be indicative of a diet of terrestrial animals – not fish – which would likely lead to the humans presenting a minimal reservoir effect.

6.1.2.2 Only pastoralists? Rethinking continuity, introducing change

The chronological development of diet that I interpret from the isotopes allows for a rethink of Öland society and its people throughout the Iron Age. I identify significant changes (based on chronological differences in isotope values) in subsistence in at least two occasions during the Iron Age. The first shift is probably swift and, comparably, securely pinpointed in time due to the size of the material (number of human samples with ^{14}C dates). The second shift, on the other hand, is very difficult to pinpoint due to the very small amount of material (human remains) available for the middle Iron Age, occurring sometime between AD 200–700. I argue that the first subsistence shift was marked by a change from a diet which had been based on cattle or mixed domesticates and featuring some crops then shifting in the Early Iron Age to a diet based on primarily domesticates, possibly mainly sheep. In order to sustain such a diet, I suggest the primary protein sources were secondary products such as milk. Using ^{14}C dates, this appears to occur not in the typological definition separating the Pre Roman and Roman periods (i.e. AD 0), but instead sometime in the centuries just before. How swift this change appears is very difficult to say as ^{14}C dates have a span, usually of more than a century. More dates would be favourable to test this hypothesis. Apart from human remains, obviously, I would like to see more dates of partitioning walls, associated settlements, and pollen sequence data to see if any changes in land use, pasture, or crops is possible to determine by these sources. Possible explanations for this change could be improved animal husbandry techniques, climate changes favouring this subsistence, or social changes regarding land use.

The later dietary shift resulted in a diet with much more individual variation, a more opportunistic approach to subsistence, and a generally smaller proportion of animal protein. I suggest this means a shift away from the strict domesticate-based diet – less reliance on milk, for example. As proposed earlier, a subsistence of a (comparably) more opportunistic and varied nature would be likely to result from either a large societal or climatic change. One suggestion is the collapse of the great Alvar; no longer supporting grazing could spark such a change in subsistence sometime during the end of the Roman period. The possibility of the Fimbul Winter (e.g., Gräslund & Price, 2008; Gräslund, 2011; Löwenborg, 2012; Tvauri, 2014) striking Scandinavia and Öland in the mid sixth century, potentially several hundred years after the Alvar collapse, could also have caused a shift in subsistence. Bondesson and Bondesson (2014) in particular argue for the potentially huge consequences of an instant climate change and colder temperature causing outbreaks of ergotism in domesticates which would not only kill the animals but also reduce their fertility. In a pastoralist and milk-based subsistence, such an event could indeed be catastrophic and spark a more diverse subsistence practice to be adopted. A third possibility is that the population on Öland was largely replaced by immigrants colonising the island, bringing with them diverse subsistence strategies. A population replacement of significant magnitude, no matter what the cause, could potentially be investigated by looking at the DNA variation in the population before AD 200 if compared to after AD 800. If there was a population bottleneck, this approach might be able to identify it and narrow down the dates for when this occurred.

6.1.2.3 Migration: a hidden bias in paleodietary studies?

After combining the diet isotopes ($\delta^{13}C$ and $\delta^{15}N$) with the $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ results in Chapter 5, I argue that the diet isotope results and their translation to diet need to be understood in the context of migration as this clearly could be a confounding factor (as detailed in 5.3.3). If the migrants' isotopes could be reflecting their diets before migration, should these isotope values not be interpreted according to a specific diet from their local fauna? This level of complexity in diet interpretation is virtually impossible to address properly as it requires a pinpointing of origin of each individual and availability of faunal isotope values from each of these regions. It is for these very reasons I have not pursued this approach here. However, I do see this as further evidence that caution needs to be taken if using diet isotope values alone for interpreting diet – both human and animal – in any society where migration is likely. This too highlights the importance of using other sources for understanding diet and subsistence; archaeozoological assemblages are less biased in this respect, for example, and clearly reflect food practice on a local scale. This can be more or less of a problem depending on the level of immigration in a society and the diversity in food practice and subsistence in the homeland vs the new land. For Öland, a place with significant immigration and probable specialized subsistence, this could clearly be a problematic issue and is thus an important caveat to add to the dietary isotope interpretations.

Rethinking migration

6.1.3

The effects of rethinking the interpretations of isotope results

6.1.3.1

When studying migration, I chose to use two, somewhat conflicting, approaches in interpreting the same basic isotopes ($^{87}Sr/^{86}Sr$) in order to be able to use the results at either a population or individual level. When studying migration only on a population level, as in Paper II (in contrast to Paper IV), it was not necessary to use a traditional division of the sample by determinations (interpretations) of individuals as local or non-local. Instead, the proportion of non-locals in the sample was defined by a purely statistical definition of local/baseline (using a mean value and two standard deviations of the faunal values) rather than individuals being defined as either local or non-local. This approach allowed the gravity model of migration to be tested, and for comparison with other defined areas and their baselines as determined by the same exact approach. A model relevant to migration could thus be applied to the $^{87}Sr/^{86}Sr$ distribution, taking the discussion on migration from isotopes one step further than for $^{87}Sr/^{86}Sr$ studies in general by viewing the migration process on a population level. However, as demonstrated by Paper IV, not only is this type of construction of baseline for $^{87}Sr/^{86}Sr$ questionable on the individual level, the expanded $\delta^{18}O$ baseline (the "informed baseline") led to the detection of several non-locals with a local $^{87}Sr/^{86}Sr$ profile. This would lead to a misclassification of individuals as locals. The bi-isotopic approach is, therefore, in my opinion, clearly preferable as it allows us to avoid some of the problems arising from identical bioavailable variation in $^{87}Sr/^{86}Sr$ in multiple regions. In this case, the bi-isotopic approach (in Paper IV) proved the assumption that the mobility was regional (which was the basic assumption for the use of Bayesian modelling in Paper II) to be erroneous to some extent. This is interesting as the regional model otherwise fits the $^{87}Sr/^{86}Sr$ distribution in Öland. This is possibly a testament to the limited baselines (based on comparably few samples) in the selected regions which have resulted in the "overidentifying" of regions as more distinct than they in fact are.

The outline of Paper IV was more traditional for this type of isotope study in comparison to that of Paper II. I used an individual-level approach to migration by correlating locals and non-locals with osteological and archaeological information. A pivotal point in this approach was defining the baseline (local bioavailable $^{87}Sr/^{86}Sr$), as well as the process of translating this into an interpretation of the individual as local or non-local. Defining the local baseline from faunal values turned out to be difficult for Öland. There was considerable variation in the values and a statistical approach to define a local $^{87}Sr/^{86}Sr$ profile (using the mean and two standard deviations) gave a definition working on the four-decimal level. Applying such a definition when the local variation covered most of the third decimal made it apparent how easy it is for the statistical approach to become absurdly precise. Based on the comparison of the approaches to study migration from isotopes used here, I would give future studies the following specific advice:

- Use a varied and large number of animal proxies;
- The use of the mean and two standard deviations for defining local values from bioavailable $^{87}Sr/^{86}Sr$ samples should be considered carefully. The results of a strict four decimal border should be considered in relation to the overall distribution of the values;
- Consider using not only a local and non-local range, but also an undetermined range of $^{87}Sr/^{86}Sr$, unless it is obviously superfluous (one such scenario where this was the case would be that of a population of only non-locals, e.g. Price et al. 2016);
- If possible, use a bi-isotopic approach and preferably isotopes reflecting different aspects of provenance (such as $\delta^{18}O$ for climate and $^{87}Sr/^{86}Sr$ for geology);
- If the purpose is to study migration, take samples to cover the variation in the population (population level patterns), not just the deviant burials with specific artefacts;
- For $^{87}Sr/^{86}Sr$ in particular, consider soil variation, not just geology.

These conclusions, operating on a methodological level, primarily highlight limitations and problems on a general level for using isotopes to investigate migration, regardless of taking a human-centred approach or not. Below, I will instead focus on the potentials for furthering the understanding of migration from a human-centred approach.

Regional or inter-regional mobility? Large or huge immigration? 6.1.3.2

There is a great increase in rates of immigration to Öland in the course of the Iron Age. The isotopic evidence for this should be seen as a minimum as this can only identify some of the permanent immigrants, and only the first generation. This challenges the notion of Viking expansions as a phenomenon of primarily outward colonisation by proving that significant immigration occurred at the very same time and, to a lesser extent, long before as well. The addition of $\delta^{18}O$ isotope values in Paper IV revealed evidence of long-distance migrants, making it necessary to revise the conclusion of Paper II which stated that the immigration was mostly regional. Recently, values from Estonia were published which cover an almost identical baseline to that of Öland (Oras et al., 2016:20, $^{87}Sr/^{86}Sr$ baseline was determined from fauna to 0.7106–0.7159). The distance to Estonia by sea is substantial and yet the $^{87}Sr/^{86}Sr$ baseline is virtually the same as in Öland. In theory, this would make a long-distance migrant from Estonia appear as local to Öland. This example demonstrates the great risk of using only $^{87}Sr/^{86}Sr$ values for migration modelling as many different regions may have similar local $^{87}Sr/^{86}Sr$ baselines. Since $\delta^{18}O$ values appear lower (more negative) in that study than the baseline for Öland, it is unlikely that a great deal of the population, from $^{87}Sr/^{86}Sr$ seemingly local to Öland, could have originated from the southern Baltic shores instead. However, at the moment, the temporal variation of $\delta^{18}O$ levels is poorly understood and the definition of $\delta^{18}O$ baselines is more complicated than that for $^{87}Sr/^{86}Sr$. As the samples from Estonia are slightly older than the bulk of the Öland samples, it is thus risky to use this difference in $\delta^{18}O$ as a reliable indicator. There is a real danger in relying simply on $^{87}Sr/^{86}Sr$ isotopes for provenance, as in Paper II, but I argue it is not necessarily sufficient to rely on $\delta^{18}O$ as well if not taking into account the temporal factor for climate variations. It is a problem for $^{87}Sr/^{86}Sr$ studies in general in Europe that the $^{87}Sr/^{86}Sr$ variation is not yet mapped in more detail. The constant accumulation of values in the last few years is offering a promising development, however.

In this case, contrary to the dietary isotopes, the $^{87}Sr/^{86}Sr$ values of animals from an earlier study gave very similar, indeed virtually identical, results. This fits with the assumption that animals assimilate $^{87}Sr/^{86}Sr$ similarly, regardless of time. Moreover, this earlier study also made the large variation of bioavailable $^{87}Sr/^{86}Sr$ on Öland apparent, despite a very simple unvaried geology. It also indicated how important it is to take many samples and not just a handful from any given region. My interpretation of the variation in bioavailable $^{87}Sr/^{86}Sr$ on Öland is that it is dependent on the complex soil composition on the island, resulting from the transformation of the land surface as the ice cap was moving over and then melting away from it, bringing other, older bedrock from adjacent areas with it. As $^{87}Sr/^{86}Sr$ variation is usually attributed to geology (whether verified by bioavailable values or not) and bedrock, it is a somewhat controversial hypothesis that, if correct, would potentially be a complicating factor for all $^{87}Sr/^{86}Sr$ studies dealing with areas affected similarly by the ice cap. Also, the suggestions concerning the importance of using large numbers of animal samples and taking into consideration the soil variation could be considered contributions to $^{87}Sr/^{86}Sr$ discussion in general, and not just on Öland.

6.1.3.3 Why were the women so mobile in the Late Iron Age?

As concluded in papers II and IV, based on the remains of uncremated individuals, there was a great increase in the rates of immigration to Öland in the Late Iron Age compared to the Early period which was suggested to result from the introduction of boat sails in Scandinavia. The approach in Paper IV allowed us to establish that women in particular arrive in Öland to a greater extent in the Late Iron Age. They are the reason immigration doubles at this time in comparison to the Early period. What is even more curious is that, as a group, the women do not increase proportionately to the men compared to the Early period.

This means the cremation burial practice, even if assumed to apply only to local women, cannot explain this change. There is a big overrepresentation of non-local women in the Late Iron Age regardless of potential biases. Below, I will suggest some possible explanations.

Using the Early Medieval period as an analogy, along with its view on female social roles, could give one possible explanation for the situation on Öland. The presence of marriage exchange amongst the higher social classes – where women moved away from their homeland to form new alliances – meant that women in particular were both participants and orchestrators with political ambitions of their own (c.f. discussions in Hermanson, 2000). This practice is set in a patriarchal system where power is inherited from father to son. According to Hermanson (ibid:8), this is introduced in the ninth or tenth century only to the highest social strata in Scandinavia. It is a possibility that the women immigrated to Öland as part of the building of alliances between families by marriage. Nevertheless, the proportion of non-local females within the female population is so high that marriage exchange alone seems an insufficient explanation.

Jesch (e.g. 2001) has emphasized the connection between women and ships. She presents women as actors travelling on ships, as owners, and as active traders in the Viking Age in Scandinavia based on written sources (mainly rune stones and sagas, c.f. ibid, 1991). In the Viking literature of late, Price (e.g. 2014) in particular has highlighted that women travelled and engaged in piracy and Viking exploration, roles that are likely underestimated today. There are other discussions of Viking travel in connection with high social status that either do not mention gender, or mention only males. For example, Ashby (2015) emphasizes "stranger kings" (i.e. males) instead of a more gender-neutral denomination such as "ruler", for example. Dobat (2015) also discusses high social status acquired through travelling as a male phenomenon. In contrast, I would argue that the idea of travelling as a means to improve one's social status during the Viking Age could apply to women as well, maybe even "stranger queens" instead of kings. The data from Öland, here interpreted as showing a much greater level of female mobility than male, does not challenge the idea in current research that higher social status and travelling are connected, only the notion that it would apply primarily to males as indicated by some authors. Based on Öland, I suggest that women travelled to at least a similar extent, but clearly migrated to an even greater extent, and that they could acquire higher status from doing so.

Of the high-status individuals whose sex was identified (see Paper V for detail), two were female, three were male, and all were non-local. The numerous incidences of written accounts of powerful queens, as well as the archaeological finds of richly equipped female graves in Scandinavia, are convincing pieces of evidence for a female status that could be very high (e.g. Jesh, 1991; review in Lihammer, 2012). Other earlier cases have also revealed women of high status as migrants and travellers (e.g. Frei et al. 2015), whilst other cases from this very time period reveal women at the top of the social ladder (Christensen et al., 1992; Nyhlén & Schönbeck, 1994; Svanberg 2003). The remarks from Jesch (2001) and Price (2014; compare also Streiffert Eikeland, 2014) which connect maritime communication with significant female mobility can thus be given support by the results from Öland. Along with Gardela's (2013) discussion on female warriors, this research presents quite a contrast to other recent research which presents women as passive, and as being retrieved to the homelands (e.g. Barrett 2008, 2010). The retrieval of non-local women would be caused by an apparent deficiency resulting from infanticide of girls (Barrett, 2008). I find it curious that a selective infanticide practice is the only explaination for a deficit in women while the possibility of women actually moving away is not considered. I assume that such a practice of infanticide would indicate a lower social status of women, such as in societies where this is practiced today. As argued above, based on evidence from other archaeological sources and from Scandinavia generally, women could clearly have a very high social status during this period as well as being able to travel.

Why were women so mobile in the Late Iron Age on Öland and not the men? There is no simple answer to this question. It could be a combination of the explanations suggested above relating to status, general greater mobility, marriage alliances, or something different. Many new questions are also unanswered, such as where are the remains of the local women? And why did men not migrate to Öland to the same extent? It is for future studies to answer these questions. ^{87}Sr/^{86}Sr isotope analysis of the cremation burials might be one way of increasing the understanding of the situation on Öland in particular.

Rethinking society 6.1.4

Integration of non-locals: conservatism or creolization in the Late Iron Age? 6.1.4.1

The differences detected, regardless of archaeological sources used, clearly indicate that society on Öland in the Late Iron Age (primarily the Viking Age) was different from in the Earlier period. In particular, migration pattern, diet, burial practice and hierarchy highlight these social changes. The migration pattern showed a great intensity, with the majority of the population – almost 70% – not being local to Öland (in Paper IV). It is important to bear in mind that this is the proportion of the population not cremated and as such is possibly a misrepresentation of the entire population. However, as there are almost double as many inhumations (Table 2) as cremations dated to the Viking Age on Öland (although I can add even more inhumations with the ^{14}C dates in this study), it is unlikely that the proportion of locals would be comparable to the non-locals even if all cremations turned out to be local individuals. The very large proportion of non-locals is therefore probably indicative of a society with a large rate of immigration during this period. What effect would such a great rate of immigration have on society?

As a group, the inhumation burials are much more diverse in the Late Iron Age on Öland (orientation, use of cists, coffins, etc.) than in the Early Iron Age, which on its own indicates a more diverse society. The variation in ^{87}Sr/^{86}Sr origins is similar to that found in the Early period but the δ^{18}O values also show some apparently more distant migrants than in the Earlier period, from both the south and the north/east. The proportion and variation in provenance of migrants is therefore much more apparent in the Late period, and the non-locals appear to be a highly heterogeneous group with relation to geographical origin. Creolization as a phenomenon is similar to that of multi-ethnic communities but is characterised by "cultural borrowing and blending, a fusion of disparate elements of culture both heterogeneous and local in the creation of new forms and practices" (Naum, 2008:174 and references therein). In contrast to borrowing and blending, there is the concept of conservatism. In his analysis of Viking Age burial practice, Svanberg makes an especially interesting conclusion in comparing Öland to other South Scandinavian regions:

> [T]he different collective ritual practices most probably reflect the living side-by-side of specific groups of people who shared common settlement district but saw themselves as different from each other and found this difference so important that different ritual practices were followed. One possible interpretation would be that this reflects a more or less massive immigration of people from somewhere else who chose to continue over a long period of time to practice old traditions specific to them rather than adopt the traditional practices of Öland. (Svanberg, 2003: 174).

This raises the question of what would constitute "traditional practices" in Öland: inhumation, or cremation, or both (a bi-ritual practice)? In the centuries leading up to the Viking Age, cremation burials appear dominant but there is a very small, but still present, bi-ritual element throughout these centuries also (c.f. 2.3.4, Table 1). Even before, and leading up to the third century AD, many more burials are inhumations and the majority of these are also locals. It seems Öland's history of being bi-ritual is a very old tradition going back at least to 500 BC and, to a lesser extent (more cremations), being present only between AD 200–800, leading up to Svanberg's period of focus – the Viking Age. The inhumations in the Late Iron Age are therefore likely to stem from the large immigration. Indeed, I found a very large proportion of non-locals in this same group but there is no apparent correlation with any specific variants in burial types (orientation, for example) and a specific geographic indication (Paper IV, either in $^{87}Sr/^{86}Sr$ or $\delta^{18}O$). In my opinion, Svanberg's idea of conservatism, in which rituals from the homeland are preserved, is difficult to prove with the evidence from Öland in this study. Individuals of very different origins (geologically and geographically) still have very similar burials, making it quite possible, even likely, that they did not share a homeland tradition and yet, despite this, were still buried in a uniform way. Instead, I would argue that as a result of living side by side (as also argued by Svandberg), creolization has resulted in a complex burial practice where some aspects do not necessarily match the homeland practice, but are instead mixed and influenced by each other.

Another interesting discovery in this study, resulting from the new ^{14}C dates, is on the re-use of cists for inhumations in the Late Iron Age. In particular, there is one example (ID 1105, 1106) where a non-local individual was buried in a cist atop the much earlier (at least several centuries older) burials which were still present. The importance of connecting to the ancestors through burial practice, which this is an expression of, is a feature discussed before for Late Iron Age Scandinavia (e.g. Hållans-Stenholm, 2012). The physical reconnection of being buried in an old grave fits with Naum's conclusions for Late Iron Age Bornholm, another Baltic island. She suggested that "...relation with ancestors [has] a critical meaning for social reproduction and with continuity of a place (be it a place of settlement or a place of eternal rest) being a physical and social expression of continuity." (Naum, 2008:197). Non-locals being buried in the same grave as ancestors that they probably had no relation to could be a way for non-locals to claim the new home as theirs, a blending of rituals that I argue could also fit with the concept of creolization.

Diet shows a variation in Late Iron Age Öland similar to that found in the large trading centres of Birka and Haithabu (see 5.2). This variation, especially if emphasising the cultural aspect of food, could be seen as an expression of the long-distance contacts. The generally diverse diet in the Late period in Öland cannot be solely attributed to non-locals as the locals also show a varied diet. Rather, like burial practice, diversity seems to be an overall pattern. I interpret the diverse choice of subsistence and diet as evidence of a tolerance for other cultural expressions and ways of life which is much more apparent than in the earlier periods on Öland. I also interpret this as an indication of creolization within Viking-Age society on Öland.

6.1.4.2 Hierarchy and violence: a shifting society? Kin or new money?

The lack of cremations in my material means that I study only part of the population but clearly the larger part in the Viking Age (as argued above), if not for the rest of the Late Iron Age. In terms of material wealth there seems to be no difference between inhumation and cremation in Viking Age Öland, contrary to Southwest Scania and Denmark where the cremations are comparably poorer (c.f. Svanberg, 2003:173f). This is an interesting observation in comparison to Paper V, where I concluded, though based solely on the inhumations, that the locals and non-locals did not differ in social status or wealth. The non-local inhumations presented individuals of possibly even higher status in the Late Iron Age in comparison to the locals. Could it be that with the large immigration – the arrival of rich migrants, perhaps – that Öland's society became less focused on land as organised very strictly in the past, potentially by birthright, and more on material wealth, where land could also be claimed by those not born on the island? Was the potential significance of birthright to land and kin diminished at the same time as immigration increased, or were these two separate occurrences?

Based primarily on burials and artefact determination of gender in Öland, Räf (2001) suggested that a social change around AD 200 resulted in a more patriarchal society. I argue this could fit with the patterns of violence, and deadly and excessive uses of force, including upon older women and men up to AD 200. If violence is regarded as a form of renegotiation of social status, as in modern social theory (c.f. discussion in Paper V, based on Nordström, 1998; Scheper-Hughes & Bourgois, 2004), then it would be primarily directed at those in positions of high social power – leaders. In turn, this would mean the victims of violence were those with social power for the taking. For Öland, I argue this is an indication that women, as well as men, could have great social power, at least up to AD 200. Moreover, it demonstrates that older individuals of mature or even old age were powerful. Older leaders, and of both sexes, would fit well with a kin-based society. Should a patriarchal society be assumed also in cases where the head of the family dies, leaving a male child as heir, the widow would step in and take the role of family head instead (c.f. discussions in Gustin, 2009, on medieval Scandinavia). A kin-based society, patriarchal or not, would also correspond well to the strict organization of settlements and graves (Fallgren, 2006) on Öland. For the earlier part of the Iron Age, I consider the society to be highly controlled (evident in diet, for example, but also landscape organisation of burials and settlement). The comparably low proportion of non-locals in the early Iron Age allowed for the perpetuation of a kin-based society on the island, with social competition for resources possibly an issue as population increased. Sometime after AD 200, I hypothesize, this society was replaced by one which was more warfare-oriented, where young men were those subjected to, and likely carrying out violence. This could be seen as an increase in military organization, indicated, for example, in war spoils that occur in Öland after AD 200 (Hagberg, 1967). The focus on military power could also be supported with the occurrence of the ringforts on Öland. Although the fort dates could be older than AD 200, most are considered to be from AD 200–700 (Fallgren, 2009). It is also possible that young men from Öland went to the Roman Empire to serve as mercenaries (suggested by Herschend 1980, 1991) and came home not only with wealth, but also with a new view of how to get social power, i.e. taking it by force instead of acquiring it by birthright.

The case of the woman who was over 60 years old and who was killed with excessive force and buried, or possibly concealed (ID 1094), is of great significance. I interpret her death as indicative of a woman of very high social status, most likely a powerful leader. This is a new and different type of evidence, derived from the human remains directly, rather than those presented before for Öland of powerful women in the Early Roman Iron Age. Previously, Hagberg (1987) had suggested that the occurrence of half-moon knives during this period should be understood as indicating the high social standing of some women. With this new evidence, I would take this even further and argue that women could not only have a high status but also great social power, even being leaders during the Early Iron Age.

6.2 New questions resulting from the human-centred approach

I have detailed above how the human-centred approach has resulted in a rethinking of the four major themes which I chose to investigate and of the people and society in Iron Age Öland. Furthermore, the results of the new chronology (based in ^{14}C) presented here raise new questions and call for another discussion.

6.2.1 A new chronology from human remains: rethinking settlement and population on Öland?

The ^{14}C dates of both dated and undated graves have shown the burial practice in Öland to be more complex than is often assumed. One and the same cist could contain multiple individuals spanning a thousand years so that not only the grave fields, but even one and the same grave is reused over and over. This has implications for all burials but primarily reveals that a burial form, the cist, could have been in use much longer than was previously possible to establish. Moreover, this discovery warns that all dating of human remains without a clear relation to artefacts is questionable. This means it is imperative if studying human remains (and isotopes, for example) to know whether these remains are in fact just from one burial or are possibly one of many burials related to the artefacts. This discovery thus has wide implications for many earlier studies relying on the established relative chronology from burial form (as detailed in Paper III).

6.2.1.1 A population decline?

With the revised chronology from ^{14}C from this study, the idea of the undated burials as compensating for the decline in the Late Roman and middle periods (Migration and Vendel periods) as previously thought needs rethinking as well. This means that either there was a decline in population starting sooner than previously anticipated at AD 200, or that there was a more abrupt shift to cremation (and undated burials) or other burial rites, leading to these graves not being detectable. The detectable burials (both cremations and inhumations) decline at the same time that the extensive stone foundation house settlements, partitioning systems, and forts are argued as being built, just after the period with the greatest number of confirmed burials (the Early Roman period). As discussed before, the burials are considered to be linked to the houses as there is some continuity in terms of spatial relations (Fallgren, 2006) making this mismatch in chronology of settlement and graves a problem. An easy explanation, in my opinion, would be if the houses could be older than is assumed today. The comparably few dates are dependent on secondary sources (artefacts and analogies) and it would seem likely they were contemporary to the many earlier inhumation graves dating to before AD 200. As shown here, for example, in A 108 (ID 1024, 1105, 1106), the grave fields were clearly in use and even re-use well before AD 200 and since they correspond to settlements, this also indicates the settlements to be older. Svedjemo recently renewed this discussion of the potentially earlier dates for these types of houses, in Gotland and elsewhere (see discussion in Svedjemo, 2014:60). He added some more recent examples of houses of earlier dates (before/around AD 0 from ^{14}C), concluding that they are more than just anomalies (Svedjemo, 2014:60) and should be considered in more detail. However, he considers them as possible cult houses rather than settlements due to construction in Gotland. The partitioning of fields is a feature also spatially concurrent with the house foundations on Öland and is generally dated to the same time as these houses (as detailed in 2.3.1). Recently, partitioning was determined as occurring in Scania already in the late Pre Roman–Roman period (200 BC–AD 300) when settlements were focused in a village-like structure. The need to separate one's estates from the common, or other estates, is clearly expressed this way (e.g. Friman, 2008:103ff; Björhem & Skoglund, 2009:21ff). Considering the great number of burials on Öland from the Early Roman period (up to AD 200), this could be seen as an indication of a large population and potentially as a competition for land that could have made this division necessary to manifest earlier here, as in Scania.

In addition to the new findings regarding settlement and partitioning chronology (on Gotland and in Scania), I argue that the shift in diet occurring on Öland in the final centuries BC requires a debate on the dates of both stone-house foundations and the partitioning systems in Öland. The dietary isotopes are interpreted as evidence of a greater reliance on domesticates which starts around the final centuries BC – a finding that would fit well with the introduction of the partitioning system occurring at this time. This would mean both the houses and partitioning systems would be at least 200–300 years older than currently believed. The human-centred approach has thereby resulted in the need to question what have been seen as established facts based mainly on analogy and relative typology rather than on specifics such as ^{14}C dates.

6.3

Going to and beyond the humans: limitations and advantages of a human-centred archaeology

6.3.1

Specific limitations of the human-centred approach for Öland

The most obvious limitation with the human-centred approach, which has been applied here only to uncremated human remains, is that the source material is biased. This is true for archaeology in general, of course, by the very nature of all materials. The proportion of the living population who have entered the archaeological record in a way that means their skeletal remains were discovered, excavated, and curated in a museum, is most likely very small. A pressing limitation in this study of Öland is the lack of possibility of integrating the cremation burials as these represent a significant proportion of the population. The proportion of misrepresentation from the inclusion of only uncremated remains is varying throughout the Iron Age on Öland, but is an especially (and unfortunate) great loss in the middle Iron Age despite efforts to identify these periods with the extensive ^{14}C-dating campaign in this study. Especially in terms of trying to understand the change to a more intense immigration in the Later Iron Age is this lack of uncremated human remains problematic. It is not possible to pinpoint when exactly the turning point is. It is defined here as AD 400, the start of the Late Iron Age, but it might, in fact, be centuries later, for example AD 800, when inhumations become frequent again. However, to some extent, future studies could investigate this as ^{87}Sr/^{86}Sr analysis can be performed on cremated bone today, filling this gap in knowledge for Öland. Another option could be to look at the genetic variation in the population before AD 200 and after AD 800 to see if there is any difference, for example, whether there has been a population replacement.

Another misrepresentation is the fact that children are not included in this approach. To be more accurate, the small children that died in childhood are not included (c.f.

the osteological paradox as discussed by Wood et al., 1992; Knudson & Stojanowski, 2008) but the children that lived and went on to become adults, dying at a later age, are very much included. The commingled human remains, acting as singular or multiple skeletal elements primarily in the cist burials, are also a proportion of the population inevitably lost. As it turns out, from the results in this study, they would be very costly to investigate since this would require extensive ^{14}C samples which are very expensive. Without a secure date, they would not, in my opinion, be useful for any interpretations relating to the Iron Age society.

Another limitation in this study is the reliance upon only a few isotopes when there are more options at hand. New isotopes for geological provenance, such as lead (Pb), could help considerably in understanding migration better (c.f. Chenery et al., 2014), as could larger DNA studies on a continental (not just regional) level. Diet could also be addressed with other isotopes or tissues, such as bone apatite $\delta^{13}C$, which could help establish the proportion of carbohydrates in the diet (determining whether it is as low as I interpret it here) and see how it corresponds to the changes in $\delta^{15}N$.

6.3.2 Specific advantages of the human-centred approach for Öland

The new way of approaching archaeology on Öland – a human-centred archaeology – gave new insight into society and other archaeological evidence. The approach has shown potential that can also be of interest for other studies. In particular, it allowed for:

- the integration of isotope study, archaeology, and osteology;
- the study of the society of lesser known periods (such as the Pre Roman period on Öland);
- the transcending of relative chronology and the challenge of the periods as necessarily corresponding to local socio-economic watersheds (for Öland in particular, the dietary change in the final two centuries BC);
- a deepened understanding of the context of death (*mortographies*), as well as the possibility for revealing new information on the sequence of events forming the specific archaeological record;

- integration of field and laboratory osteology in a reflexive approach more comparable to that found in archaeology;
- the demonstration that interpretation is an integral part of isotope studies, both for diet and migration, and that it is clearly negotiable, which is rarely expressed clearly within specific isotope studies;
- the construction of a new chronology, challenging preconceptions by dating previously undated material or erroneously assumed uncomplex typological dates by burial form;
- the challenge and confirmation of some of the existing interpretations of society and hierarchy in Öland, particularly the roles of women.

In my opinion, the limitations of human-centred archaeology are balanced by the many advantages it demonstrates, as fulfilled in this study of Iron Age society on Öland. The new results from this study have added to the understanding of multiple aspects of the life, death, and development of the island during the previously unexplored period. The many new questions that arise from these findings are a further advantage. What happened to the population after AD 200 and was there a depopulation at this time or later on in the sixth century? When was the partitioning system introduced in Öland and was it in the final centuries BC as this study suggests?

CHAPTER 7

Conclusions

In this study, a human-centred approach to society was applied to Öland during the Iron Age. Four different themes were studied (taphonomy, diet, migration, and social organization and hierarchy) which focused on human skeletal remains. The study took an interdisciplinary approach, and interpretations given, and the use of different methodologies and aspects of the human skeletal remains, all resulted in entirely new conclusions, calling for a rethinking of past approaches and, in some cases, the consolidation of some earlier research.

In exploring the first theme, a new methodology, *Virtual Taphonomy*, was devised in Paper I. This gave new information relating to the site formation process which is crucial for its interpretation and which, so far, has been unattainable through other methods. It was also an important contribution to osteology and archaeology, emphasizing the potential in osteological fieldwork, as well as lab analysis, for both osteology and archaeology. A potential that can be curated despite limited time and resources is therefore relevant to the field at large. The digital methods also facilitated the addition of a further reflexive step in the analysis when integrating lab osteology with the archaeological context revisited in 3DGIS. Furthermore, this methodology allowed the significance of the concept of *mortographies* to be highlighted; it is important that research considers what happened to a human at the time of, and after, death, regardless of whether the archaeological context is categorized as a "proper" burial or is more complex. This is an addition to the more classic biographical approach in osteology.

Dietary development during the Iron Age could be discussed and earlier conceptions from isotopes challenged while other sources, such as archaeozoological assemblages and interpretations of landscape use, could be confirmed. Here, the chronological development was a major finding as well, proving more complex than previously assumed when given access to a larger number of ^{14}C dates. The previously undated graves showed great complexity in their use and re-use throughout the Iron Age on Öland, to an extent previously unacknowledged. The period poorly represented by graves in the transition period between the Early Iron Age and the Late Iron Age (circa AD 200–700) could indeed be proven as apparent and not just a function of burial customs where artefacts were not included. It is possible this corresponds to an actual population decline or that the dominance of cremation practice is both underestimated and took dominant position over inhumations. DNA, for example, might be able to shed light on whether the population went through a reduction at this time by comparing the Early Iron Age variation with the Late Iron Age.

With regards to migration, the Late Iron Age showed a dramatic increase in immigration where non-locals often appear in high-status contexts. Furthermore, the proportion of female immigrants increases greatly which is suggested to result from the improvement in maritime technology (sails) and an increased female mobility. More important than the size of immigration is also its character which is very diverse, with non-locals from many different areas appearing, both regional and more distant. In addition to this, the burial practice and dietary evidence support an interpretation of the society as one undergoing creolization. All these aspects are also of interest in the current discussions of pirate culture in Scandinavia and its role in the Viking expansions. As an island, Öland would be a suitable base for such activities. The results from Öland thus validate earlier research related to the island, as well as allowing for Öland to be viewed in a larger context where it has not yet been discussed. The two approaches to migration investigated in papers II and IV demonstrated how using just one isotope instead of two could risk the entire basic assumption (that it was just a regional migration) being erroneous. The statistical method, Bayesian mixing, further appears to have reduced transparency as this error could not be found and the results seemed to make sense despite this.

Social organization and hierarchy were shown to be very complex issues when taking a human-centered approach which was highlighted particularly by the dynamic and transparent network approach. The most important conclusions for Öland revealed that there was great complexity in terms of social organization and hierarchy, and that non-locals and locals appear to have had very similar roles. The only exception was during the Later Iron Age when non-locals were more likely to be of high status than locals. In terms of social power, there appears to be a shift dating to around AD 200 when older age (both in men and women) becomes a less significant factor in power holding, and young men instead are those negotiating power within society.

In conclusion, this study has served to show some of the advantages and limitations of a human-centred approach to archaeology, as well as providing some interesting specific results for Öland.

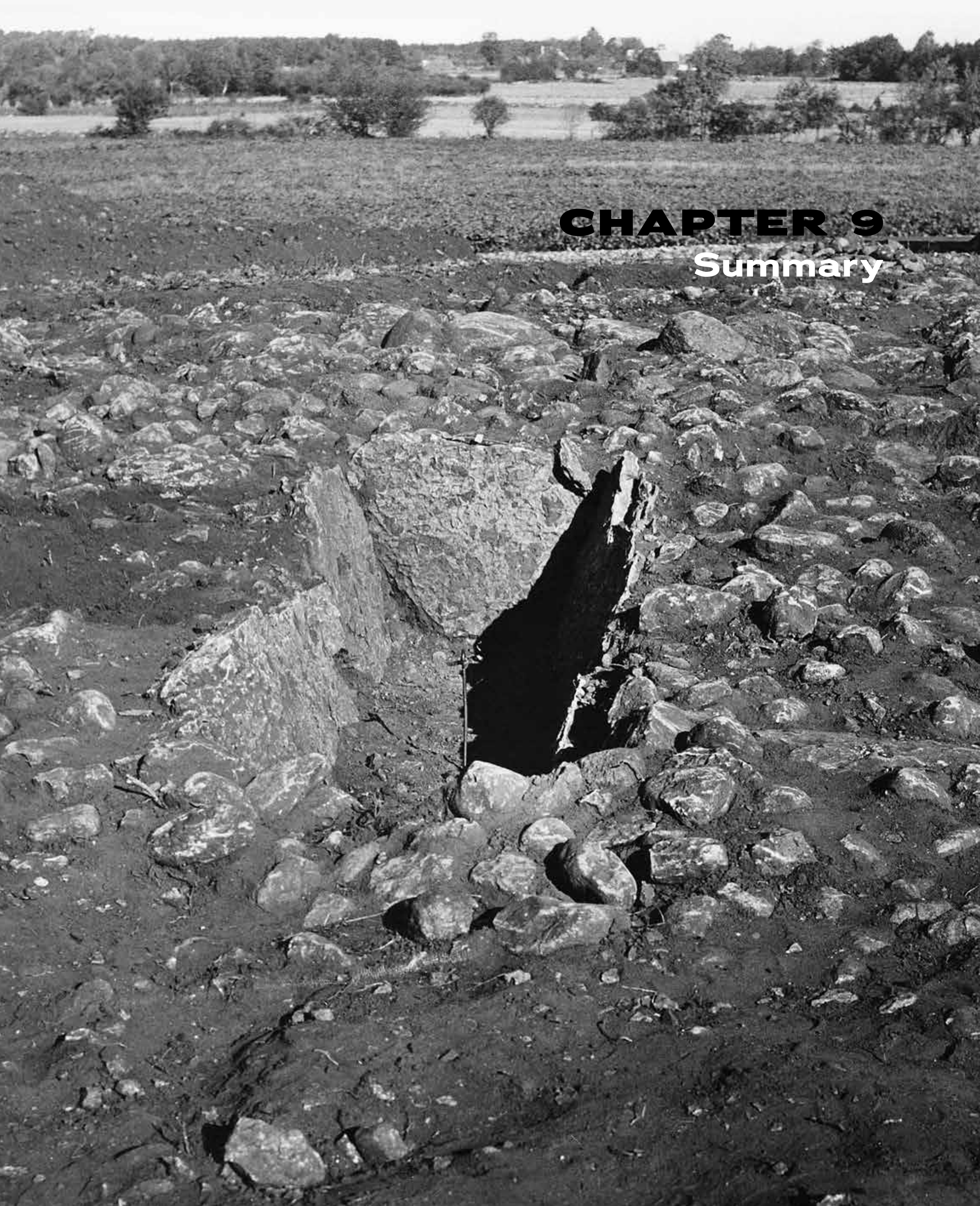
CHAPTER 8

Prospects

Following the results presented here for Iron Age Öland, especially rewarding avenues for future research could be directed as follows:

- investigating cremation burials (especially from the Viking Age) for provenance with $^{87}Sr/^{86}Sr$ isotope analysis
- dating more burials (both cremated and uncremated) and commingled (secondary) individuals by ^{14}C to possibly extend the currently available isotope record (as the osteological value of these individuals is limited)
- investigate chronology of settlements and forts in greater detail with an AD 200 socioeconomic watershed in mind, as well as the dietary shift in the last centuries BC
- should more cist burials be excavated, a detailed taphonomic approach (such as *Virtual Taphonomy*) could help to clarify the reburial pattern and the reopening of them for looting/ritual or other manipulation
- further excavations and studies of archaeozoological assemblages could add more information about diet not only on archaeozoological terms, but also in order to investigate the isotope variation in the species. This could help to better understand the human values and additional DNA studies in line with those of Telldal et al. (2010) for other domesticates
- integrating the isotopic information now available for the first-generation migration with DNA and focusing on genetic indications of regional and local mobility
- DNA could also be useful to investigate the population stability on Öland, i.e. whether there is any significant difference between the Early and the Late Iron Age to further the understanding of the “gap” created by cremation practice for the middle Iron Age. There could be a population shift during AD 200 when cremation becomes dominant, which was before believed to be less abrupt than this study has shown it to be. Another possibility could be later, after AD 500, when a possible drop in population is indicated by a change in settlement patterns and an apparent abandonment of some settlements.

Why do I think you should care that a human-centred archaeology is valuable, and that striving for the best practice of it is important? Because, if done right, human-centred archaeology allows us to connect with past humans, their lives, and their deaths… perhaps even making sense of some things we see today. Moreover, it allows making the past personal and relevant to the present – not only folding back time so we can look at individuals of the past, but, just sometimes, with such striking detail that we can even catch a glimpse of our own selves in their eyes. Looking back. At us.



CHAPTER 9

Summary

I aimed to investigate the possibilities of increasing and deepening the understanding of people, as well as society, with a specifically formulated human-centred approach. Iron Age Öland (500 BC–AD 1050) was selected as a case study for this approach and methodologies were chosen to highlight the diverse information and aspects of society which are possible to study from the uncremated skeleton.

In order to develop and demonstrate the advantages of investigating the skeleton as part of the archaeological context, a new method, *Virtual Taphonomy*, was designed combining elements of osteological and archaeological investigation methods. This method was tested on a case study in Öland, house 40 in Sandby borg, and yielded new conclusions relevant to the interpretation of the site. This analysis alone led to the hypothesis that the site was actively demolished sometime after the attack when the bodies had decomposed, a hypothesis not possible to propose using other archaeological analyses so far. Moreover, this method allowed for the integration of osteology with archaeology using a human-centred approach.

Isotopic analysis of bone collagen, $\delta^{13}C$ and $\delta^{15}N$, was used to study dietary development on Öland. There were clearly changes occurring throughout the 1500 years of the Iron Age. In the Late period, the diet became more diversified which could be part of this development when placed in context with the results of the provenance of isotopes indicative of a considerable immigration. Furthermore, due to extensive ^{14}C dating, a shift in diet could be established as occurring in the final centuries of the Pre Roman period (circa 200–100 BC) rather than, as suggested by conventional typological dates, coinciding with the chronological period of the Roman Iron Age (AD 0). This approach begs the question of whether it is relevant to investigate dietary shifts based on relative chronology at all as this assumes that diet shifts as culture shifts and that these two things are co-dependent. With regards to interpretation of the isotopes into a specific diet, the more recent methodology using a higher $\delta^{15}N$ TLE level proved to concur best with both the archaeozoological assemblages and the landscape partitioning characteristic of the island. This approach, and the different interpretations of the isotope results possible today through experimentation with different accepted values for $\delta^{15}N$ fractionation, allows researchers to question the utility and confidence with which these interpretations are put forward to the scientific community, and especially to anyone not specialized in isotopes.

The analysis of the provenance of isotopes could also be interpreted differently if using just $^{87}Sr/^{86}Sr$, or if including $\delta^{18}O$. The interpretation of these results was also highly dependent on the choice of strategy for defining the local baseline, bioavailable $^{87}Sr/^{86}Sr$, and a methodology which would best represent the complexity of Öland was chosen. This vital element of interpretation of the isotope results is as pivotal for the conclusions as the choice in $\delta^{15}N$ fractionation is for diet interpretation. The great increase in immigration in Öland in the Late period compared to the Early period is an interesting result, especially in relation to two things. Firstly, this is interesting as it is during this period that the greatest diversity in burial practices (especially in the Viking Age) occurs. However, this diversity is not possible to connect to non-locals except for the EW-oriented burials which are all non-locals. Secondly, the diet in this study could be established as much more varied than in the earlier periods. This did not co-vary with individuals being local or non-local, as with the graves. All in all, it seems non-locals were included in society, and included themselves in what appears to be a culturally diverse society on Öland during this period.

With regards to social organization, some changes were concluded from an approach including elements of network analysis and social theory. It was not only locals who could have a high status in the Early period; low status individuals appear as both local and non-local in both periods. In the Late period, high-status individuals appear to be mainly non-local and include both men and women, as in the Early period. The case of a most violent murder of an elderly woman in the Early Iron Age, who was probably a leader of some sort to die in this way, could be used to argue that women were able to have a high social status. With regards to the victims of violence, it could be argued that there was a shift in societal organization, with elders of both sexes having social power up until around AD 200 when the power seems to have switched to the hands of young men and possibly a more military approach was taken towards conflict. The concept of hierarchy could also be considered most complex when viewing aspects of the individuals in relation to their archaeological context.

With the exception of the first theme, taphonomy, the population level on which the results of each theme (diet, migration, and social organization and hierarchy) was approached was pivotal. This approach allowed the complexity in society to be clearly seen by including the different types of burial/disposal of uncremated human remains used throughout the Iron Age. It is no doubt a considerable bias to be unable to include the cremated proportion of the population as well, but at least this human-centred approach allowed as much of the population as possible to be taken into account from all contexts, not just the burials, and included more diverse dates (from ^{14}C) than has previously been possible by artefact chronology. The population level was also pivotal for understanding the proportion of migration, and the integration and effect it had on society. It was also the crucial element in investigating the dietary development over a long-term period. The importance of having a specified chronology (from burial or ^{14}C) and being able to directly relate results on diet, migration, and social organization to this chronology cannot be understated. Contrary to the somewhat unclear (or less specified) chronology of the bulk of other archaeological sources (archaeozoological assemblages, settlement and landscape partitioning in Öland), the human remains allow a direct contextualization and reflect what actual individuals that were part of the society did and how they lived. In conclusion, the human-centred approach allowed the discussions on migration, diet, social organization, and taphonomy to be fully contextualized.

In conclusion, the approaches, the specific methods, and the theoretical considerations used for the case study of society in Öland in the Iron Age gave some new results and called for a rethinking of these methods, as well as raising questions about how human remains are part of such analyses. Some recommendations for methodological practice, based on this case study, could be given that would be relevant to consider in any study of uncremated human skeletal remains. These are primarily to contextualize the interpretations with the human remains, and/or other archaeological sources, and to strive to be more transparent with the interpretation elements in the methodologies.

SVENSK SAMMANFATTNING (SWEDISH SUMMARY)

Detta arbete syftar till att undersöka förutsättningarna för fördjupad och ökad förståelse för forntida människor och deras samhälle baserat på människorna i allmänhet och deras skelett i synnerhet. För att belysa hur olika sätt kan användas för att öka förståelsen för människornas liv och död utvecklade jag en strategi som jag har valt att kalla *människocentrerad arkeologi (human centred archaeology)*. Som fallstudie valdes ön Öland under järnålder (500 f.Kr.-1050 e.Kr.). Det fysiska materialet utgjordes av de obrända skelett som är funna på ön. Fyra teman valdes ut: tafonomi, diet, migration och social struktur. Dessa teman studerades med osteologiska, kemiska (isotopanalyser), digitala metoder (IBM, GIS) av skeletten som kopplades till det arkeologiska sammanhanget, arkeologiska metoder och frågeställningar.

För att utveckla hur skelettet tolkas i relation till dess arkeologiska sammanhang utvecklades i Paper I en metod, *Virtual Taphonomy*, genom att kombinera metod och teori inom digital arkeologi och osteologi. Metoden testades på en fallstudie från Öland, närmare bestämt på två skelett funna i hus 40 i Sandby borg. Den resulterande analysen visade hur nya slutsatser, och en ny fas av reflekterande analys, gav nya möjligheter att förstå såväl skeletten som händelseförloppet i borgen.

Kronologi baserad på relativ typologi (föremål och/eller gravformer) jämfördes med ^{14}C-analyser av skeletten från gravar eller andra kontexter. Detta ledde till slutsatsen att kronologin för Ölands gravar är mer komplicerad än vad som tidigare varit känt. Skelettgravarna var vanliga även mycket tidigt under järnålder och även mycket vanliga under vikingatid. Dessutom har samma gravar återanvänts under hela perioden. Den nya kronologin hade också en stor betydelse för att förstå dietens utveckling.

Diet studerades i Paper III genom att jämföra resultaten från isotopanalyser (δ^{13}C och δ^{15}N) av benens kollagen för människor och djur. Två skiften i diet kunde fastställas, ett under de sista två århundradena före år 0 och ett under perioden 200 e.Kr.-700 e.Kr. Det första skiftet i diet tolkar jag som att befolkningen övergick till att primärt vara boskapsskötare vilket är särskilt intressant med tanke på de mycket omfattande hägnadssystemen på Öland. Genom den nya kronologin (baserad på ^{14}C) var det möjligt att belägga att dietskiftet inte sammanföll med arkeologiska perioder (övergången förromersk till romersk järnålder år 0) utan var oberoende av dessa. Detta resultat problematiserar grundantagandet, som ofta är förknippat med hur isotopanalyser används arkeologiskt, att diet och typologi hänger samman. Jag demonstrerade även det stora utrymme som idag finns i tolkningen av isotopvärden baserat på referensvärden för fraktionering (TLE) och hur detta kunde användas för att finna överensstämmelse mellan isotopresultat, arkeozoologiska (animalosteologiska) resultat och landskapsanvändningen.

Isotopanalyser använde jag även för att studera migration, men då på tandemalj istället för ben. Detta diskuterade jag i Paper II (på en befolkningsnivå), och IV (på individnivån). Det visade sig vara avgörande att ha tillgång till ytterligare isotoper (δ^{18}O) i Paper IV än bara en (^{87}Sr/^{86}Sr, som i II) som är vanligt förekommande inom arkeologi. Liksom för dietisotoper blev det tydligt att isotopvärdena (för ^{87}Sr/^{86}Sr) även här har en oerhört stor betydelse. Variationen i ^{87}Sr/^{86}Sr på Öland visade sig också vara komplex. Definitionen av vilka individer som kunde vara uppvuxna på Öland är därför annorlunda i Paper IV jämfört med i Paper II och en gråzon (för individer som inte kunde bedömas som lokala eller icke-lokala) infördes, till min vetskap, för första gången i arkeologiskt sammanhang. I min tolkning av migrationsisotoperna ökade immigrationen till Öland kraftigt i yngre järnålder (400-1050 e.Kr) jämfört med i äldre järnålder (500 f.Kr.-400 e.Kr). Främst kvinnor stod för inflyttningen och liksom i tidigare perioder kom migranterna från olika områden. Värdena för δ^{18}O visade att människor främst i yngre järnålder började flytta in från mer avlägsna områden, vilket enbart ^{87}Sr/^{86}Sr inte kunde avslöja. Under yngre järnålder blir såväl gravskick som diet mer varierad, för såväl de som växt upp på Öland som migranter. Detta tolkar jag som ett kreoliserat samhälle där influenser från olika håll blandas och just blandningen är det som sedermera blir Ölands signum.

Nätverksanalysen av individerna från Öland i Paper V gav ytterligare en dimension till samhället och problematiserade hierarki-diskussionen. Den visade att såväl lokala individer som migranter kunde ha låg status under järnålder och att framförallt migranter hade hög status under yngre järnålder. Våldsoffer visade sig under hela järnåldern lika ofta ha begravts i vanliga gravar som i andra typer av sammanhang och även i de typiska högstatusgravarna. Offerprofilen tolkade jag även som ett uttryck för ett maktskifte kring 200 e.Kr. I detta skifte förlorade de äldre makten och vad som skulle kunna vara ett släktbaserat system luckras upp till förmån för en mer militärt baserad makt.

Urvalet av individer i hela studien gjordes med tanken att kunna diskutera samhället och inte bara individer. Studien kom att inkludera, såvitt möjligt, alla perioder under järnålder och alla arkeologiska sammahang där obrända kvarlevor förekom. Samhällsnivån visade sig vara avgörande för att diskutera samhällsutveckligen under järnålder avseende såväl diet, migration som social struktur och hierarki. Enda undantaget var för första temat, tafonomi. Källmaterialet som fanns att tillgå för tafonomisk analys var endast tillräckligt för dessa två individer. Sättet att arbeta med en människocentrerad arkeologi som demonstrerats i de olika artiklarna (Paper I-V) gav helt nya insikter och tolkningar av samhällsutvecklingen men även stöd åt andra tidigare tolkningar av Ölands järnålder utifrån arkeologiska perspektiv. De kremerade individerna, som inte ingick i studien då de inte kunde studeras på samma sätt med isotoperna, begränsar tolkningarna. Speciellt under övergången mellan äldre och yngre järnålder lämnar de frågor öppna.

Betydelsen av att kunna relatera tolkningarna av olika typer av analyser relaterade till skeletten till en kronologi som inte var beroende av relativ arkeologisk typologi visade sig direkt avgörande för att nå vidare i förståelse för järnålderns utveckling på Öland. Detta är en avgörande fördel med den människocentrerade arkeologin som utgångspunkt, då benen är en primärkälla för att studera många aspekter av samhället såsom diet, migration och samhällelig organisation.

Denna studie visar framförallt inte bara att en människocentrerad arkeologi kan ge en ny typ av förståelse för samhällen. Den ger också konkreta exempel på hur de metoder som används inom olika områden av arkeologin (exempelvis isotopanalyser, osteologi, digital metod, teori, och nätverksanalys) tvärvetenskapligt kan integreras med densamma i stort.

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PPA – The Paleopathology Association, www.paleopathology-association.wildapricot.org

THE APPENDED PAPERS

PAPER I

Virtual Taphonomy: A new method integrating excavation and postprocessing in an archaeological context

Helene Wilhelmson, Nicolò Dell'Unto

This paper was previously published in *American Journal of Physical Anthropology*, 2015, 157(2): 305–321.

PAPER II

Iron Age migration on the island of Öland: Apportionment of strontium by means of Bayesian mixing analysis

Helene Wilhelmson, Torbjörn Ahlström

This paper was published in *Journal of Archaeological Science*, 2015, 64: 30–45.

PAPER III

Shifting diet, shifting culture? A bioarchaeological approach to island dietary development on Iron Age Öland, Baltic Sea

Helene Wilhelmson

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PAPER IV

Migration and integration on the Baltic island of Öland in the Iron Age

Helene Wilhelmson, Douglas Price

The paper is accepted for publication in *Journal of Archaeological Research: Reports, 12*: 183-196.

PAPER V

Island hierarchy, violence and society: a bioarchaeological approach to Iron Age Öland

Helene Wilhelmson

The paper was submitted to a peer-reviewed BAR conference volume with contributions from the session "Islands and Archipelagos" in EAA (European Association of Archaeology) in Glasgow 2015.

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Virtual Taphonomy: A New Method Integrating Excavation and Postprocessing in an Archaeological Context

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KEY WORDS image-based 3D modeling; 3D GIS; 3D models; burial; osteology

ABSTRACT The objective of this paper was to integrate excavation and post-processing of archaeological and osteological contexts and material to enhance the interpretation of these with specific focus on the taphonomical aspects. A method was designed, *Virtual Taphonomy*, based on the use and integration of image-based 3D modeling techniques into a 3D GIS platform, and tested on a case study. Merging the 3D models and a database directly in the same virtual environment allowed the authors to fully integrate excavation and post-processing in a complex spatial analysis reconnecting contexts excavated on different occasions in the field process. The case study further demonstrated that the method enabled a deeper understanding of the taphonomic agents at work and allowed the construction of a more detailed interpretation of the skeletal remains than possible with more traditional methods. The method also proved to add transparency to the entire research process from field to post-processing and interpretation. Other benefits were the timesaving aspects in documentation, not only in the excavation process but also in post-processing without creating additional costs in material, as the equipment used is available in most archaeological excavations. The authors conclude that this methodology could be employed on a variety of investigations from archaeological to forensic contexts and add significant value in many different respects (for example, detail, objectivity, complexity, time-efficiency) compared to methods currently used. Am J Phys Anthropol 157:305–321, 2015. © 2015 Wiley Periodicals, Inc.

The use of the third dimension in taphonomic analysis of human remains is definitely old news. In 1915 the zoologist/anthropologist Wilder and the geologist Whipple used the relatively new technique of photography in an excavation and achieved the most complete three-dimensional (3D) documentation possible, i.e. bringing an entire grave to the laboratory *en bloc*. This method permits analysis of the movement and decomposition of the human remains and their relation to the archaeological context (Wilder and Whipple, 1917). Today, image-based 3D modeling techniques enable the generation of a 3D scene starting from a series of unordered images (Dellepiane et al., 2012; Verhoeven et al., 2012). Systematic use makes it possible to construct a virtual *en bloc* of human remains in their archaeological context at different steps of the investigation. This facilitates a methodological advance in taphonomic analysis when the 3D surface models, along with the results of the osteological laboratory analysis, are integrated in a 3D geographic information system (3D GIS) and the analysis is conducted in this environment. The authors present this argument in the formulation of a specific methodology, *Virtual Taphonomy,* and demonstrate its application in a case study. The aim is to develop the existing standards by which to study human remains within their archaeological context and to show the potential benefits, primarily within osteology but also between osteology and archaeology, of integrating field and laboratory analysis of human remains.

The concept and definition of taphonomy was launched by Isaac Efremov more than 70 years ago and has since then taken on several and sometimes conflicting meanings within archaeology (for discussion see Lyman, 2010) and in this article taphonomy is referred to strictly in the sense used by Efremov and Lyman (as argued in Lyman, 2010), i.e. including *all* processes affecting animal remains, whether cultural or natural, in their transition from the biosphere to the lithosphere. In taphonomy in human osteology (whether forensic or archaeological) there is considerable focus on the actual bones themselves and the marks of different processes/manipulation on their surface observable in postprocessing in the laboratory (see e.g. Nawrocki, 2009; Marden et al., 2012). Taphonomic analysis of human skeletal remains within the excavation context has been given many names: burial taphonomy, forensic taphonomy, necrodynamics, and *archaeothanatology/anthropologie de terrain*. The first steps in this direction were taken in the early 20th century with the pioneer publication of Wilder and Whipple (1917) on body decay and the skeletal remains in relation to the archaeological context, later named "necrodynamics" (Wilder, 1923), a legacy seldom

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acknowledged in literature on human taphonomy (cf. Buikstra et al., 2003). This area of investigation has been a growing field of interest internationally in osteology, especially in the last ten years (for discussion see Duday, 2006, 2009; Duday and Guillon, 2006; Cheetham and Hanson, 2009; Dirkmaat and Passalacqua, 2012). In the last three decades the French school of *archaeothanatology*, previously *anthropologie de terrain* (based on the work of Henri Duday, cf. Duday et al., 1990) has gained ground, applied in a largely European context (cf. Bello and Andrews, 2006; Gerdau-Radonic, 2008). So far, however, specific protocols and methods for the documentation of the bones as part of an archaeological or forensic context are largely unstandardized and experienced-based (for discussion in a forensic setting see Wright et al., 2005). The information gathered in the field is for the most part observations of anatomical deviances in body (or relative element/fragment) positions, sometimes accompanied by spatial references such as relative location/drawings (Duday and Guillon, 2006:124f), photos or single measurements, and very rarely incorporated in the Geographic Information System (GIS) together with the rest of the archaeological context. Practical issues such as weather conditions, tools available for documentation, and time constraints in a contract archaeology situation always play a crucial role in how the context is documented. In this process information is inevitably lost and the observations made in the field are the subjective selection of the archaeologist/osteologist doing the documentation (and the current research questions) and, as such, complicated for other scientists to evaluate independently.

In the last few decades digital instruments have been employed in archaeology at every level, and their constant use increases the possibilities for researchers and scholars to detect, document, analyze, and visualize almost all the information collected during field investigation and in the postexcavation phase. In archaeological practice, the diffusion of instruments dedicated to documentation and mapping, and the development of visualization platforms such as the Geographic Information System, have given the opportunity to reconstruct and visualize, with high accuracy, the spatial and temporal relations that characterize the fragmented material recovered during the excavation (Katsianis et al., 2008). An important improvement in this direction comes with the development and the introduction of acquisition instruments capable of generating 3D geometrical replicas of the site. Specifically, the increasing availability of documentation techniques, such as image-based 3D modeling reconstructions, permits the documentation and analysis of archaeological contexts during field investigations (Callieri et al., 2011; Dellepiane et al., 2012; De Rue, 2013; Dell'Unto, 2014). Unlike laser scanning, where operation time and costs often discourage use during excavation, image-based 3D modeling techniques enable documentation and processing of archaeological features on a daily basis, providing a complete and detailed 3D geometrical description of the site in a short time and with a low budget (Dellepiane et al., 2012; Forte et al., 2012).

Digital techniques have become increasingly important in dealing with human bones, whether in an archaeological or forensic context, primarily for visualization, or increasingly as a method of documentation and study. In the last few years 3D modeling has been frequently applied in osteology with the use of Optical Laser scanners, computed tomography (CT) or radiography, but so far mainly to describe special cases or single bones. An interesting example is represented by the newly launched website, www.digitiseddiseases.org, where sensitive skeletal collections/specimens and paleopathology references are accessible online for researchers, students, and the public. Photogrammetry has also been explored for osteological purposes, as has CT (and 3D models developed from it) and 3D scans in order to study morphology and dimensions, mainly in special cases (e.g. Volpato et al., 2012; Noldner and Edgar, 2013; Polychronis et al., 2013; Katz and Friess, 2014) or as a means to develop methods such as sex or age determination based on 3D information, primarily based on morphology, in bones (e.g. Shearer et al., 2012; Osipov et al., 2013; Villa et al., 2013).

Digital techniques for recording spatial information about bones in a physical context (e.g. a grave or the like) have been implemented in the last decade by way of different approaches. CT scanning and digital X-ray of urns containing cremated human remains recovered from archaeological contexts have recently been explored in order to study taphonomy, including the spatial relations of the bones (Harvig et al., 2012) in a secondary archaeological context (the pyre being primary and the urn secondary). In a forensic setting, Richard Wright has developed the software Bodies 3D, aimed at reconstructing the 3D disposition of the bones by means of simple geometries creating 3D representations of human remains in a 3D environment (Wright, 2012). Archaeological studies have been using CAD, GIS or 3D models of human remains but without integrating or employing this in a spatial analysis or for the interpretation of the remains (cf. Isaksen et al., 2008; Marquez Grant and Loe, 2008; Ducke et al., 2011; Loe et al., 2014). In the literature one can find descriptions of attempts to document burial contexts using image-based 3D modeling techniques and GIS (Optiz, 2012; Knüsel et al., 2013), but so far this approach has never been explored to highlight and analyze human remains and their spatial relationships within their archaeological context. The spatial qualities of human remains have previously been examined, in archaeological and forensic mass grave contexts, but only as GIS-coded geo-objects used in turn for simplified 3D representation (i.e. reconstruction) as stick figures/cones and not actual models of the remains *in situ per se*. However ambitious these endeavors have been, they have thus far inadvertently viewed the human remains as separate from their physical context and, just as important, as separate from the process of the excavation itself.

This study is the first of its kind to utilize image-based modeling within 3D GIS in an osteological analysis of human remains and perform a taphonomic analysis in this digital environment. Compared with traditional methods, this enables significant methodological and analytical advances. Most imperative is the possibility to revisit the context *in situ* in three dimensions via a 3D GIS platform and the resulting opportunities when integrating the results of the laboratory analysis in the same platform. This allows continuing the analysis and reconnecting context and osteology within a platform designed for complex spatial analysis.

MATERIAL AND METHODS

On the Baltic island of Öland 15–18 ring forts were detected (Fallgren, 2008) of which only one is situated immediately on the coast, Sandby borg—the Sandby ring fort (Fig. 1). The site is a marked elevation with prominent wall constructions and traces of internal structures

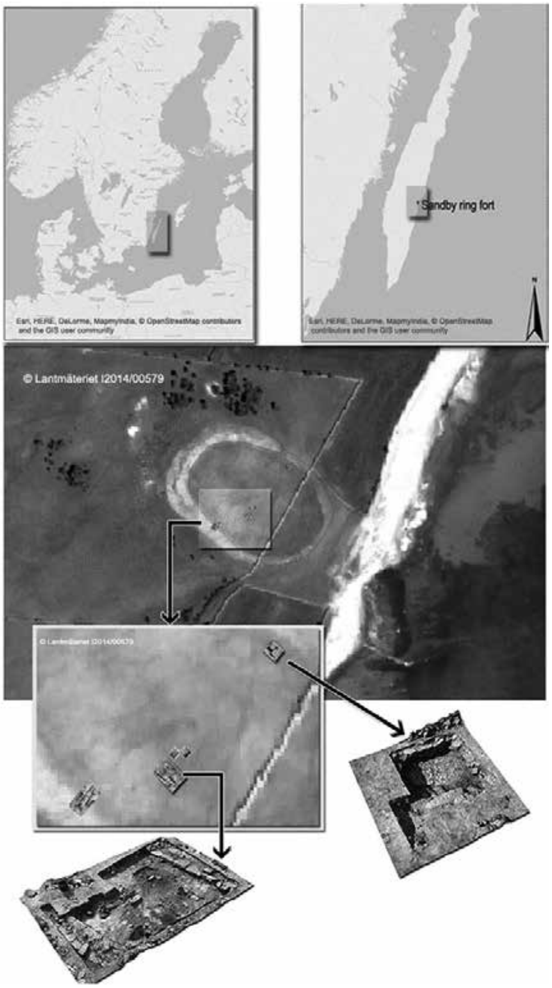


Fig. 1. The location of Sandby ring fort on Öland and the location of part of the 3D trenches generated by the authors and excavated in 2013 by a team led by the Department of Museum Archaeology (Kalmar County Museum). 3D models generated with Agisoft Photoscan Pro, and visualized with ArcScene 10.1.

still visible from the air (e.g. Stenberger, 1933:225f; Beskow, 1996:188). Ground Penetrating Radar (GPR) and magnetometer surveys conducted on the site in 2010–2011 highlighted house foundations remaining between the walls. The site is dated to the late fifth century by archaeological typology (460–490 AD) and C-14 dating of human bone (Viberg et al., 2012:11, 15). The site was excavated by the Department of Museum Archaeology at Kalmar County Museum (http://www.sandbyborg.se) in field campaigns in 2011, 2012, and 2013. The excavations are being processed for publication by Kalmar County Museum, and the only details discussed are specific observations and documentation exclusively connected to the two authors of this article in the excavations in 2012 and 2013 and postprocessing analysis.

In the area around Sandby borg in Sandby parish there are only two excavated graves from the Migration Period (400–550 AD), both in grave fields typical for Öland in contexts with burials from both older and younger chronological burial phases (Beskow, 1996). No uncremated human remains securely dated to this period in the entire island of Öland are currently available for bioarchaeological analysis and for comparison with the human remains from the Sandby ring fort. This is most likely an effect of there being very few clearly dated and excavated graves from the Migration Period despite the large number of investigated graves on Öland (see e.g. Beskow, 1987, 1991; Hagberg et al., 1996; Fallgren, 2001), with the vast majority of these being cremation burials, while the few uncremated burials were very poorly preserved and/or not collected in early excavations (cf. Stenberger, 1933:62ff).

The skeletal remains of individuals 1 and 2 and other human skeletal elements in direct contact with them, as excavated in house 40 (Trenches 2b–2c), are the full extent of the osteological material discussed in this article. In 2011 the feet and a short section of the lower limbs of individual 1 were discovered and partly collected (the left foot and distal tibia) and documented with a few photographs and thus cannot be included in the spatial analysis of the remains explored in this study. The skeletal remains were excavated to the most visible extent and left *in situ* for documentation of the precise physical position of all bones before retrieval in the field campaigns in 2012–2013.

During both the 2012 and 2013 field investigation a systematic acquisition of the different excavation phases was carried out. In order to achieve a more complete overview of the skeletal remains recovered, image-based 3D modeling techniques were used by the authors to generate 3D digital replicas of the site during different stages of the investigation. Specifically, the commercial package Agisoft Photoscan 1.0 (www.agisoft.ru) was used to generate resolute 3D geometries to import and visualize using a 3D GIS, ESRI ArcScene 10.1. This operation allowed i) reconstruction of the entire excavation sequence, ii) reestablishing—in three dimensions—the spatial relations among the different features detected (Fig. 2), and iii) providing a direct connection between 3D objects and their related description (attribute table).

The *Virtual Taphonomy* method

The aim of this article is not only to highlight the osteological material as a dynamic and inseparable part of the context in which it is recovered, but also to actively integrate the results retrieved in field and the laboratory in the virtual context recorded and visualized in the 3D GIS. This operation permits display—in the same 3D space—of most of the information retrieved during the entire excavation, linking together data detected at different points in the process. The creation of such "dynamic" simulations permitted a reflexive interpretation of the materials retrieved on site in relation to the information collected during the postexcavation analysis (Fig. 3). The use of these methods made it possible to take different scenarios into account, creating a very transparent process for other researchers to evaluate and reinterpret. The focus of the *Virtual Taphonomy* analysis can be summarized in three major topics: 1) anatomical representation, 2) fracture patterns, and 3) necrodynamics, which are defined below.

Anatomical representation. Anatomical preservation, i.e. what bones are recovered or not from the

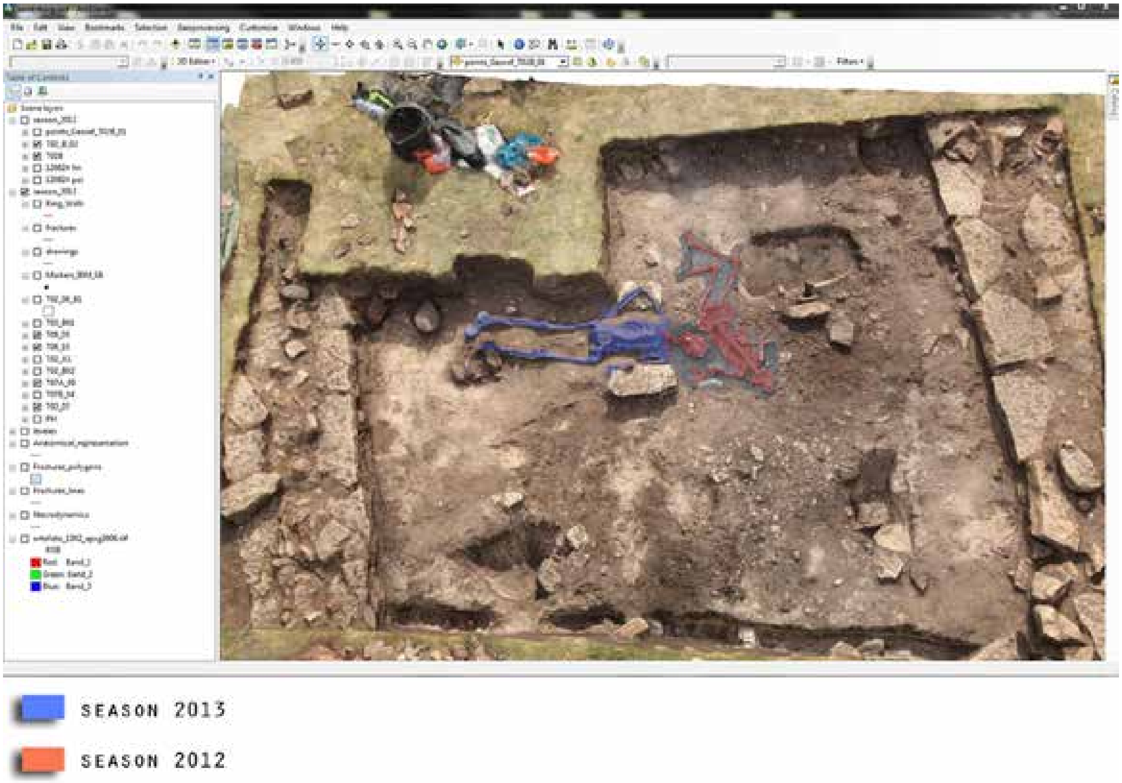


Fig. 2. The excavation process in house 40 is simulated in 3D in ArcScene. The scene is composed of 3D features belonging to the same phase that were identified and removed during different stages of the investigation. In the house are displayed: individual 1—excavated mainly during season 2012 and part of individual 2 (in red), individual 2—as the skeleton looked at the end of season 2013 (in blue). 3D models generated with Agisoft Photoscan Pro, and visualized with ArcScene 10.1.

excavation, is one of the most basic types of osteological information. That bones are missing may be due to their differing fragility, the excavation technique employed, or the ability of the excavator to distinguish bone from other elements of the deposit and depositional manipulation by animals, humans, or destruction by depositional factors (root or fluvial activity, for example). Interpreting the pattern of anatomical representation (preservation and spatial distribution *in situ*) is crucial for understanding the anatomical preservation in the context of the physical properties with respect to the decomposition process (the proportion of cancellous or cortical bone, age, and pathology, for example) that could affect the state of preservation of the bones (cf. Bello and Andrews, 2006 and discussion therein). Anatomical preservation was recorded according to the method of a modified API (anatomical preservation index) distinguishing mainly WPB (well preserved bones, i.e. 50% or more present) as one group and less preserved as one group (Bello and Andrews, 2006:3). In the discussion of anatomical representation, anatomical preservation will be included with spatial distribution (i.e. bone displacement).

Fracture patterning. The bone fracture patterning is also an aspect of the human remains that might have a spatial relationship and be useful in a taphonomic analysis. A recent study investigating the correlation between blunt force trauma characteristics, bone moisture content and postmortem interval found an overlap of occurrence of some features of the "classical" definitions of dry and fresh bone fractures (Wieberg and Wescott, 2008). Wieberg and Wescott concluded that the fractures most likely to be correctly classified are the dry bone fractures (frequently denoted breaks instead of fractures to distinguish them from ante- and perimortem trauma in the forensic literature) with right angles and a jagged surface, and these also most likely reliable considering the purely mechanical properties of dry bone as well (cf. Symes et al., 2012:348f). Fractures with these characteristics are therefore singled out as the most significant group in establishing postmortem changes in the subsequent analysis and hereafter denoted dry fractures.

Some bones show a chipping (triangular/limited loss of bone directly related to the fracture) in the fracture site, indicating contact with a harder surface, in this study denoted as *fracture loading point* (FLP) (Fig. 4). The question of a limited area of impact is of potential interest in interpreting the fracture patterning, and this is included in the fracture pattern analysis to test for possible correlations within the context while *in situ* via the 3D GIS. The identifications of fractures in terms of dry fractures and FLPs was made in the laboratory analysis

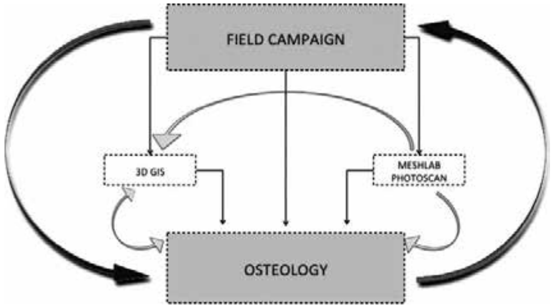


Fig. 3. This image presents a schematic view of the process developed and tested as part of this research, i.e. *Virtual Taphonomy*. The archaeological material retrieved during the field investigations was initially integrated and studied by different researchers in the Osteology Department, the 3D GIS system and the visualization in Meshlab, developed by the Digital Archaeology Laboratory, Lund University. Once integrated and studied, the information previously retrieved was imported into the GIS for the 3D spatial analysis and interpretation of the results.

and this information was entered in the 3D GIS database created for this purpose.

Necrodynamics. The movement, necrodynamics, of the individual bones as a body decomposes and disarticulates in becoming skeletonized is a complex but nonetheless potentially extremely valuable source of information. The basic principle is, in the words of Roksandic: “Amplitude of movement, i.e. displacement *in situ* from the original position, will depend upon the position of the remains, as deposited, and the available space in which the movement takes place” (Roksandic, 2002:103). This is a very dynamic concept as the available space is not a constant in the process of decay but a changing entity due to both internal (i.e. space appears as the soft tissue decomposes at different rates throughout the body) and external factors (external structures decomposing in different rates, or slowing down the decomposition of the body or parts of it).

Necrodynamics as a concept was defined by Wilder (1923:197f) but it is currently often employed in the form of *archaeothanatology*, although—curiously—this specific method does not acknowledge this (Duday et al., 1990; Duday and Guillon, 2006; Duday, 2009). According to the method of *archaeothanatology*, the joints of the human body can be divided into more or less persistent (stable and labile) articulations which in turn permits one to interpret the sequence of these movements (Duday, 2006, 2009; Duday and Guillon, 2006). The articulations in this study were classified according to the definitions and recommendations in the literature (of Duday and Guillon, 2006) with the addition of comparing minor anomalies in articulation to overall patterns for a larger anatomical unit such as an entire lower limb. The degree of articulation was observed during excavation and the articulation patterns were analyzed within the 3D GIS, integrating the virtual archaeological context in the analysis.

3D GIS application. To link the information acquired in the laboratory analysis to the spatial context of the human remains available in the 3D GIS, the authors designed a Geo database management system (GeoDBMS) using ESRI ArcGIS software, ArcScene 10.1. The current 3D Analyst extension makes ArcScene 10.1 a highly suitable environment for this specific type of 3D geo-spatial analysis. For the purpose of extremely detailed analysis (for example the gnaw marks) the high-resolution 3D models (1,000,000 points) were observed in MeshLab, an open source mesh processing tool (Cignoni et al., 2008) used during the experiment for confirmation of spatial relations. The results of the observations made using MeshLab were subsequently added in the database ArcScene together with the rest of the data. 3D polylines and polygons, directly applied over the georeferenced 3D geometries, were linked to an attribute table designed to describe the information retrieved in the laboratory, including the fracture patterns, anatomical representation, and necrodynamics.

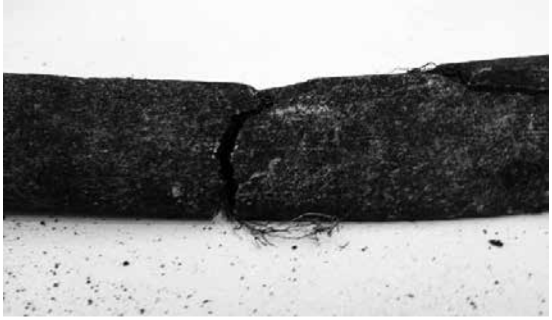


Fig. 4. The right tibia (viewed laterally; posterior is up, proximal to the right) of individual 2 with a fracture loading point, FLP, and associated characteristic transverse dry fracture of the diaphysis.

A 3D polyline was created to map the articulation of the remains. The creation of this layer made it possible to identify and separate the spatial patterns of the differential disarticulation of the remains and different parts of them. A second 3D polyline was created to map and record the anatomical representation of the remains; this procedure permitted estimation of the extent of bone loss in order to interpret the spatial distribution. As a third and final part of the taphonomic analysis, 3D polygons were employed to display bone fractures and their spatial relationships, to permit comparison of the fracture patterning between the two individuals and different elements of them independently. All three different taphonomic themes could also be compared by these methods and, most significantly, be visualized in relation to features in the archaeological context removed at different stages of excavation.

Osteological laboratory analysis and field observations

The results of the osteological laboratory analysis and field observations (performed solely by the authors) presented here are restricted to those most relevant to the taphonomic approach to the case study. Further details, not relevant for the current discussion on taphonomy (such as which weapon/weapons caused perimortem trauma etc.), will be presented in forthcoming publications.

Methods. The age of the two individuals was estimated using the methods of Brooks and Suchey (1990), Buckberry and Chamberlain (2002), and epiphyseal development (Schaefer et al., 2009). Sex was determined using primarily pelvic characters and secondarily cranial features as recommended by Buikstra and Ubelaker (1994). Stature was estimated using regression formulae given in Sjøvold (1990). The measurement used for stature estimation was derived from the femur (maximum length; Femur 1). The individuals were also examined for ante- and perimortem pathology, bone fracturing (including breakage) and any type of surface indication of manipulation by taphonomic agents, aided by microscopic examination when necessary. Anatomical preservation and fractures were recorded and defined as specified in the *Virtual Taphonomy* method section.

Individual 1. Individual 1 was an almost complete skeleton (anatomical preservation specified in Supporting Information 1) lying in supine position with parallel flexed lower limbs. The postmortem breakage of the bones was extensive. The individual was a male aged 17–19 years. His estimated living stature was 171.06 ± 4.49 cm (left femur). The only antemortem trauma was a partial mal-aligned fracture in one of the lower left ribs (rib number not possible to identify due to fragmentation) with callus formation located halfway along the corpus. There were perimortem sharp-force traumatic injuries of the right scapula, the left parietal and temporal (Fig. 5). No signs of healing with remodeling of the margins of any of these injuries, with characteristic sharp force injury morphology, were visible in the microscope.

Fig. 5. Perimortem sharp force trauma of the parietal of individual 1.

Individual 2. The preservation of the skeleton of individual 2 was very similar to that of individual 1 (details in Supporting Information 1), an almost entirely complete skeleton. Already in the excavation it could be observed that the individuals were probably in direct physical contact when deposited (taking the now completely decomposed soft tissue into account), but no articulated bones were overlapping the other individual *in situ*. Individual 2 was positioned prone (and face down). This individual was also a male and slightly older than the first, 19–22 years old. His living stature was estimated at 175.40 +4.49 cm (right femur). He had sustained an antemortem fracture of the right fifth metacarpal, probably a penetrating injury. An unhealed sharp force injury was present in a right rib, from a vertical incision considering wound morphology and probably delivered from the posterior (dorsal) to the interior (ventral) surface. This trauma was perimortem and showed no signs of healing.

The bones were scrutinized in the lab for marks potentially indicative of specific taphonomic agents. Some surfaces were poorly preserved, exfoliated or heavily fragmented and marks ambiguous to interpret, but there is at least one conclusive case of manipulation. Parallel striations clearly indicating gnawing of rodent incisors are present on individual 2's right humerus (specifically located on the margin of the lateral supracondylar crest, Fig. 6). This anatomical location is the location of considerable cortical bone thickness as well as a projection. Depending on which species of rodent is responsible for the gnaw marks, they are usually described as being principally related to acquiring minerals such as calcium from the bones and wearing down their continuously erupting teeth (e.g. Nawrocki, 2009; Dupras et al., 2011:94; White et al., 2011) but have also been associated with the acquisition of nutrients (fat) in the case of the brown rat (Klippel and Synstelien, 2007). When nutrients are the target of the gnawing it is concentrated on more accessible and nutritious cancellous bone (i.e. bones with minimal cortical thickness), and where mineral is the target the focus is directed at the opposite type of tissue, i.e. parts of bones with a thick cortex such as projections. The gnaw marks present in this case appear to have been inflicted in association with a principally mineral-oriented rodent behavior. As established by forensic study trials of decomposition in a natural temperate environment, the gnawing of rodents appears to be primarily in the later part of the postmortem

Fig. 6. The gnaw marks on the right humerus of individual 2.

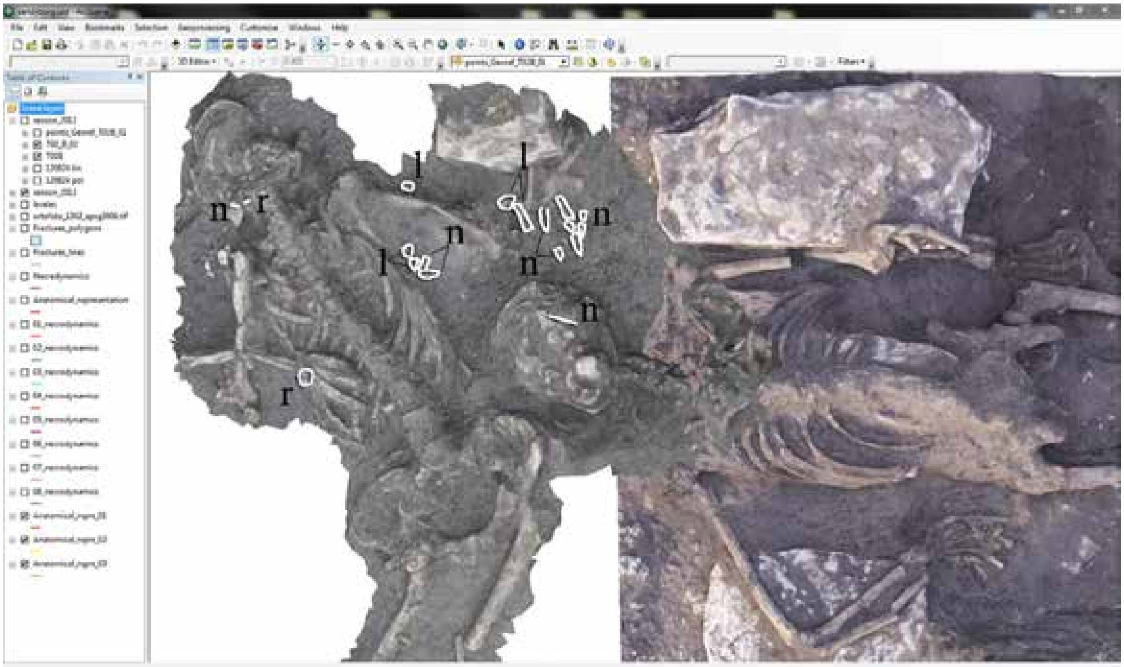


Fig. 7. 3D spatial distribution of carpals, metacarpals, phalanges probably belonging to individual 1 are highlighted in white (r = right, l = left, n = side undeterminable). The hand bones divide along the mid line, probably still perfectly separated into right and left, but apparently disarticulated and with significant loss of bones. This type of spatial anatomical representation could be caused by necrodynamics, manipulation, or possibly excavation factors. 3D models generated with Agisoft Photoscan Pro, and visualized with ArcScene 10.1. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

interval, PMI, in all cases but one only when exposed for more than 30 months (Klippel and Synstelien, 2007:771), i.e. when the bones are no longer fresh but have lost most organic and nutrient content.

RESULTS

The archaeological context in this case is quite complex. The two individuals were found in a house located inside a fort and could be contemporary with the house. If the individuals were killed (as can be inferred from perimortem trauma) and left in the house or possibly buried in an already collapsed house, the taphonomic analysis should be a useful tool in determining the factors influencing the remains as they decomposed and the shifting environments in which this occurred. The major changes to the context, and the order in which they occurred or coincided could be separated based on the following factors:

i. The relative sequence of disarticulation
ii. The timing of the collapse of the house
iii. The compaction of the entire context (house with possible fixtures/structural elements, floor layer, etc.)
iv. Further manipulations of the remains

Generally, since both individuals were young men of very similar size, deposited in very close proximity and most likely simultaneously (i.e. likely direct physical contact) and displaying only minor paleopathological lesions, their taphonomic history could be expected to have been very similar. The perimortem traumatic injuries identified are, however, different and might have played a significant part in taphonomic loss, as these entry points would attract the attention of both insects and scavenging animals (e.g. Haglund et al., 1989), with some authors highlighting penetrating trauma as one of the more significant factors in decomposition (e.g. Mann et al., 1990). The decomposition above ground is different if the individual is in contact with the soil or in the open air, which could hence imply a difference between the two individuals' decomposition patterns (cf. Micozzi, 1986) as one was prone and the other supine, if they were not buried but left on the floor of the house.

Anatomical representation

The anatomical representation is generally excellent for both individuals, even though some bones were very brittle and fragmented due to factors that included moderate root action and crushing. Very few bones are missing entirely, and the recovered bones include even those most sensitive to destruction or failed detection during excavation (see Supporting Information 1 for details). There are some anomalies in the anatomical representation that might be indicative of manipulation during excavation, postburial or preburial deposition by either human or animals.

The forearms and hands of individual 1 are anatomically underrepresented in comparison with the same elements for individual 2. The reason for this is most likely at least partly related to the different necrodynamics influencing the spatial distribution of the forearms. The spatial distribution of the mainly disarticulated forearms

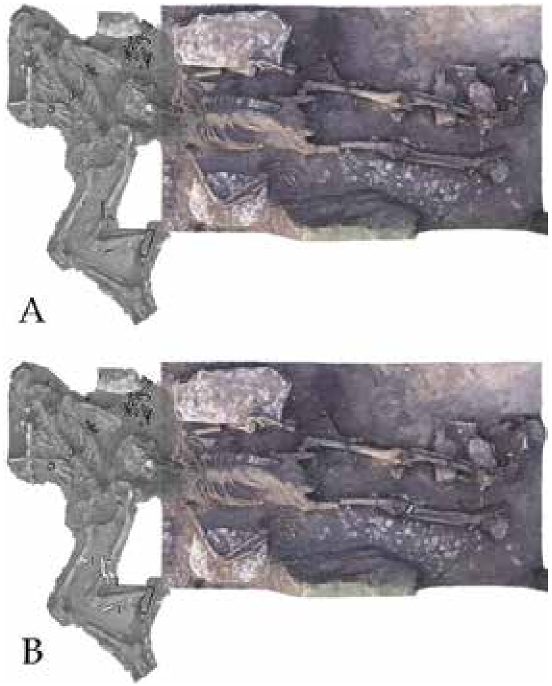


Fig. 8. **A**: The 3D spatial distribution of all bones discovered significantly displaced or largely missing from the analysis (for example the left foot of individual 1 which was collected in an earlier excavation in 2011 and not documented in 3D). **B**: The bones that are uncertain to belong to individual 1 or 2 are highlighted in white: 1 = metacarpal, 2 = ulnar fragment (distal diaphysis, definitely from a third individual), 3 = metacarpal fragments 4 = metacarpal fragment, 5 = proximal foot phalanx. 3D models generated with Agisoft Photoscan Pro, and visualized with ArcScene 10.1. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

and hands of individual 1 is not random, however, clearly displaced some of the elements are. The anatomically sideable elements/fragments indicate a separation of left and right elements to their respective sides in individual 1 (Fig. 7), so at least the two upper limbs appear to not be commingled with each other despite being disarticulated.

There are some additional bones that are not accounted for and others that are clearly out of anatomical order when viewed *in situ* in the 3D GIS (Fig. 8). A distal part of a left ulnar diaphysis was lying over individual 1's left femur with some disarticulated metacarpal and phalanx fragments close by (Fig. 8B). The spatial distribution of the bones and the fact that at least the ulna is definitely from a third individual (since this section of the bone is already accounted for in both individuals) is indicative of manipulation of the context. Another bone with an unexpected spatial distribution is a fragmented proximal foot phalanx recovered in between the femur and the tibia of the left knee of individual 2. It is not possible to determine whether this is from individual 2, possibly from individual 1, or from another individual since it is very poorly preserved and not all foot phalanges from these two individuals were recovered.

From an analysis of the data within the 3D GIS environment, it appears as if these individuals were left largely intact (Fig. 8A), with some interesting exceptions, judging from the anatomical representation of the bones *in situ*. The elements that either possibly or definitely do not belong to either individual 1 or 2 are those that disarticulate early in the decomposition sequence (Fig. 8B), metacarpals, phalanges of hand and foot (Duday, 2006), but with the third individual's ulnar fragment as a possible exception to that pattern.

Dry fracture patterns

The dry fractures highlighted in 3D in the GIS project were analyzed spatially by means of different queries in order to separate different phenomena in a more detailed spatial analysis (Fig. 9). Most long bones had dry fractures in at least one place on the diaphysis and almost all bone fragments are in a location very close to that expected anatomically. Minor movement has in some cases undoubtedly occurred after these fractures, mostly only in the vertical plane but sometimes also horizontally (Fig. 9A).

The result of the analysis displayed an apparent bilateral symmetry in the distribution of the fractures in the larger long bones (femora and tibiae especially). The location of the fractures on the long bones is not consistent, however, between the two individuals, even though they were males of virtually the same age and size and therefore should possess very similar biomechanical properties (Fig. 9B).

The pattern highlighted by the analysis could indicate that the fractures occurred due to external factors influencing the two individuals differently, but internally symmetrically for each one. The patterns were highlighted using multiple 3D polylines to connect the fractures; using this method it was possible to find correspondences between the fractures. Once drawn, the lines almost parallel each other, displaying (as regards the major fractures) a constant distance of approximately 0.45 m (Fig. 10). All the structural elements (so far detected) suggest that these fractures could have been caused by the collapse of the roof on the individuals. In the future this hypothesis could be tested if more houses (or more of this house) were excavated using these specific methods. In that case this result could represent a valid and important reference in order to interpret the buildings of Sandby ring fort. In addition to this, the pattern of the fracture loading points (Fig. 11) yielded a possible pattern in the second individual with an asymmetrical distribution. Only the right side had these FLP and not the left. This could possibly be an indication that the forces responsible for the fractures on the right side were different from those on the left side, an observation that in the future would also be interesting to test in a spatial analysis of the house structures.

When performing different types of fracture pattern analysis in the 3D GIS environment, especially when using some tools available in ArcScene, the conclusions and interpretations of the bones when integrated in their spatial relationships show some interesting results. However, the complex situation of dry bone fractures needs further consideration and will be further developed below.

Necrodynamics

The spatial distribution of the bones can be compared with the expected location in relation to the anatomical articulations of the body. The relative position of the

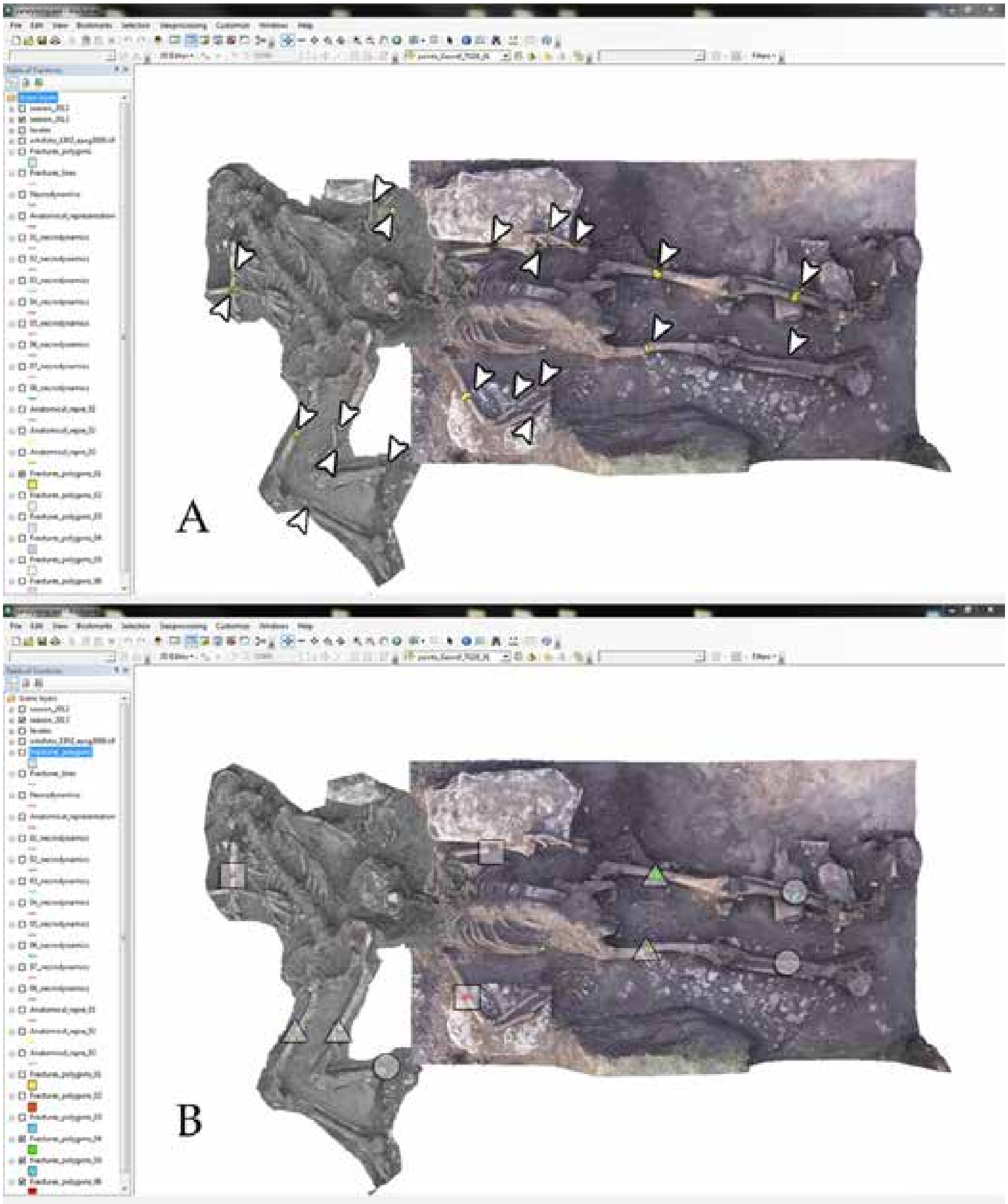


Fig. 9. 3D spatial distribution of different types of dry fracture patterns as derived from queries in the 3D GIS project. **A**: The overall distribution of dry fractures (i.e. postmortem) observable on the bones and the exact location in the 3D model represented by colored polygons (highlighted here using arrows for visibility in grey scale). **B**: Dry fractures highlighted by element in polygons in different colors (presented here with the addition of symbols for visibility in grey scale), circle = tibia, triangle = femur, square = humerus. 3D models generated with Agisoft Photoscan Pro, and visualized with ArcScene 10.1. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

bones in the 3D context while *in situ* can be considered when this data is integrated in the 3D GIS environment, further aided by high-resolution 3D models for detailed observations. All joints, classified as stable/persistent or labile articulations, and the overall pattern of articulation for parts of a body can be considered in detail (Fig. 12). In the interpretation of the original position of the body when deposited—whether if prone or supine—the differential decomposition of articulations that might result from this could be considered.

Through the use of the 3D GIS database, the complex spatial distributions of the articulation vs. disarticulation

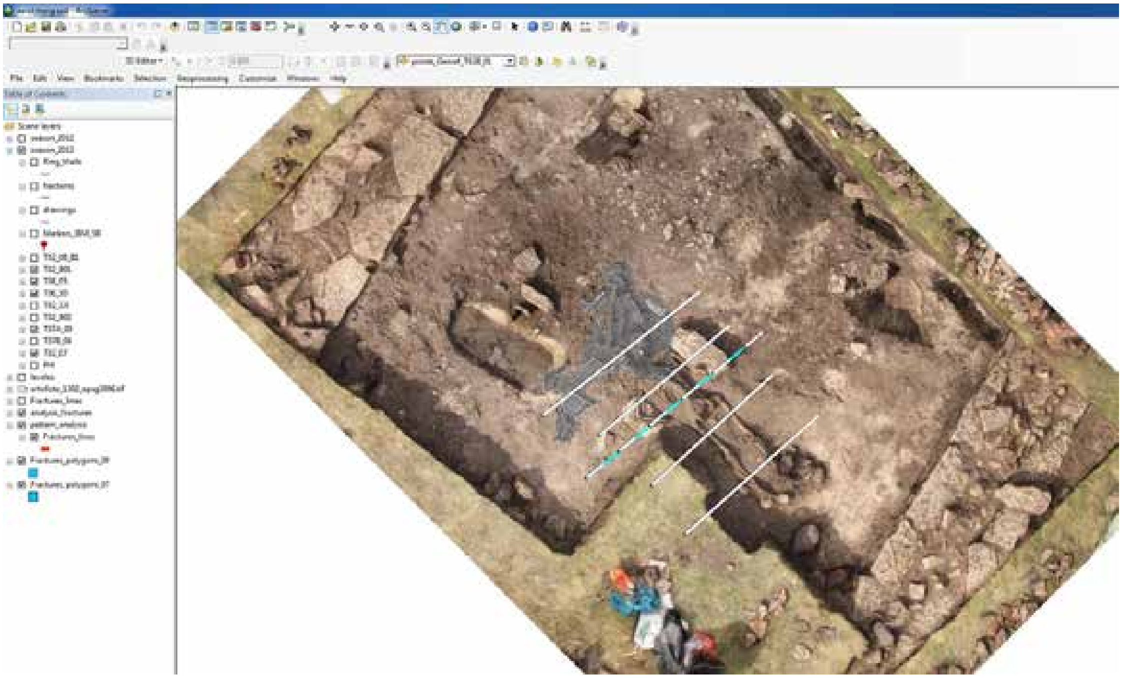


Fig. 10. The patterning of the dry fractures are highlighted in this image of the house with walls exposed and three of the stones from the walkway still partly *in situ* (indicating the midline of the house). The white solid lines indicate the connections between large postmortem (i.e. dry) fractures and the dashed line indicates the multiple and not so linear pattern of fractures in the slimmer long bones (radius and ulna); for details see Figure 9A. 3D models generated with Agisoft Photoscan Pro, and visualized with ArcScene 10.1. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Fig. 11. The 3D distribution of FLPs (fracture loading points, these polygons have been highlighted by arrows for visibility in grey scale) in comparison with the 3D polylines (black with white border). Note that in the femur and tibia FLPs occur only on the right side for individual 2. Compare the view of FLPs in Figure 9B. 3D models generated with Agisoft Photoscan Pro, and visualized with ArcScene 10.1. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

of labile articulations (i.e. those that decompose early in the process) could be compared with the persistent articulations (Figs. 12A and B). This type of visual analysis made it easy to investigate the internal symmetry of the two individuals and also of the different sides of the same individual.

When one considers the pattern of articulation of the labile articulations, they appear mostly articulated in both the individuals, although the distribution in individual 1 seems more complex (Fig. 12A), indicating that both are primary depositions, i.e. interred in a fully articulated state.

The hands of individual 2 are a good example of how well articulated most of the labile joints are (Fig. 13). Even the interphalangeal joints appear at least partially articulated, as the intermediate phalanges seem to be lying in anatomical position (dorsal surface up) with the fingers in a flexed position, albeit with slight vertical displacement. This could indicate that the body was left undisturbed as soon as fewer than 20 days had passed after death (Duday et al., 2009:25f). This number is not to be taken too literally, however, since the depositional environment is so complex (also depending on season and climate, if inside the house, for example; see discussion in Bass, 1996 or Anderson, 2011, decomposition of unburied remains) but certainly the remains were not exposed to any type of disturbance for long, if at all, after deposition. Considering that the open wounds on both individuals would likely attract various animals, this timeline is especially significant.

The right femur of individual 2 is slightly disarticulated, but the left hip is still fully articulated, i.e. a bilateral asymmetry. This joint, although labile, is still considered more persistent than the many interphalangeal, metacarpal, and carpal joints that it partly

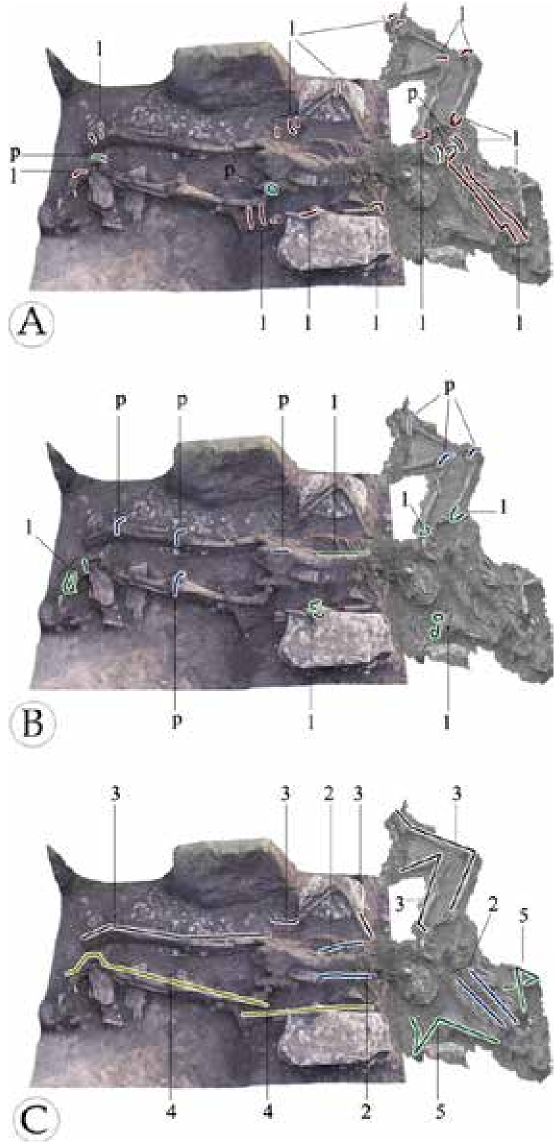


Fig. 12. 3D spatial distribution of different types of articulations and degree of disarticulation of the two individuals as derived from queries in 3D GIS. **A** and **B** show the distribution of articulation/disarticulation of joints that are persistent or labile separately. **C** shows the overall articulation of limbs/parts of the individual. A: Articulated labile joints (l) and disarticulated persistent (p); B: articulated persistent joints (p) and disarticulated labile (l); C: 2 = score 2 (i.e. minor movement); 3 = score 3 (i.e. joints articulated for a limb as a whole, only minor disarticulations); 4 = score 4 i.e. (partially articulated limb joints), 5 = score 5 (i.e. major disarticulations of limb joints). 3D models generated with Agisoft Photoscan Pro, and visualized with ArcScene 10.1. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

overlaps (Fig. 13), due to the close fit of the femoral head in the acetabular joint. Both the right and left femora have diaphyseal dry fractures but only in the right is the proximal part displaced laterally, indicating that the movement occurred after disarticulation (or possibly causing it). For individual 2 some of the most persistent articulations (such as the sacroiliac and sacrolumbar) are disarticulated even though most of the labile articulations are still articulated (Fig. 12A).

When comparing the labile joints with the persistent ones in individual 2, an intricate pattern is revealed, with distinct asymmetry in the right and left feet (Fig. 12). In the left foot the labile and persistent articulations are in articulation for those that are present, but in the right foot some metatarsals are articulated and one is disarticulated (two are also missing), as are most of the tarsals. The most likely cause of this pattern is probably the great difference in elevation of the right tarsals compared with the rest of the lower extremities. The relative deviation was investigated using a measurement tool available in ArcScene that can be used to study microtopography (Fig. 14). The use of this tool permits measurement of the height of any 3D entity imported into the 3D GIS, providing information about the altitude and the linear distance of any single bone in relation to other archaeological material. By this method the level of the right foot can easily be established to correspond to the torso lying on the walkway stones. What the remains show here is actually how much the softer soil floor had decompressed in comparison to the lime-slab-paved walkway in the mid axis of the house (leading from the front door, as the structural elements are interpreted by the authors of this study). A possible explanation for the right-left asymmetry in the feet could have been the presence of clothing on only the left one, but in this case, when viewed in the spatial context, it is much more plausible that the compression of the floor layer is the key taphonomic agent.

Some of the more stable/persistent articulations are still articulated, such as the left sacroiliac joint of individual 2 (Fig. 12B) and the knees of both individuals. Because of the body position (lower limbs flexed to the right side), the knees of individual 1, the patellae in particular, are actually suspended against gravity once disarticulated. Considering this, it is debatable whether this articulation instead should be considered labile, due to the nature of the anatomy (i.e. time to decompose); it is, in accordance with Duday (2006), still defined as persistent. One conclusion from this, however, is that once the knees disarticulated they were held in position by supporting material (possibly clothing or other perishable elements) holding them in position against the force of gravity.

The articulation of the torso/ribcage is largely similar in the two individuals, with even the internal spacing of the ribs in anatomical order despite compression and/or breaking of the ribs (Fig. 12C). In individual 1, lying supine, it is notable that even though the ribs appear broken approximately mid diaphysis, both the sternal and the vertebral portions seem internally organized in anatomical order. This is indicative that compression occurred while the labile sternocostal articulation was intact enough to persist, i.e. relatively early in the decomposition process, and that there was not much room for disarticulation after this articulation ceased. Individual 2 is lying prone and the ribs appear less compressed (not broken) than in individual 1 and also internally in anatomically correct positions. The ribs are, however, disarticulated from the vertebrae on the left side and the vertebrae (thoracic and lumbar but not the cervicals) are rotated to the right with the lateral side of the vertebral bodies exposed posteriorly instead of the

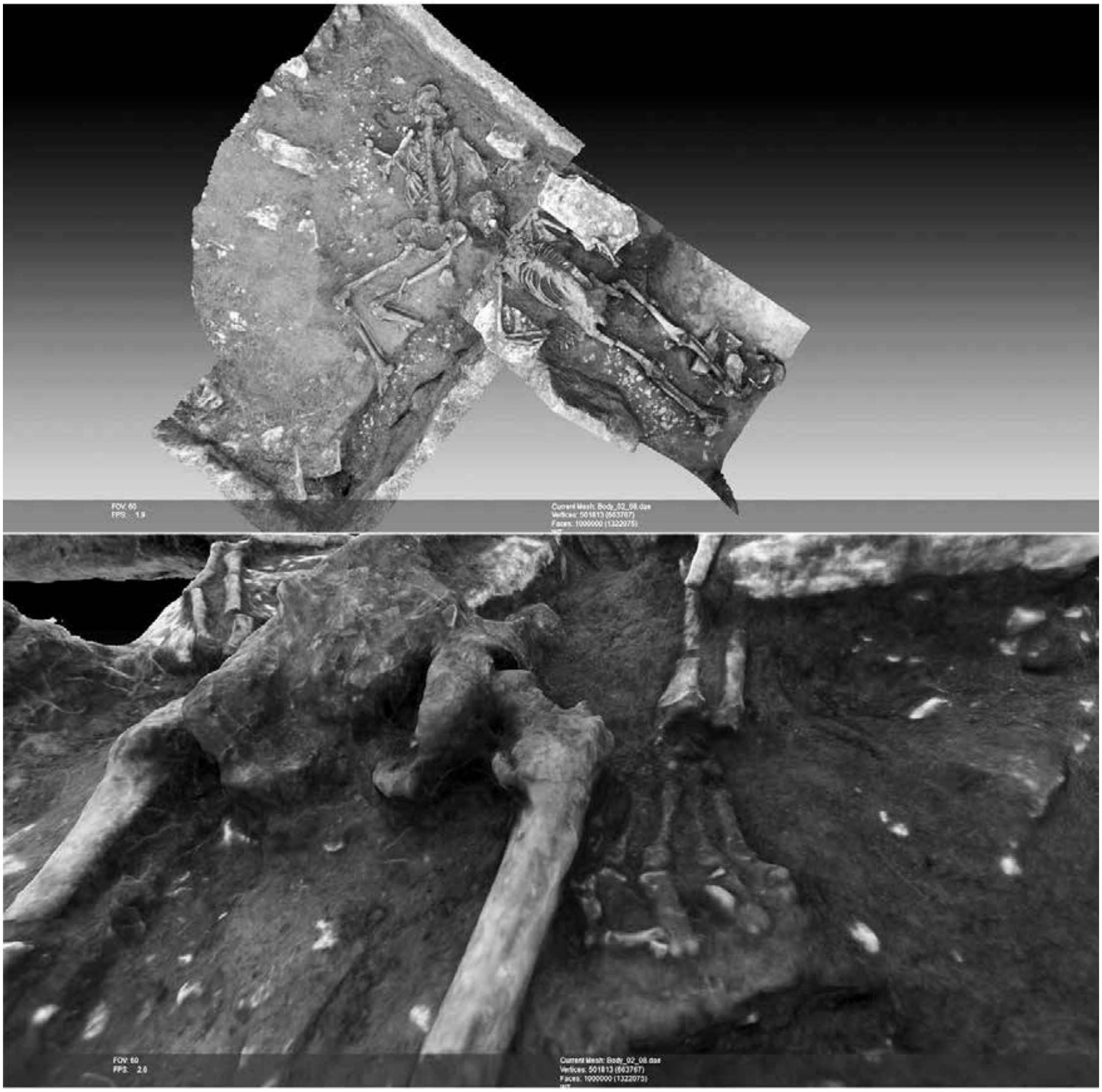


Fig. 13. The high-resolution 3D model (viewed in MeshLab) of the two individuals (above) with a detailed view of the right hand of individual 2 (the palmar aspect is visible in this prone position).

arches (which would be the anatomically correct position for a prone body posture). The curve of the thoracolumbar vertebrae is slightly S-shaped due to the torsion and displacement of the vertebrae as a unit. The right costovertebral articulations seem more intact, indicating these were probably intact as the vertebrae were displaced to the right, but the left ribs also appear to be in relative anatomical position despite being disarticulated from the vertebral column.

Some further overall symmetry and patterns of articulations of skeletal elements (not only joints) can be observed in the spatial 3D GIS analysis (Fig. 12C). The best articulated parts are the ribs (relative to other articulations) and the left extremities of individual 2 and lower extremities of individual 1. Both the upper and lower right limbs of individual 2 present some major exceptions but still an overall pattern of articulation as a whole limb. Both the forearms and hands of individual 1 are poorly articulated and anatomically represented, although the few parts available (and possible to side) are divided into right and left along the midline (i.e. vertebral column) of the body, possibly indicating displacement in the area of the ribcage as it collapsed and subsequently opening up an empty space to be filled by surrounding soil.

The upper part of the torso and humeri of individual 1 are articulated but clearly elevated, a relationship that can be observed using the measurement tool in Arcscene

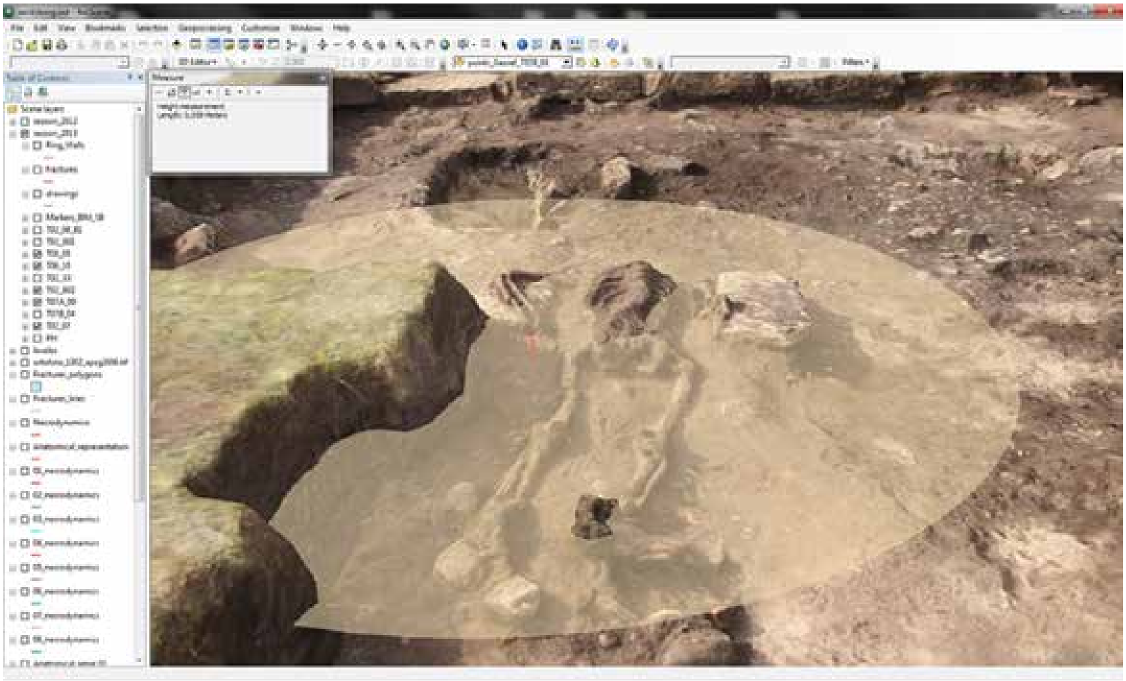


Fig. 14. Highlighted in the image is the 3D measurement tool used to indicate the difference in floor level from the walkway stones to the position of the remains in relation to this. The different levels of different parts of the individual are very clearly seen this way, showing the differential decomposition in relation to spatial elements recovered at different stages of the excavation. The exposed bones are those lying on the walkway stones and the right foot as situated on a stone i.e. demonstrating that the foot is in perfect anatomical position relative to the floor level and not at all elevated *per se*. 3D models generated with Agisoft Photoscan Pro, and visualized with ArcScene 10.1. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

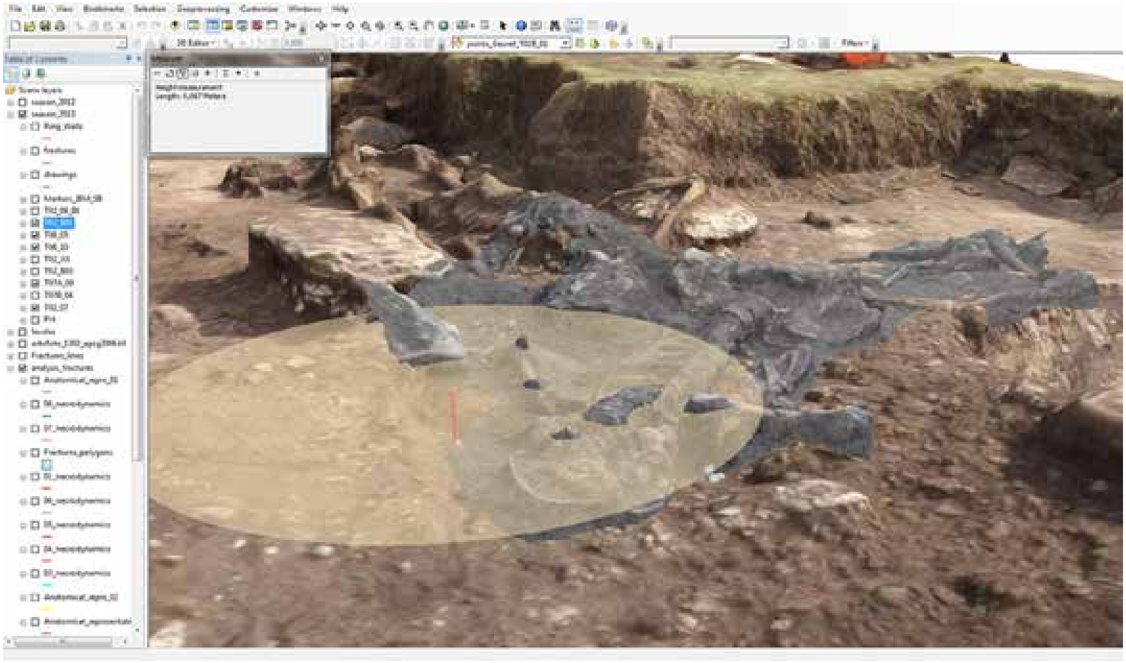
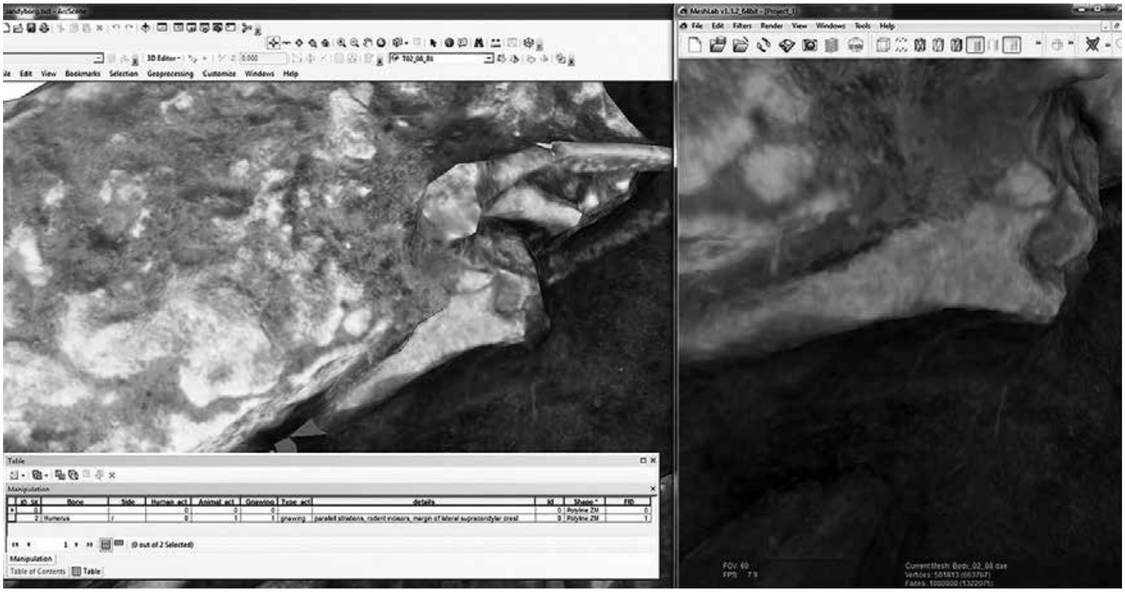


Fig. 15. The 3D measurement tool applied to highlight the differences in elevation in disagreement with expected necrodynamics. The neck and shoulders (the upper torso) are most superior as illustrated by the circle, which could only be possible if they were resting on a perishable element. This tool shows how elevated the torso and humeri are, indicating a probable space into which the forearms could fall, possibly accounting for at least some of the poor anatomical representation of upper limb body parts. 3D models generated with Agisoft Photoscan Pro, and visualized with ArcScene 10.1. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]



	id_sk	Bone	Side	Human_act	Animal_act	Gnawing	Type_act	details	Id	Shape *	FID
▸	0			0	0	0			0	Polyline ZM	0
	2	Humerus	r	0	1	1	gnawing	parallel striations, rodent incisors, margin of lateral supracondylar crest	0	Polyline ZM	1

(0 out of 2 Selected)

Fig. 16. Images of the humerus with gnaw marks as they appear in the 3D model in GIS (left) and MeshLab (right).

(Fig. 15). Anatomically, this part of the torso, for example the cervical vertebrae, would not be expected to protrude to such an extent if not supported by some perishable material. This could also explain why the forearms appear to be more disarticulated in this individual, the perishable element/elevation of the vertebral column creating a space for them to disarticulate into as the ribcage collapsed. Due to the extensive open wound to the right shoulder, which was in contact with some surface inferiorly, this part would have potential to decompose more quickly than the lower part of the torso, for example. The elevation of the upper part of the torso might thus explain the high degree of articulation if the body was resting on some perishable materials.

Another movement revealed in the bones was probably the direct effect of animal manipulation. In the laboratory analysis gnaw marks to the right humerus of individual 2 were found (Fig. 6). When viewing the specific orientation of the gnaw marks *in situ* in the 3D GIS platform and in MeshLab, a displacement of the bone fragment was apparent. It included both a significant movement to distal as well as torsion in the mediolateral plane toward the walkway stone (Fig. 16). Clearly the bone was broken first (since it is a dry fracture) and displaced later. The orientation of the bone suggests that the gnawing likely occurred while it was in the position found, which is consistent with this type of rodent gnawing behavior on mainly skeletonized remains. This demonstrates the great potential for integrating the osteological laboratory analysis with the 3D GIS, allowing the researcher to virtually revisit the excavation once new information is discovered in the laboratory analysis.

DISCUSSION

The integration of virtual models of the site in 3D GIS with osteological analysis in field and laboratory provided multiple methodological developments in studying human remains within an archaeological context. The most specific advantages in using the *Virtual Taphonomy* methods can be summarized in three different aspects as highlighted in this case study:

i. The possibility of interpreting the spatial distribution of disarticulated bones (anatomical representation) in 3D while merging different sequences of excavation belonging to the same (original) stratigraphical event
ii. The possibility to interpret the articulation patterns (necrodynamics) in full 3D while merging different sequences of excavation into one stratigraphical event
iii. The possibility of interpreting the minor mechanical changes to the bones detected in the laboratory analysis (for example dry fracture patterns and gnaw marks) in relation to the archaeological features

These aspects and their specific merits in the taphonomic analysis require further discussion within the specific case study in order to give broader insight into the potential application to other contexts.

i. The 3D GIS enabled viewing the full extent of both individuals and the disarticulated bones in connection with these, all recovered in two different excavations, as in one reconstructed moment with correct stratigraphic relations (Figs. 2, 8). There were some clearly disarticulated, elements of which at least one was definitely from a third individual (an ulna). The possibility of a third complete individual decomposing on top of the two individuals appears unlikely considering the few elements recovered and their spatial distribution in 3D as stratigraphically superior or at the same level. However, potentially part of a forearm and hand could have been partially articulated when deposited above individual 1 (Fig. 8B, bones 1–5) considering their close spatial relationship. This secondary deposition of potentially articulated human remains might indicate animal scavenging of a more accessible individual (perhaps in another part of the house or elsewhere in the fort) but as the bones in the immediate vicinity in both individuals appear to be unaltered themselves by animal scavenging (i.e. fully articulated and no gnaw marks) they were likely covered and protected from manipulation before these remains were deposited above them.

ii. The pattern of articulation of the two individuals is quite complex, but with the integrated use of the 3D GIS analysis developed in the *Virtual Taphonomy* approach, it was possible to get a clear visual overview of the process and possible scenarios/sequences from death to discovery. The individuals appear to be in primary and simultaneous depositions. The pattern of disarticulation, with labile joints articulated while some persistent joints are disarticulated, indicates decomposition in an open space, i.e. a "nondelineated empty space" (cf. e.g. Roksandic, 2002: 106f and references therein), probably constituted in this case by the house standing over the bodies, which was later infilled, leaving some of the persistent articulations intact.

There was some movement of larger units of the individuals occurring as persistent articulations were preserved, causing, for example, the vertebral column of individual 2 to rotate to posterior and to the right and the ribcage to flex and fracture while preserving the anatomical relationships in the different parts in individual 1. Considering that these parts (the torsos), in a body in at least semifresh state, would be those most elevated (especially if the bodies were still in a bloated state), and thus protruding most, a possible cause of these large displacements could be, for example, the roof (or other overhanging structures of the house) falling down over the bodies and affecting the most elevated parts of the body first, while they were possibly partly but definitely not completely skeletonized. The GIS analysis concluded that the floor had been considerably compressed and showed exactly how much (when comparing the remains to the walkway element in the floor of the house), explaining some necrodynamic patterns such as the right ankle of individual 2, which was very elevated (but actually just still in the original position in relation to the floor level). In this case the spatial relation of the bones to the context can assist and complete the archaeological interpretation of the structural elements of the house and how the layers have altered the original spatial relations. This example shows exactly how intimate and intricate the relationship between bones and context is, and how easy it is to do such an analysis in the 3D GIS environment, adding value simultaneously to the interpretations of the bones and to the archaeological context in a broader sense.

The most labile articulations (e.g. the hands of individual 2) were very well articulated, which indicates a very short first period of decomposition (probably in the range of weeks) without any animal access (no small or large scavengers, birds or terrestrially bound) to the remains despite the open wounds in both bodies, that would have been highly attractive to scavenging animals. In this context a possible scenario could be that the door was closed until the building collapsed over the bodies covering them; judging by the overall articulation pattern, this probably did not take very long, as some persistent articulations were intact when major movement and breakage of the bones occurred.

iii. The dry bone fractures, when integrated in the 3D spatial analysis in GIS, highlighted a pattern with some very specific asymmetries (the occurrence of unilateral FLPs) and a strong spatial regularity. This in turn provided a potential indication that the patterns might correspond to the structural elements of the context (i.e. the house) rather than simple bone mechanics and chance. Lastly, animal intrusion in the context was detected by the postprocessing analysis, revealing the remains bearing gnaw marks (right distal humerus of individual 2). The bone with gnaw marks was fractured when in a dry bone state before the gnawing occurred, timing that is in agreement with the specifics of this type of rodent gnawing behavior. When reviewing the position of the located gnaw marks in the 3D GIS it became apparent that the bone had been displaced in a way corresponding to the animal activity pulling and rotating the fragment up toward the surface for easier access. The consistent integration of the GIS and detailed osteological analyses, both in the field and in the laboratory, made all these sequences transparent while serving as tools to help to analyze material.

In conclusion, the documentation and visualization aspects using these methods were also significant improvements in detail and accuracy compared with more traditional methods based on two-dimensional representation. In addition to allowing a deeper and more integrated interpretation of the archaeological and osteological context, the methods used were also time-efficient without adding costs. The authors would recommend that, in order to obtain optimal results these methods should be integrated in the entire investigation process, not only in the field and in postprocessing but also in interpretations combining these results.

CONCLUSIONS

The methods developed, tested, and applied to the case study described in this article (as summarized in Fig. 3), *Virtual Taphonomy*, showed several different potential uses. The integration and re-interpretation of data from both field and postprocessing into the 3D GIS considerably facilitated the possibility to view the results integrated in the physical archaeological context, and to use the system to retrieve new data as a result of specific queries.

Specifically, for a taphonomic analysis, this method—when implemented from the very beginning (with great attention paid to the excavation process and the anatomical distribution of the bones)—can provide an excellent base for in-depth studies of intricate sequences of body decomposition in relation to the physical context. One specifically prominent strength is the extremely high degree of precision available using the 3D models as a geometrical reference and, at the same time, a very time-efficient process (compared with traditional drawing/GIS documentation of the bones).

These characteristics make this approach applicable to all field investigations, whether research-based or rescue excavations (Dell'Unto, 2014). Additionally, this method could be used in more complex contexts such as mass graves and secondary depositions, with the potential to create separate 3D geo-objects that can be isolated and compared with different materials or fragments detected and excavated during different stages of the field investigation. In this way research results can be very transparent and used for comparison with other studies, providing insight into the investigative process for other researchers and the public alike.

The implementation of this method in anthropology could also be useful as a contribution to the discussion of missing bones in funerary contexts, perhaps inviting a reconsideration of the often favored "ritual" element in taphonomic loss of bones (see e.g. the discussion in Knüsel et al., 1996) and put this in relation to the other taphonomic factors when the analysis is integrated *in situ* and involves both bones and context.

The potential use of this method in a forensic context is also significant. Not only can it contribute to investigation of the crime scene (even recording parameters such as light conditions on site), but it also has the potential for analysis and presentation of results. The high accuracy and detail of any 3D space that can be captured in such a short timeframe and using easily accessible tools (only a digital camera and RTK GPS or Total Station are required to retrieve the data) adds further value to this type of application where time is often the most critical factor. Additionally, these data could easily be viewed and analyzed via an immersive system permitting virtual access to a 3D environment within a short timeframe, regardless of geographic location.

The method presented in this article, termed *Virtual Taphonomy*, revealed significant technical improvements in accuracy, detail, and time aspects compared with methods previously used such as drawing or GIS-based reconstruction with or without CAD applications. This was accomplished without increasing the associated costs, with the technical elements required being accessible in most archaeological excavations. The successful integration of osteological and archaeological analysis and interpretations achieved in the case presented highlights the extensive possibilities of integrating field and postexcavation processing, to add value to the entire archaeological process (field-laboratory-researchers-public) with transparency as a key element.

As promoted in the pioneer publications on burial taphonomy by Wilder (Wilder and Whipple, 1917; Wilder, 1923) the potential in photographic-based documentation and *en bloc* methods for analysis was on the right track from the start. But it is only today, almost 100 years later, that this vision can be achieved with simple and accessible methods. The research presented here is an advance comparable to a paradigm shift within burial taphonomy. It will add to the growing interest in this field and bring a new focus and appreciation of the great significance of the context of human remains in any anthropological analysis.

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Supplement 1: ANATOMICAL PRESERVATION

	Individual 1		Inidvidual 2		Disarticulated bone/remarks
	R	L	R	L	
Occipitale	2		2		
Parietale	2	2	2	1	
Frontale	2	2	2	2	
Maxilla	2	2	2	2	
Palatinum	2	2	2	2	
Temporale	2	2	2	2	
Spenoidale	2	2	1	1	
Zygomaticum	2	2	2	2	
Mandibula	2	2	2	2	
Skull, general preservation	2	2	2	2	
Vertebrae cervicales, *number that are WPB ( ) less preserved	7*		4* (3)		
Vertebrae thoracicae	12*		12*		
Vertebrae lumbales	5*		3* (2)		
Scapula, cavitas glen.	2	1	2	2	
Scapula, coracoid	1	0	2	2	
Scapula, other	2	1	1	1	
Clavicula medial	0	1	2	1	
Clavicula diaphysis	2	2	2	2	
Clavicula lateral	1	1	2	1	
Humerus proximal	0	1	2	2	
Humerus diaphysis	2	2	2	2	
Humerus distal	2	1	1	1	
Radius proximal	0	2	2	2	
Radius diaphysis	0	2	2	2	
Radius distal	0	0	2	1	
Ulna proximal	2	2	1	1	
Ulna diaphysis	1	2	2	2	Additional: part diaphysis, L , the third individual
Ulna distal	0	0	1	1	
Scaphoideum	2	2	2	2	
Lunatum	(2)	2”	2	2	( ) Disarticulated, among the skull fragments of individual 1 “ disarticulated close by forearm L ,individual 2
Hamatum	0	2”	2	2	“ Disarticulated, among the ribs on the L
Capitatum	(2)	0	2	2	( ) Disarticulated, among the ribs on the R
Trapeziodeum	0	0	2	2	
Trapezium	0	2”	2	0	” Disarticulated, among ribs on the L
Triquetrum	0	2	2	2	
Pisiforme	0	0	0	0	Additional: Unsided; among skull fragments of Individual 2, from individual 1 possibly
Metacarpus I	0	0	2	2	
Metacarpus II	0	0	2	2	
Metacarpus III	0	0	2	2	
Metacarpus IV	0	0	2	2	
Metacarpus V	0	0	1	2	
Metacarpus, unspecified	0	(3)	0	0	( ) disarticulated, by forearm L, 4 fragments from at least 3 bones. Additional: 3 fragments by the ulna of individual 3
Manus, Phalanx I (*=number of bones WPB)	0	0	4*	4*	
Manus, Phalanx II	1*	0	3*	2*	Additional: 1 bone among the skull fragments of individual 1
Manus, Phalanx III	0	0	1*	2*	
Manus, Phalanx, unspecified	_0_	_(6*)_	_0_	_2*_	( ) Fragments (proximal/intermediate phalanges) by forearm and among ribs L
Seamoidea	0		0		
Hyoideum	2				
Thyroideum	0				
Tricoid	0		0		

Sternum	1		0		
Manubrium	0		0		
Xyphoid	0		0		
Costae I	1	1	1	2	
Costae II	1	1	1	2	
Costae III-XII (*=number of bones WPB)	10*	9*	10*	9*	
Sacrum S1	1		2		
Sacrum S2	1		1		
Sacrum S3	0		1		
Sacrum S4	0		1		
Sacrum S5	1		1		
Coggygis	1		0		
Ilium	2	2	2	2	
Ischium	1	2	2	2	
Pubis	0	0	2	2	
Femur proximal	2	2	2	2	
Femur diaphysis	2	2	2	2	
Femur distal	1	1	2	2	
Patella	1	2	2	2	
Tibia proximal	0	1	2	2	
Tibia diaphysis	2	2	2	2	
Tibia distal	1	1	1	0	
Fibula proximal	1	1	1	0	
Fibula diaphysis	2	2	2	2	
Fibula distal	2	1	0	0	
Calcaneus	2	1	1	1	
Talus	2	0	2	1	
Cuboideum	2	1	1	0	
Naviculare	1	2	2	1	
Cuneiforme mediale	2	2	2	1	
Cuneiforme intermedium	2	2	1	1	
Cunieforme laterale	2	2	1	2	
Metatarsus I	2	2	2	2	
Metatarsus II	2	1	2	2	
Metatarsus III	2	1	0	2	
Metatarsus IV	2	1	0	1	
Metatarsus V	2	1	0	0	
Metatarsus, unspecified	0		0		
Pedis, Phalanx I	3*	2*	1*	2*	Additional: 1 ; discovered lodged inside the left knee of Individual 2 between femur and tibia
Pedis, Phalanx II	2*	0	0	0	
Pedis ,Phalanx III	0	0	0	0	
Pedis ,Phalanx, unspecified	*0*		*0*		
Sesamoidea	0		0		
Unfused small epiphysis:	Costae: heads Vertebrae: annual rings				

For the bones that are disarticulated the exact location is specified in the 3DGIS database with a polygon (with a unique id) for each bone with a description in the attribute table.

2= Well preserved, WPB (50-100%)

1=Less preserved (<50%)

0=Absent

R=right, L=left

PAPER II

Iron Age migration on the island of Öland: Apportionment of strontium by means of Bayesian mixing analysis

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Iron Age migration on the island of Öland: Apportionment of strontium by means of Bayesian mixing analysis

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ABSTRACT

Migration is a complex subject to approach in archeology and the new materials and methods available, such as isotope analysis and DNA, make it possible, and necessary, to ask new questions. The objective of this paper is to highlight the possibilities with using a new approach to migration on a population level by applying Bayesian mixing analysis of strontium isotopes. The selected case, the island of Öland in the Baltic, was based on 109 human samples dated to the Early (500 BC–AD 400, n = 71) and Late (AD 400–1050, n = 38) periods. The results from both periods demonstrate that the distribution of Strontium (Sr) is multimodal with several peaks not associated with the local variation. Our results show a large immigration to Öland from other geological areas, with 32% of the population in the Early period and 47% in the Late period being nonlocal. In order to unravel these distributions, we use a Bayesian mixing analysis. The Bayesian mixing analysis provides us with a mean to disentangle the distribution of Sr that is not uninformed. The gravity model, however simplistic, is relevant for explaining the strontium variation in the population in Öland both in the Early and Late period. Our results indicate a significant internal migration in Scandinavia that is increasing in the Late Iron Age at the same time as the Viking expansions (the more well studied external migration), which is usually the only migration discussed. We argue that the method proposed and tested on the case of Öland adds new perspectives for approaching migration patterns in general on a population level, a perspective that is hitherto lacking in archaeology.

1. Introduction

Migration is an area of study in archaeology that is focused upon defining deviance instead of contextualizing migration on a population level. Despite new methodologies allowing us, even compelling us, to pose entirely new questions to our sources, the process in studying migration and the questions asked remain largely the same. Here, we use the methodologies of isotope analysis in combination with Bayesian mixing models to explore one of the most well established theoretical models of migration—the gravity model. We use this method on a complete sample (i.e. not deviants) taken from the Swedish island of Öland in the Baltic Sea throughout the Iron Age (500 BC–AD 1050). By this approach we move migration studies in archaeology forward, not only by combining these methods, inherently calling for a "complete" (not deviant-focused) approach, but also by proposing and addressing new questions based in these methods rather than directed at them.

The Baltic and its larger islands, such as our selected case study Öland, entered a highly dynamic and communicative phase with the advent of the Iron Age in Scandinavia and the advances made in maritime communication (c.f. Randsborg, 1991; Callmer, 1992). Regardless of the archaeological sources in focus, the changes apparent between the Earlier (500 BC– AD 400) and Later Iron Age (AD 400–1050) are closely intertwined with communication outside of the local community. Despite recent significant methodological advances, studies of migration during the later period are still entrenched in the publicly engaging notion of "Viking expansions". The literature dealing with Viking legacy outside of Scandinavia is truly plentiful (despite a sometimes very limited material) and the interest has increased with the use of isotopic analysis in particular (c.f. Loe et al., 2014; Harding et al., 2015). Studies on migration, specifically those on isotopic analysis for provenance, are very often focused on burials which can be considered deviant in artefacts (imported artefacts) or style. Attention to these samples fails to get a full cross section of the

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entire population (c.f. discussion in Eckardt et al., 2014). In this study, measures were taken to avoid biased sampling by taking samples from diverse contexts, including as many burials as possible that were clearly dated. This allowed us to connect to a specific archaeological cultural context within a given time and place. Our approach will enable us to study migration processes, not deviant individuals. We probe questions concerning, for example, the nature of immigration involving Öland during the Iron Age. Is the proportion of locals the same over time? Are the migratory patterns the same if we compare the Early Iron Age with the Late Iron Age? Here, we examine the local situation within the southern Scandinavian Peninsula asking how our results would fit a much broader perspective involving the expansions we see emanating out from the Scandinavian Peninsula, a perspective that has been lacking.

Strontium (Sr) isotopic analyses offer a solid indication of geological origin that indicates at least some very clear cases of migrations of individuals during their lifetime. Many more complex aspects and facets of migration as a process could, however, remain elusive (for example seasonal, temporary, or returning migration). The distribution of Sr in a given region (for example, Öland) may be understood as a mixture of local and non-local isotope signatures. A reasonable assumption in the absence of migration is that the distribution of Sr in a population would be Gaussian with a mean and dispersion mimicking the local signature. Affected by migration in a region with a heterogeneous distribution of Sr, this distribution is likely to develop a multimodal shape reflecting the geographical heterogeneity of the sample, with the height of the different modes reflecting the proportion of individuals emigrating from that specific region (source).

Bayesian mixing models supply a framework for incorporating prior information into the analyses of a mixture of sources (Phillips and Gregg, 2001, 2003; Moore and Semmens, 2008; Parnell et al., 2010). According to Bayesian theory, statistical inference is based on the posterior distribution, a distribution that is given by the data and existing knowledge (i.e. the prior) (Hilborn and Mangel, 1997). We could work with an uninformative or flat prior meaning that all sources are equally likely to contribute to the distribution of Sr in the target population from Öland. But we could also adopt informative priors based on some prior knowledge of human migratory patterns, such as implied by the gravity model (Hodder and Orton, 1976:187). In this context, we employ a method that will incorporate the gravity model as a prior. Based on this model, we posit that non-local individuals are more likely to have originated from regions that are closer to Öland rather than further away, and define the priors in a Bayesian Mixing Model accordingly.

Migration implies the physical movement of humans from one area (origin) to another (destination), with the aim of settling temporarily or permanently at the destination. Once presented as a major force with a substantial explanatory power within cultural historical archaeology, its importance was actively diminished in the New Archaeology paradigm. However, following advances in natural sciences, human migration of the past is resurfacing as an active field of research within the field (Burmeister, 2000; Hakenbeck, 2008; Clark and Cabana, 2011; Cameron, 2013; van Dommelen, 2014). The aim of this paper is to advance the study of human migration in archaeology by asking new questions which have only been possible to pose through combining methods and theoretical approaches: Sr isotopes, the gravity model and Bayesian mixing. Using this approach we focus on migration processes rather than deviant individuals and provide a new perspective on the globally enticing phenomenon of “Viking expansions” using our case study of Öland. We also offer a new direction for migration studies in archaeology which is based not only on employing, but on *exploring* the full potential of methods like isotopic analysis by posing new research questions based on the method, rather than subjecting it to old questions. This is made possible with integration of isotopic analysis with archaeology on the theoretical level.

2. Material and methods

The material used in this study is the unburnt skeletal remains of 109 individuals excavated on Öland (Appendix A, Fig. 1). The individuals were selected primarily on the basis of available permanent teeth (premolars) for Sr isotopic analysis. Other selection criteria were aimed towards gaining as representative a material as possible regarding (in descending order of importance): date, region of the island, archaeological context (burial or other), age (from seven years and up), and sex. However, the available material could not fulfill all criteria equally. This is not only a product of preservation and excavation bias but is also reflective of the varied burial practices and differing contexts containing human remains during the Iron Age on Öland. Although more than one individual was frequently identified in the graves (primarily in the stone cists), only those remains that could be clearly identified and sorted with confidence into separate individuals were selected for further study. If more than one individual from a grave was suitable for analysis by the criteria stated above, they were included in the sample. The sample has been osteologically analyzed by one of the authors (HW).

In this article the data are presented as pooled into two periods: the Early Iron Age (500 BC–AD 400) and the Late Iron Age (AD 400–1050). In the case of burials, the distinction between the two periods is relevant in that there appears to be a significant shift in burial practices, from a mix of inhumation and cremation to a seemingly almost exclusive practice of cremation during the transition from the Early to the Late Iron Age (Beskow-Sjöberg and Arnell, 1987; Beskow-Sjöberg and Hagberg, 1991; Hagberg and Beskow-Sjöberg, 1996; Fallgren and Rash, 2001). In the Iron Age on Öland, as in Scandinavia in general, burial practices shifted back and forth from cremation to inhumation and both practices were used in parallel for much of the period. The uncremated individuals selected in this sample have an obvious bias as the parallel cremation practice removes a significant proportion of the entire population from analytical access. However, the uncremated population can be seen as representing a social identity (or possibly many social identities, shifting between the different periods) and its division by Sr is of interest in that respect also.

All but four of the sampled teeth are premolars and only enamel was sampled. The list of samples, various other information, and isotope results are provided in Appendix A. Premolars were selected for this study for functional, practical and representational reasons. The premolar is a common tooth; there are eight premolars in the dentition. The availability of the premolars is unsurpassed by any other tooth in the sense that an individual only needs to have one of the eight premolars preserved (in contrast to one of four first molars) in order to be sampled. Premolars are developed almost simultaneously and are therefore comparable to one another with regard to enamel composition. Another important feature is that the premolars are often usually not as worn as most other teeth (especially in comparison with first molars) in that enamel remains intact, even in very old individuals who can thus be included in the sample. In addition, premolars generally form after weaning so that the mother's diet has little effect upon the formation of the tooth (in contrast to first molars). Since sampling is always a destructive process another advantage to using premolars (rather than molars) is that they are less useful in terms of morphological or metric analysis and the scientific value lost by sampling a tooth is therefore lower. The animal samples were also taken from tooth enamel but the type of tooth differed depending

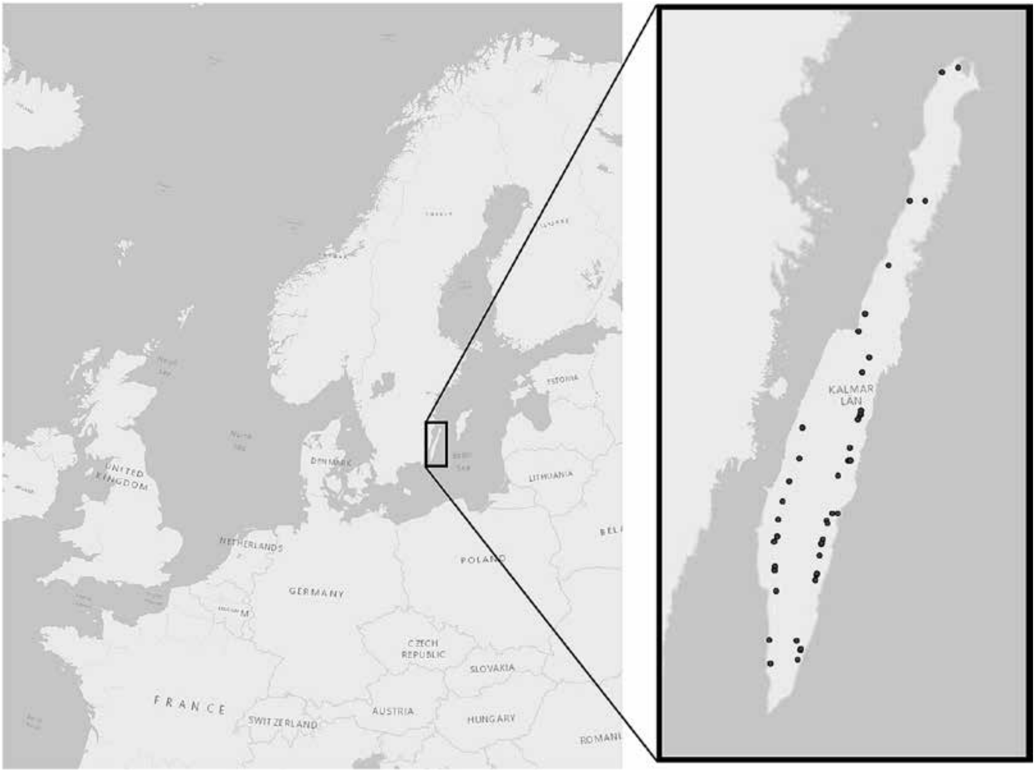

Fig. 1. The location of Öland in Scandinavia (left) and the distribution of the 109 samples across the island (right). Esri, HERE, DeKorme, MapmyIndia, ©OpenStreetMap contributors and the GIS user community.

on species and preservation of the remains as they were all from Iron Age archaeological contexts on Öland.

2.1. *Strontium isotope methodology*

The human skeleton may assimilate radiogenic Sr in lieu of calcium from the surrounding environment. As the ratio of ^{87}Sr to ^{86}Sr is dependent upon the age of the bedrock (rubidium [Rb] decays to Sr as a function of time), a heterogeneous geological landscape produces patches with distinctively different compositions of bioavailable Sr (Ericson, 1985; Bentley, 2006; Price et al., 2002). In archaeology the ratio of ^{87}Sr to ^{86}Sr is mainly measured in skeletal tissues, specifically bone apatite and enamel. Enamel is formed early in life and remains inert once mineralization is complete preserving the Sr composition deposited in that specific period. Bone turnover, however, makes the Sr composition mirror a longer, and ongoing, period of metabolized Sr, i.e. not reflecting origin but changing throughout the life course (Bentley, 2006). For this study we chose to sample only tooth enamel from humans and animals considering the lesser risk for diagenetic alteration compared to bone apatite and in order to study whether migration from the childhood place of residence could be detected.

The protocol and methods for the Sr isotope analysis are described in detail in other works (c.f. Sjögren et al., 2009; Frei and Price, 2012). Sr is isolated from clean powdered enamel using cation exchange chromatography. Samples are then analyzed using a thermal ionization multiple collector mass spectrometer (TIMS). The samples were measured using a MicroMass Sector 54 instrument at the University of North Carolina. ^{87}Sr/^{86}Sr analyses ($n = 40$) of the NIST SRM strontium carbonate yielded a value of 0.710259 ± 0.0003 (2 SE). Internal precision (standard error) for the samples analyzed at UNC-CH is typically 0.000006 to 0.000010, based on 100 dynamic cycles of data collection.

2.2. *Carbon isotope methodology*

The level of δ^{13}C in skeletal tissues reflects the proportion of terrestrial or marine and C4 plant food sources in the diet. In Scandinavia, however, C4 plants (specifically millet) are not likely to have been grown or imported to any significant extent during this period and there is sporadic evidence from the earlier period but none in the Late Iron Age (c.f. Grabowski, 2011:488). In mineralized tissue, such as dental enamel, the δ^{13}C reflects diet in a more complete way than in bone collagen, as it takes in more than protein alone (Ambrose and Norr, 1993; Kellner and Schoeninger, 2007). Moreover, measuring δ^{13}C in dental enamel also measures childhood diet composition as the enamel is inert once formed. The proportion of marine input in the diet is of interest in interpreting provenance from Sr values as the marine Sr could affect the Sr signal for the individual. The proportion of Sr in comparison to δ^{13}C is therefore of interest to test if the Sr values for humans are comparable to the animal samples. Furthermore, it is imperative to investigate whether there is any correlation between the Sr and δ^{13}C distributions in the humans indicating a shift in the Sr values due to marine dietary input. Therefore when the tooth samples were subjected to Sr isotope analysis an additional sample of the enamel (apatite) was also processed for carbon isotopes for both the human and animal teeth. The $\delta^{13}C$ was measured using an automated carbonate preparation device (KIEL-III) and a gas-ratio mass spectrometer (Finnigan MAT 252) at the University of Arizona. Finely powdered enamel samples (of approximately 700 μg) were reacted with dehydrated phosphoric acid under a vacuum at 70 °C. The isotope ratio measurement was calibrated based on repeated measurements of NBS-19 and NBS-18 and precision is ±0.06‰ for $\delta^{13}C$ (1 sigma). Since all the samples for both Sr and δ13C are from the same tooth for all individuals, they reflect the same time period in both diet and provenance.

2.3. Öland geology, soil and strontium profile

The geology of southern Scandinavia, along with investigations approaching the bioavailable Sr variation for the area, are summarized in recent publications (Sjögren et al., 2009; Price et al., 2012a; Dobat et al., 2014). Scandinavia is a heterogeneous area dominated by old rocks such as granite and gneiss except to the very south, for example Denmark, Scania and Öland, where younger sedimentary calcareous bedrock prevails.

Seven samples of Ordovician lime and shale from two locations on Öland have been analyzed for Sr isotope ratios yielding values between 0.7089 and 0.7092 with the mean 0.7090 ± 0.0001 (Ebneth et al., 2001:2290). Nearby mainland Sweden is composed primarily of ancient granites and other metamorphic rocks formed around 1800 million years ago (Königsson, 1968; Wastenson and Fredén, 1994; Loberg, 1999) (Fig. 2A). These deposits lie on top of a Precambrian basement that is unexposed on the island. However, the western shore of the Kalmarsund strait is dominated by plains of exposed bedrock clay and silty shales.

Öland's northern part, the narrower half of the island, is an eroded landscape with considerably less soil thickness and associated biomass compared to the southern part. In the south the landscape is divided by two beach ridges (Landborgarna) formed by the fluctuations of the Baltic Sea due to both postglacial isostatic rebound and worldwide sea-level rise during the transition from the Pleistocene to the Holocene, effectively tracing the east and west coastlines. Between the ridges and the sea the lower coastal plains result in a more eroded landscape, especially prominent in the west and suitable for more extensive types of agricultural activities like grazing. The area encompassed between the beach ridges can be divided into a northern "midlands" with a fertile and varied landscape and the southern Alvar plain which is a heavily eroded large limestone barren, largely lacking in topsoil. The traces of human activity in the landscape are evident in the extensive Iron Age sites where both the settlements and burial grounds are focused along the beach ridges which function as excellent natural

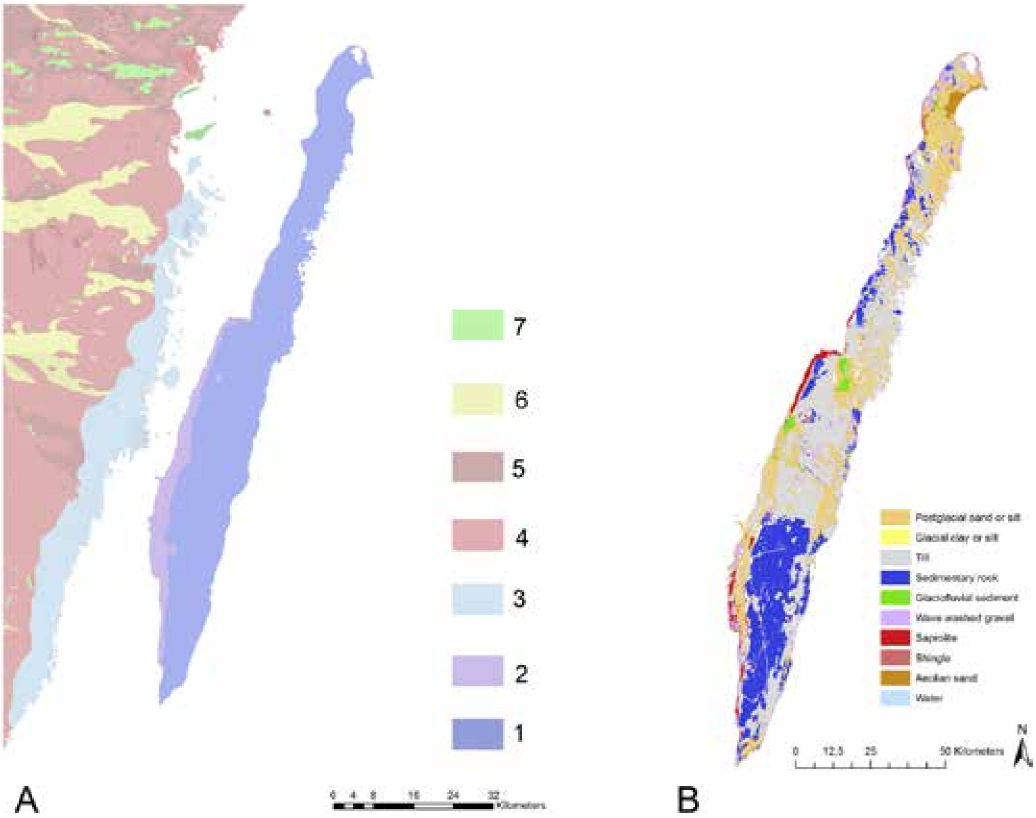

Fig. 2. A) The bedrock composition in Öland and the adjacent mainland. Legend: 1, Carbonate-rich sedimentary rock (limestone, dolomite, marble etc.). 2, Mica-rich sedimentary rock (shale, siltstone etc.). 3, Quartz–feldspar-rich sedimentary rock (sandstone, greywacke etc.). 4, Acidic intrusive rock (granite, granodiorite, monzonite etc.). 5, Acidic intrusive rock (granite, granodiorite, monzonite etc.). 6, Acidic volcanic rock (rhyolite, dacite etc.). 7, Ultrabasic, basic and intermediate intrusive rock (gabbro, diorite, dolerite etc.). 1–3: Mainly bedded rocks in the youngest bedrock unit (850–34 million years. 4–7: Partly gneissic rocks in the Svecokarelian orogen (1880–1740 million years). B) The dominant soils distribution in Öland. Both maps: Data © SGU. Basemap: Esri, HERE, DeKorme, MapmyIndia, ©OpenStreetMap contributors and the GIS user community.

roads in close connection with natural harbors or in the more fertile midlands (Bergsten, 1948; Regnell, 1948; Fallgren, 2006). The geologically uniform landscape of Öland does, however, have variations in the soils that could be of relevance for Sr provenancing. There are local deposits with glacial till and outwash resulting from the melting of the ice at the end of the last Ice Age (Regnell, 1948) that are likely to give higher Sr values since they would reflect older rock transported there and encapsulated in the ice cap. The deposits (see Fig. 2B for details) of till cover most of the fertile "midlands" and extend along the beach ridges while glaciofluvial deposits are distributed in limited patches. The majority of the island is similarly homogenously patchy with combinations of till, glacial sand and silt, and exposed bedrock in close relation to one another. The only exception is in the most northern part where there is a dominance of postglacial sand and silt. This makes it very likely that the heterogeneous Sr variation attainable when combing these soils would be similar across the island and would thus, in that sense, give a very homogenous, although potentially wide (in contrast to the bedrock values), local Sr signal common for the entire populated parts of the island. However, this assumption warrants verification by, for example, comparing animal samples of Sr in relation to their location and associated soil types. We will address this in detail in the results, 3.1.

As Öland is an island it is imperative to take seawater Sr from rainfall, sea spray and possible marine input in the diet (via marine animals or kelp as food/fodder or fertilizer) into account when investigating the Sr profile for the island. The brackish water of the Baltic has been characterized as having Sr isotopic ratios ranging 0.7092–0.7097 in modern water samples (Andersson et al., 1992) with fluctuations connected to the variations in salinity. The salinity for the Baltic during the Iron Age is quite modest, and it is considered more brackish than marine (c.f. Emeis et al., 2003).

2.4. Bayesian modeling, strontium mixing and the gravity model

Mixing models represents a statistical technique that estimates the proportion of different sources in the distribution of Sr. Recently, in isotopic studies on diet, mixing models are advocated as the preferred approach in order to acknowledge the complexity of the isotope data in replacement of the simple comparison of carbon and nitrogen isotopes in a biplot (see discussions in Hakenbeck, 2013; Arcini et al., 2014; Makarewicz and Sealy, 2015). In comparison, Sr isotopes are usually interpreted from a simple plot distribution or in a biplot with oxygen (cf. Slovak and Paytan, 2012). However, in some cases bioavailable Sr has been approximated by using linear mixing models based on geology and/or water (Montgomery et al., 2007; Killgrove, 2010). In the literature, however, we have found only one example of Bayesian mixing applied to Sr distribution with the purpose of provenancing archaeological plant material using modern plant material (Drake et al., 2014).

The distribution of Sr from Öland will contain a mixture of individuals born and raised on the island, and individuals that migrated to the island later in life. To visualize this distribution, we produce a kernel density plot for the Sr data from Öland. Human Sr data subject to immigration could be expected to be multi-modal. Normalization produces a probability density plot (pdf) of the distribution (i.e. sum to unity). Onto this, we plot a pdf of the bioavailable Sr in terms of a normal distribution given the mean and standard deviation of the local fauna (as defined in Section 3.1). The proportion of the distribution of human statistics for a given archaeological period that is excluded by the distribution of the bioavailable Sr represents our preliminary estimate of the proportion of non-local individuals. We have also compiled data on the bioavailable Sr from regions, or sources, in the vicinity of Öland. Each source is depicted as a normal distribution with the descriptive statistics derived from data of local fauna. These regions have been identified on archaeological grounds (see discussion under Section 3.2).

The isotopic signature of the mixture from Öland (δ_M) is defined as $\delta_M = \rho_1 \times (\delta_1 + \gamma_1) + \rho_2 \times (\delta_2 + \gamma_2) + \ldots + \rho_n \times (\delta_n + \gamma_n)$, where ρ_i is the proportional input of the i-th source to the mixture, δ_i the isotopic signature of the i-th source, and γ_i the isotope-specific fractionation of the i-th source (Moore and Semmens, 2008). We only have one isotope and further, we assume that the fractionation of this isotope is nonexistent with respect to the bioavailable Sr of the faunal samples. Of interest here are the proportions of the different sources with respect to the distribution of Sr from Öland. These proportions show the relative contribution of the different sources to the distribution of Sr on Öland. To estimate these we use a Bayesian mixing model (Phillips and Gregg, 2001, 2003; Moore and Semmens, 2008; Parnell et al., 2010) within the package Stable Isotope Analysis in R (SIAR) (Parnell and Jackson, 2011) for the R statistical program (R Development Core Team, 2007) to determine the probability distributions for the proportional contribution ($_i$) of each source *i*. Within the framework of Bayesian analysis we use priors as external information to guide the model in the likely range and for this, we could use both uninformative and informative priors. Using an uninformative prior is similar to saying that each source is equally likely to contribute. This is not very likely as we have sampled all the data from just one source. Instead, we would advocate the use of an informative prior that is derived from migration theory, namely the gravity model.

The gravity model for migration is based on Isaac Newton's law of gravity. The two basic principles are that (i) population size (likened to the gravitational pull of two masses) is a determining factor in migration, and that (ii) distance decay states that the further away two populations are, the less likely they are to interact. This model was in use in archaeology in the 1970s (c.f. Hodder and Orton, 1976; Renfrew, 1977) and recently, its employment in Geographical Information Systems (GIS) (Conolly and Lake, 2006) has led to the start of a "rediscovery" of it (Rivers et al., 2013). Network analysis, a theoretically very similar approach, has been employed much more frequently for studying regional contacts in archaeological context and especially in the last few years (e.g. Knappett, 2013; Leidwanger, 2013; Rivers et al., 2013). The close theoretical similarities between the gravity model and network analysis have recently attracted some interest in using them in conjunction (c.f. Rivers et al., 2013). When employing this approach the focus is mainly in mapping connections and contact, direct or indirect mobility, which could be more problematic to apply with strict relevance to human migration *per se* than the gravity model. The gravity model is a simplistic model and it could be argued that consequently it has limited relevance in explaining culturally influenced human behavior in a distant archaeological context. However, it is a thriving theory, constantly revisited and revised, within economics and sociology in approaching human migration and mobility in various complex historical and contemporary environments (c.f Molho, 1986; Karemera et al., 2000; Cohen et al., 2008; Simini et al., 2012) which speaks to its applicability and relevance. Its simplistic quality could be the key to its significant empirical success in these fields, as Molho (1986:407), in his review of migration theories, states: "The great value of the gravity model lies, therefore, not in any intrinsic contribution to migration theory, but rather in its *generality* …".

The gravity model of migration will be used to model potential migration between Öland (destination) and its neighboring regions (origins). The gravity model of migration is written $I_{ij} = a\,(P_i \times P_j)/D_{ij}^{b}$ where I_{ij} represents the predicted interaction between origin *i* and destination *j*, P_i the population size at origin *i* and P_j the population size at destination j, D_{ij} is the distance between the two populations, and finally a representing scaling and b a constant. In this context b is set as 2 as recommended in Hodder and Orton (1976:188) where the specific formulation used here is derived from.

Estimating population size (P) is arduous for archaeological populations. Traditionally, population size for a given area has been aggregated from house and floor sizes, settlement sizes, reconstruction of catchment areas, or modeling radiocarbon dates (Chamberlain, 2006). However, there is a tradition among archaeologists to identify regions based on the concentration of monuments such as grave fields, settlements, etc. These regions are well delimited from other regions, with apparently vacant or low-density regions in-between. Given that there is no major difference in economy between the regions (which is safe to assume in the relevant region discussed here), we assume that a larger region encompasses a larger population than a relatively smaller region, expressing a correlation between area and population size. The definitions of area sizes and locations are derived from earlier research (Callmer, 1991, 1992) and based on settlement and grave occurrence, primarily in the Later Iron Age. New sites have been investigated since, but the delimitation of areas with high population density as well as the definition of Iron Age settlement regions is largely intact (c.f. Svanberg, 2003; Björk, 2005). Considering the distribution of imported artefacts (c.f. Näsman, 1991; Sindbæk, 2013) these regions appear largely established already in the Early Iron Age which permits their use for the entire Öland sample. The relevance in using area size as a proxy for population size is a central theme also within the growing field of macroecology (Gaston and Blackburn, 2000; Burnside et al., 2012). We are not suggesting it is a universal answer to use area as a proxy for human population size, however, within the defined time period and region of south Scandinavia, we considered area a suitable proxy for population with regards to current knowledge on settlement patterns, subsistence, etc.

Thus, estimated areas (km^2) of archaeological regions will serve as a proxy for population size at the place of origin (P_i) and destination i.e. Öland (P_j). The distance between the populations, D_{ij}, was estimated using seafaring distance (a simple tracing of the coastlines) from the regions and measuring this distance from origin to destination. The selection of regions for comparison to Öland is based on access to baseline Sr values (from fauna) and by the geographical closeness (as distance decay is a key factor in the gravity model). The selected regions have an area approximated to estimates of settlement-area intensity in the Late Iron Age (c.f. Callmer, 1991:268; Callmer, 1992:102; Svanberg, 2003:134f). In the case of Bornholm it was extrapolated into two diverse areas as the Sr values are very variable across the island (Price et al., 2012a). However, since northern Bornholm only has two available faunal values it is too small to include in our dataset as a separate region. Some regions that potentially served as sources for immigration to Öland, such as the southern and eastern coastal areas of the Baltic, were also excluded from the analysis as they have not been systematically sampled for Sr baselines as of yet. The selected regions are defined in Fig. 3 with details available in Table 1. Studies focused on specific artefact types, especially during the Late Iron Age, have proposed intense seafaring contacts over the Baltic and beyond, all

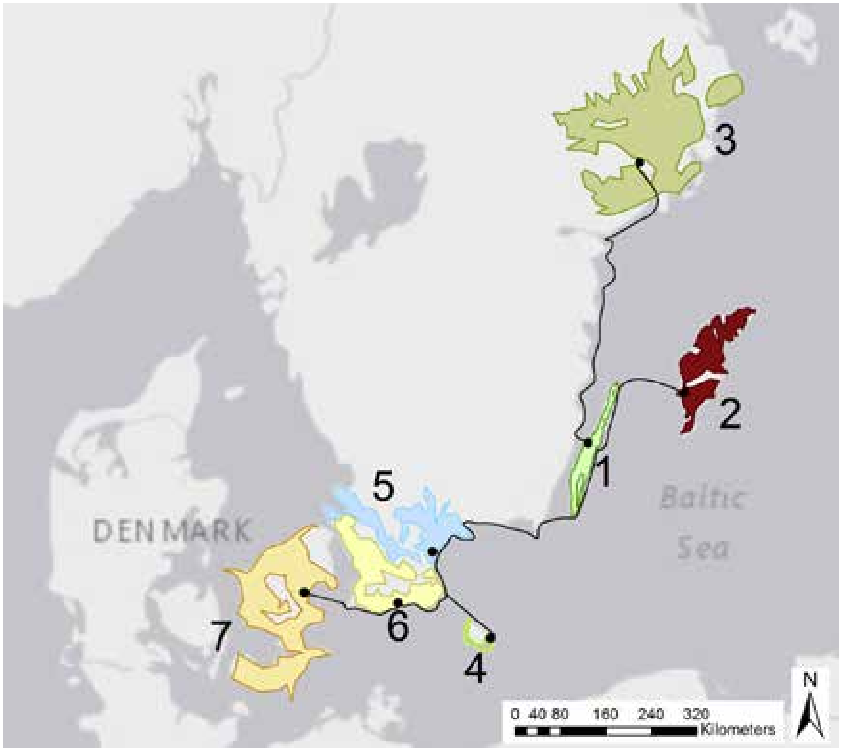

Fig. 3. The seven selected settlement regions for which we have established baselines with the routes from them to Öland indicated in black. The areas are mapped according to distribution maps in Callmer (1991: 268) and Callmer (1992:102) and following the classification in Hyenstrand (1984). For legend and details see Table 1. Basemap: Esri, HERE, DeKorme, MapmyIndia, ©OpenStreetMap contributors and the GIS user community.

Table 1
Calculation details for the gravity model. Area and distance calculated in ESRI ArcMap 10. Note: Distance by sea route was calculated between the significant Late Iron Age harbors (black dots in Fig 3) (defined according to distribution maps in Callmer, 1991: 268 and Callmer, 1992:102). The distances from the harbor closest to Öland in each region was calculated by tracing the coastline (as indicated by black lines in Fig 3). The source area was calculated in GIS after the adaption of maps in Callmer (1991: 268) to polygons.

	Source	Area (m^2)	Distance by sea route (m)	I ($M_{ij} = (P_i{*}P_{j9})/d_{ij}^2$)	$I_{\ddot{o}j}$	Prior (italics) early Iron age Pr = 0.3209	Prior (italics) Late Iron age Pr = 0.4644
1	Öland	3754053087	0,00000	–	–	$P_{\ddot{o}} = \mathit{0.6791}$	$P_{\ddot{o}} = \mathit{0.5356}$
2	Gotland	9261011808	130262	2048911721	0.4779	$0.4779{*}0.3209 = \mathit{0.1534}$	$0.4779{*}0.4644 = \mathit{0.2220}$
3	Mälaren	24885691704	329857	858615009,7	0.2003	$0.2003{*}0.3209 = \mathit{0.0643}$	$0.2003{*}0.4644 = \mathit{0.0930}$
4	S Bornholm	913177780	367675	25358700	0.0059	$0.0059{*}0.3209 = \mathit{0.0019}$	$0.0059{*}0.4644 = \mathit{0.0027}$
5	SW Scania	12920294258	362738	368626319	0.0860	$0.0860{*}0.3209 = \mathit{0.0276}$	$0.0860{*}0.4644 = \mathit{0.0399}$
6	NE Scania	10434069588	263298	565015464	0.1318	$0.1318{*}0.3209 = \mathit{0.0423}$	$0.1318{*}0.4644 = \mathit{0.0612}$
7	E Denmark	24295349902	465739	420473363	0.0981	$0.0981{*}0.3209 = \mathit{0.0315}$	$0.0981{*}0.4644 = \mathit{0.0455}$

the way up to northern Norway in the west (Callmer, 1992; Sindbæk, 2013)—apparently similar to the suggested sea routes in the Early Iron Age (Näsman, 1991) for Öland.

Priors for the Bayesian mixing analysis were estimated as follows. The proportion of the Sr distribution included by the bioavailable Sr represents our preliminary estimate of the proportion of local individuals on Öland ($P_{\ddot{o}}$) for a given period. Thus, $P_r = 1 - P_{\ddot{o}}$, represents the residual, non-local proportion of the distribution. Note that this will change between periods. Weighting this proportion with the normalized predicted interactions I, that is, $P_r \times I_{\ddot{o}j}$, where $I_{\ddot{o}j}$ is the normalized influence between Öland and region j, produces the prior. It should be kept in mind that enforcing a prior that has little or no support in the Sr data from Öland would produce a result where there is no variation in the posterior.

3. Results

3.1. Establishing Öland's local bioavailable strontium variation

Defining what is local in order to separate the humans into locals and non-locals is the most fundamental part of any Sr study. The methods for doing this are, however, somewhat varied (c.f discussion in Slovak and Paytan, 2012), leaving room for differential approaches and interpretation of the Sr data of human populations. Most frequently, sampling (presumably local) fauna that is either archaeological or modern is performed under the assumption that Sr is metabolized similarly in all animals. There have also been studies using soil, water, and/or plants in addition to animal samples (for example Evans et al., 2010; Frei and Frei, 2011; Grupe et al., 2011). When establishing the variation for Öland only animal samples were employed. We include data derived from this project in addition to the data already published by Fornander et al. (2011). When considering a bioavailable baseline based on fauna the question of diet could be of interest as a heavily marine-based diet (different in the sampled terrestrial fauna compared to the humans) could impact the Sr value. In order to investigate whether the Sr values could be biased towards seawater level for humans or animals, δ^{13}C was investigated in the enamel of the same teeth to proxy the proportion of the marine component in the diet. All but three human samples yielded δ^{13}C values in the analysis. Overall, the diet is not particularly marine-based in δ^{13}C, neither for

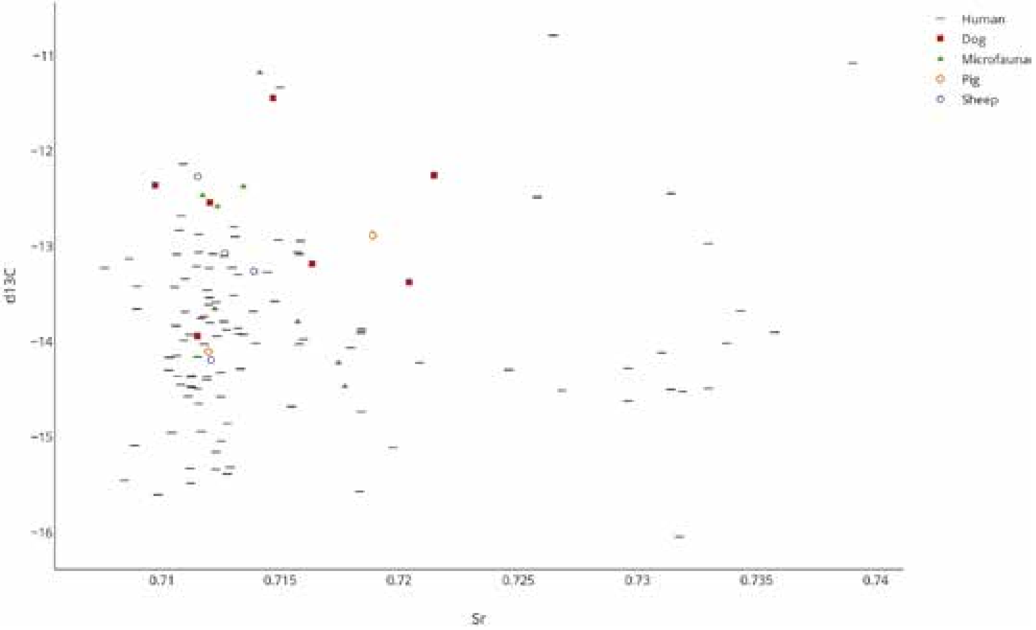

Fig. 4. Bivariate plot of δ13C in enamel and Sr for 106 individuals. Three more individuals only gave Sr values (0.7077, 0.7143 and 0.734923) but no δ^{13}C and are therefore not included in this graph.

humans nor dogs (Fig. 4, details in Appendix A) which are the two species that could be expected to potentially incorporate a significant proportion of marine resources in the diet. The statistical correlation between Sr and δ13C is very weak (Pearson's correlation coefficient 0.108238, n = 106). We therefore conclude that the diet should not affect the Sr values in the teeth to any degree relevant to an explanation of the variation seen in the sample. The graves and settlements on Öland are primarily coastal (as visualized in the grave distribution in Fig. 1) However, neither the human samples nor the animal samples show any indication of sea spray effect in the $\delta^{13}C$ values. Interestingly, one sheep appears to have more evidence of marine involvement in the diet as well as one microfauna, perhaps a tentative indication of kelp consumption or a sea spray effect. However, two of the sheep are from the most coastal of the settlements—literally on the beach—and still have terrestrial values in $\delta^{13}C$ (−13.28; −14.21; Sr 0.7139, 0.7121).

We selected 21 faunal enamel samples from Iron Age graves or settlement sites across the island (Appendix B; Fig. 5) to investigate the local baseline for bioavailable Sr on Öland. Domestic species (dogs, sheep/goats and pigs) as well as microfauna were included. The samples range from 0.709 to 0.721. The Fornander et al. data (2011) incorporate mainly archaeological faunal bone (5) and modern snails (4) in addition to enamel (2) from microfauna, roe deer, pigs and sheep. These authors chose to disregard two faunal samples (one pig and one sheep) in their definition of the baseline and consider them likely imports, but these are, however, included in our calculations using their data. The mean and distribution of the animals, presuming all to be local, should be a Gaussian distribution with only one peak. In our sample, the seven dogs stand out from the other animals and the distribution with them included there is a very clear divergence from both the rest of the animals and the distribution with the Fornander et al. data included (Fig. 6, details in Table 2) if the latter modeled as a normal distribution. We therefore chose to consider the dogs as a clearly migratory animal and inappropriate to include in estimations for a bioavailable baseline for Iron Age Öland, even if it is, of course, possible that some of them, with values that fit with the other animals, are local. The strong similarity of our data (excluding the dogs) and the Fornander data when viewed as distributions, and the large number of total samples (25), makes this a solid approximation of bioavailable Sr. The difference between estimated bioavailable Sr from that measured directly in the bedrock is +0.0050 (cf. Ebneth et al., 2001:2290). However, this type of offset is a common find (c.f. Price et al., 2002) and is not

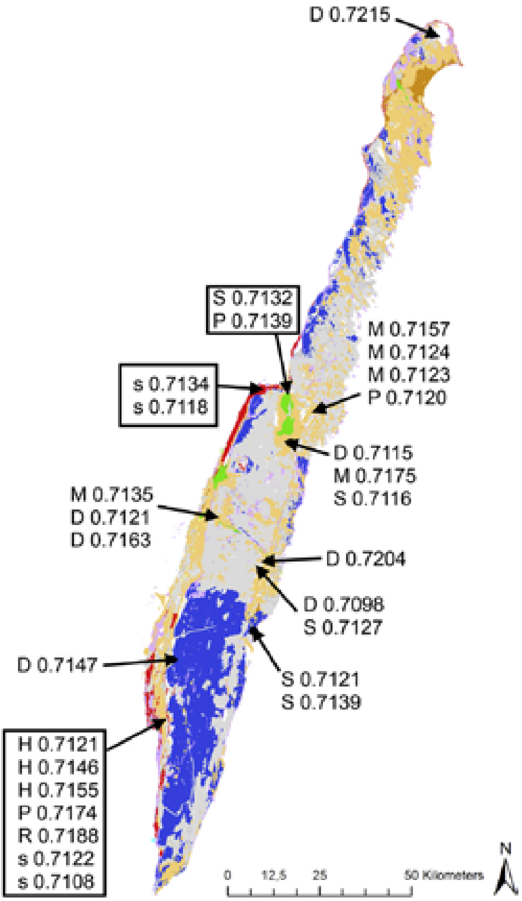

Fig. 5. Map of the distribution of the animal samples from Öland (this study) and Fornander et al. (2011) with regards to the soil distribution. D = dog, S = sheep/goat, P = pig, M = microfauna, H = hare, R = roe deer, s = modern snail. The previous study derived data from enamel, bone or shell as indicated in Fornander et al., 2011:6f. N = 21. For details see Appendix B. Basemap: Esri, HERE, DeKorme, MapmyIndia, ©OpenStreetMap contributors and the GIS user community. Data © SGU. For soil legend see Fig. 2B.

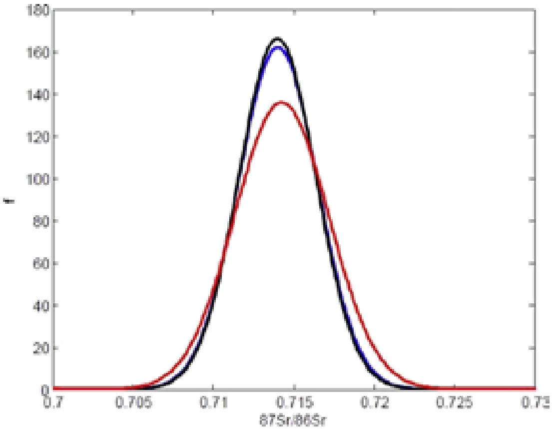

Fig. 6. Normal density plot of the animal values divided in three groups: i) the samples from this and Fornanders study but excluding the dogs (blue, N = 25), ii) all the animal samples (this study and Fornander et al., 2011) including the dogs (red; N = 32); iii) the samples in this study but excluding the dogs (black, N = 14)). For individual values see Table 2. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
Table listing details of the animal baseline calculations. Note the larger standard deviation when including the dogs and for the dogs as a separate group.

Sample	N	Mean	Standard deviation
This study, including dogs	21	0.7144	0.0032
This study, excluding dogs	14	0.7140	0.0025
Fornander et al., 2011, all faunal samples	11	0.7140	0.0024
This study excluding dogs, including Fornander et al., 2011	25	0.7140	0.0024
This study, only dogs	7	0.7152	0.0045

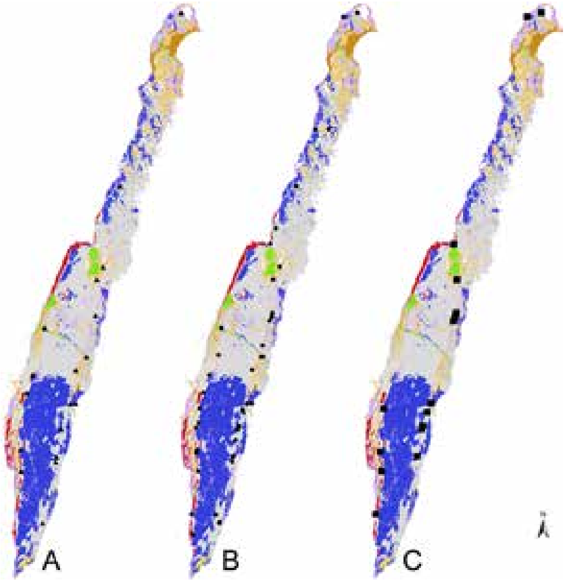

Fig. 7. The distribution of human samples divided into three groups. A: Sr below 0.7116, B: Sr 0.7116–0.7164, C: Sr above 0.7164. For soil legend see Fig. 2B.

surprising considering the varied soils, creating a heterogeneous mix of Sr but in a homogenous pattern across the island. This is supported by the animal Sr distributions over the island being homogenous in relation to small, very local potential differences in soil approximation of specific sites (Fig. 5).

The spatial patterning of the human samples shows no indications of correlation with geography or soil types (Fig. 7). The low, medium, and high Sr values are distributed according to the same pattern across the island.

3.2. Modeling the migration in Öland: Bayesian mixing and the gravity model

The first aspect to address is whether the two chronologically separated samples, Early and Late Iron Age respectively, are homogenous, i.e. from the same distribution. A randomization test was performed whereby the two-sample Kolmogorov–Smirnov statistic (D_{max}) is used. D_{max} measures the maximum difference between the samples converted to cumulative probability density functions (pdfs). The empirical D_{max} (0.2643) for the two distributions are compared to the D_{max} based on a randomization procedure (cf. Manly, 2006). The two datasets are merged into one, randomized, and split into new datasets of the same size as the original ones, and D_{max} is calculated. This randomization procedure was repeated 100,000 times. The proportion of D_{max} from the randomizations that exceeds our empirical D_{max} is understood as a test of the strength of the null-hypothesis, i.e. that there is no difference between the Early and Late Iron Age distributions of Sr from Öland. As is evident in Fig. 8, a randomized D_{max} exceeding our empirical D_{max} was rare, with a proportion of 0.0490. We reject the null-hypothesis and conclude that there is evidence for two different distributions of Sr.

For both Early and Late Iron Age, the spectrum of Sr from Öland, as evidenced by the kernel density plots (Fig. 9), is wider than the spectrum of the bioavailable Sr, suggesting immigration to the island from adjacent areas. With respect to the Early Iron Age, there is a major mode in the human Sr distribution at 0.712 compared with the bioavailable Sr that peaks at 0.714 (Fig. 9). There is also a strong tail that peaks between 0.730 and 0.735. The distribution in the Late Iron Age is similar, but with differences. There is a major mode peaking at 0.711, with a major development of the distribution to the left of this peak. We recognize the developed right tail that similarly peaks between 0.730 and 0.735 (Fig. 9). The Late Iron Age distribution is flatter than the distribution of the Early Iron Age, suggesting a greater influx of migrants to the island. This is reiterated in the proportion of the distribution included within the bioavailable Sr of Öland which amounts to 68% (0.6791) in the Early Iron Age sample, as opposed to 54% (0.5356) in the Late Iron Age sample.

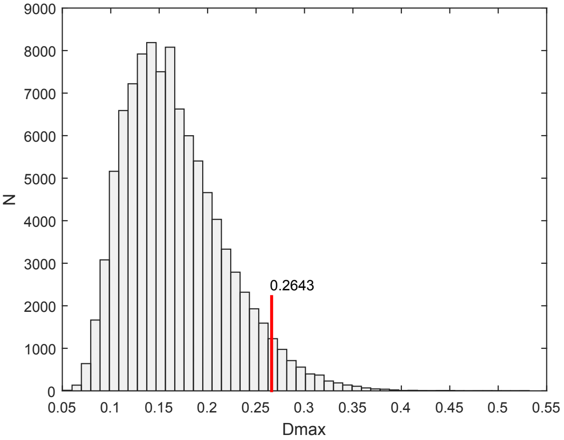

Fig. 8. Result of the randomization test of D_{max}, comparing the empirical D_{max} (0.2643) with a randomized sample of D_{max} iterated 100 000 times. The proportion of randomized D_{max} exceeding the empirical D_{max} is 0.0490.

In order to investigate the potential input proportions of our selected sources to the Sr variation seen in the human samples on Öland, we need to be able to compare the local variation in all the sources. Using probability density plots we visualized the baselines from Öland and the other sources (defined using local fauna in the manner used for Öland (see Table 3 for details) as normal distributions (Fig. 10). These regions were those identified on archaeological grounds as relevant areas of potential influence on Öland. It should be noted that the other regions are sampled in a less extensive manner than Öland. The sampling (in other studies), however, had the same specific purpose as ours for Öland: characterizing the Sr profile of the region for use in archaeological migration studies comparing to geological data. We therefore consider them sufficiently reliable for our purposes while referring to those studies for further details. This data was employed in the Bayesian mixing analysis below. It is notable that there is a significant overlap in the Öland and the northeast Scanian baseline making these virtually indistinguishable in Sr profiles.

For the sake of consistency, let us briefly comment on the results based on a uniform prior, i.e. an uninformative or flat prior, meaning that all sources are equally likely to contribute to the

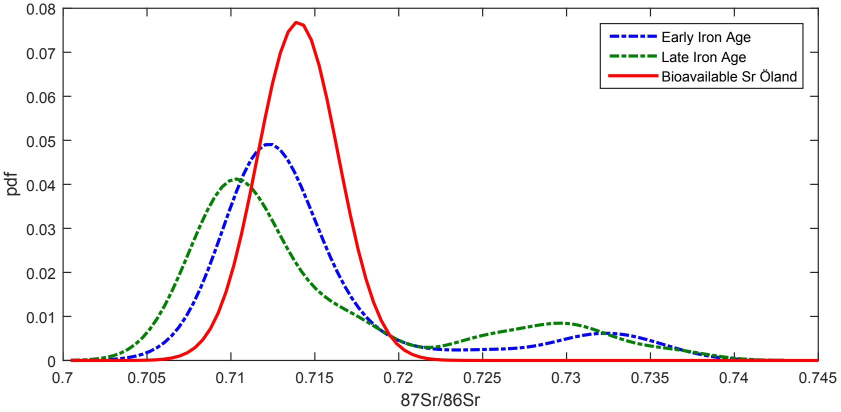

Fig. 9. Kernel density plots of the human data with the definition of the bioavailable Sr as defined this study (c.f. the blue curve in Fig. 6). Early Iron Age n = 71, Late Iron Age n = 38.

Table 3
The baselines estimated for the selected regions in the gravity model scenario. See Fig. 3 for the geographical definition of the regions. The data included here, from this and other studies, are samples of archaeological fauna (mammals) or modern (snails). In the case of the values from south Bornholm the many snail samples taken specifically on the site Ndr. Grødbygård were excluded as to not skew the region towards a local value from one site.

	Source	N	No of sampled sites	Mean	Std	Reference
1	Öland	25	11	0.7140	0.0024	this study; Fornander et al., 2011
2	Gotland	7	3	0.7106	0.0003	Arcini, personal communication 2015
3	Mälardalen	4	1	0.7335	0.0070	Bäckström, personal communication 2015
4	S Bornholm	6	6	0.7129	0.0020	Price et al., 2012a, excluding the snails from Ndr. Grødbygård
5	NE Scania	10	10	0.7138	0.0023	Price et al., 2012a, Dobat et al., 2014
6	SW Scania	6	6	0.7110	0.0006	Price et al., 2012a, Dobat et al., 2014
7	E Denmark	10	10	0.7099	0.0007	Price et al., 2012a, Dobat et al., 2014

distribution of Sr in the target population from Öland. Here, with respect to the Early Iron Age, all the south Scandinavian sources (including Öland, Gotland, S Bornholm, NE Scania, SW Scania, and E Denmark) contribute equally to the mix, with proportions of the posterior amounting to ~14%. The contribution to the mix by Mälardalen amounts to 15%. Clearly, the use of an uninformative prior does not shed much light on the apportionment of Sr from Öland. Thus, we concentrate our analysis on an informative prior based on the gravity model.

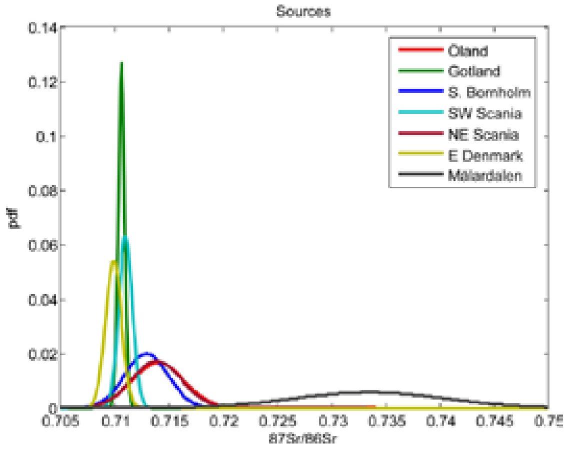

Fig. 10. Kernel density plots of the bioavailable data for the selected regions (see Table 3 for details).

The results of the Bayesian mixing model suggest the following apportionment of the distributions (Fig. 11, Table 4). During the Early Iron Age of Öland, 68% of the sampled population represented individuals with a local signature and 32% of the individuals with a signature that is non-local. The mixing analysis indicates that the non-locals derive from Gotland (15.24%), Mälardalen (6.86%), North East Scania (4.29%), East Denmark (3.31%), South West Scania (2.72%), and finally, South Bornholm (>1%). This result explains the shift towards lower Sr values of the dominant mode of the distribution, covering the span 0.710–0.711 and can be connected to the distribution from Gotland. The dominance of the north-northeastern connections is enforced during the Late Iron Age. Here, the percent locals decrease to 53%. The non-local signatures are dominated by Gotland (22.08%), Mälardalen (9.76%), North East Scania (6.26%), East Denmark (4.57%), South West Scania (4.16%), and finally, South Bornholm (>1%).

4. Discussion

Our analysis indicates that the proportion of non-locals is not

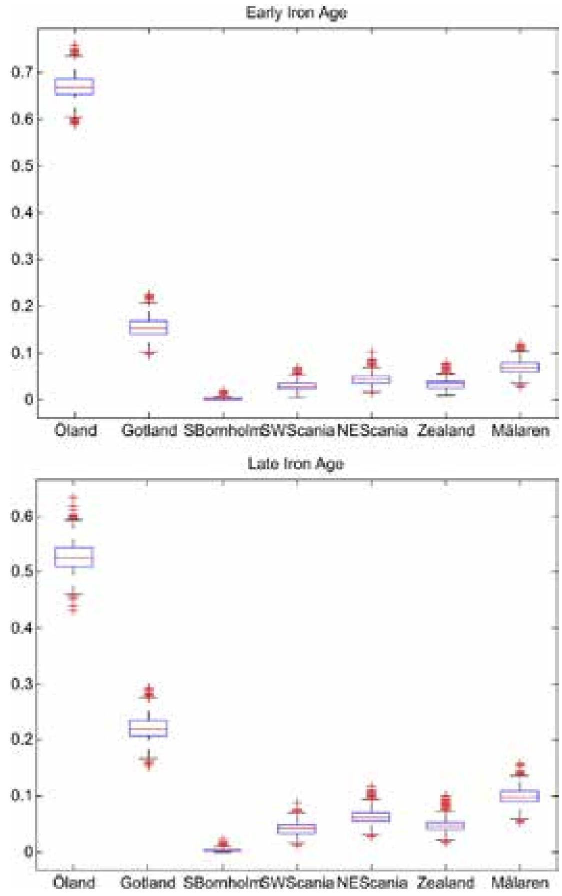

Fig. 11. The estimated proportion of the different areas from employing the Sr baselines in the Bayesian mixing. Early Iron Age n = 71, Late Iron Age n = 38.

homogenous; it increases during the Late Iron Age. However, the migratory pattern is more or less the same, dominated by the adjacent island of Gotland. One of our research objectives was the construction of a context in which to interpret human Sr values. Mapping the bioavailable Sr for estimating local range of Sr values is not a standardized procedure and is a process of interpretation in itself. For Öland we chose to use values from archaeological fauna from this study and a previous one (Fornander et al., 2011), showing that the Iron Age dogs were clearly deviating from the other animals in a similar way to the human samples. This highlights the importance of comparing faunal references within themselves.

The apportionment of Sr using both Bayesian mixing and the gravity model presents a probable explanation for the Sr distribution of the population on Öland, both as a whole and when viewed in the Early and Late periods separately. Since the posterior does show variation this demonstrates that the gravity model was able to guide us in the apportionment of the distribution of Sr in our sample. However, Bayesian mixing is not without caveats. A uniform, uninformative prior would smooth the contributions from the different sources and is not likely to be enlightening. In fact, it is even prone to overestimate the rate of immigration in our case (~86% non-locals in our Early Iron Age population from Öland). There is a potentially confounding effect when using an unguided principle for sourcing when the distributions of bioavailable Sr are identical between regions, such as between NE Scania and Öland in this case. On the other hand, had we enforced a prior with little support in the Sr distribution, we would face a posterior distribution with no variation (i.e. flat). However, further analysis of Bayesian mixing with the gravity model as a guiding principle in the formulation of the prior is needed, especially with respect to other geo-localized isotopes, not necessarily isotopes dependent on the climate (i.e. oxygen). It is important to note, however, that the Sr baselines from the selected areas could also potentially match other, more distant areas. The Danish baseline, for example, is similar to parts of England, and by depending on the current methods and just one isotope, it is not possible to be exclusive in the interpretation of a Sr baseline. There are also some practical problems to address before this approach can be truly applicable to and useful in other cases. The main issues are sampling strategies and the estimations of the specific gravity model parameters. The sampling is a question of economy. We recommend that future studies attempt to cover the entire population variation (c.f. discussion in Price et al., 2012b) and are no longer content with focusing on the deviant archaeological contexts. Additionally, regions without available baselines are also a major problem, though one that could be solved with a more explicit sampling. If the potential in explicitly sourcing the immigration to test the gravity model, or other models, was acknowledged, scholars could argue for this when drafting their research projects. In some cases the challenges in assessing the parameters for the gravity model (relevant resistance, i.e. mode of mobility and routes, and attraction force of the individual centers) could be more significant factors limiting the potential of this model compared to this specific case. This could possibly be

Table 4
The posterior distribution of proportion to the mix for the seven sources. Statistics correspond to the first quartile (Q1), Median and third quartile (Q3).

		Öland	Gotland	S Bornholm	SW Scania	NE Scania	E Denmark	Mälaren
Early Iron Age	Prior	0.6791	0.1533	0.0019	0.0276	0.0423	0.0316	0.0642
	Q_1	0.6532	0.1407	0.0005	0.0223	0.0364	0.0258	0.0602
	Median	0.6690	0.1524	0.0015	0.0272	0.0429	0.0331	0.0686
	Q_3	0.6864	0.1672	0.0032	0.0347	0.0495	0.0380	0.0783
Late Iron Age	Prior	0.5356	0.2219	0.0027	0.0399	0.0612	0.0455	0.0932
	Q_1	0.5090	0.2063	0.0009	0.0346	0.0544	0.0401	0.0890
	Median	0.5258	0.2208	0.0023	0.0416	0.0626	0.0457	0.0976
	Q_3	0.5426	0.2343	0.0045	0.0488	0.0699	0.0533	0.1084

addressed, we suggest, by employing network analysis and investigating its potential as a prior in substitute of the gravity model in the Bayesian mixing.

In the case of Öland the problem with estimating resistance (distance) was unusually uncomplicated due to the area being an island and seafaring being the most obvious mode of transportation. This limitation to only one communication strategy by default gives "equal" resistance to the other gravity centers. It has been suggested by Rainbird (2007) that islands can be seen as having fluid boundaries resulting in an aptitude to mobility (depending highly on the level of maritime technologies, of course). This could be seen as a specific *habitus*, developing from a need for contact different from that of the mainland inhabitants. This is one possible explanation of why the gravity model of migration apparently works so well on Öland. Furthermore, the calm waters of the Baltic Sea, encircled with much coast in proportion to open water would, especially when in comparison to the more perilous waters of the rest of the Atlantic or even the Mediterranean, make for a relatively "safe" environment to develop long distance travel thus making seafaring not only necessary, but attractive to a larger part of the population.

Öland seems to have had a gravitational pull on the populations, primarily in Gotland but also Mälardalen. It should be noted, however, that the sources (such as Gotland), with the only exception of Öland, have been characterized by few samples, making their profiles less well established. The suggested origins for the migrants are therefore tentative in comparison to the very specific and well investigated local signal for Öland. The overall migrational pull to Öland seems to have increased in the Late Iron Age compared to the earlier period but is still largely in line with the pattern of the gravity model. We interpret this observation as mainly due to an increase in the already established pull factors, rather than any new factors arising, i.e. the gravity model was prevailing. The proportion of migrants is, however, very large in both periods, with 32% in the earlier period and 47% in the later. We see these mobility patterns as an island characteristic, and its increase in the later period (mainly the Viking Age in our sample) as a direct reflection of the great advances made in seafaring during this period (due to technological innovations; c.f. discussion in Randsborg, 1991) in the Baltic.

Throughout this discussion the connection with the archaeological context was crucial in our attempt to understand migration—and on more than one level. The very direct connection of a person with the geology in the place where they grew up could be retrieved by Sr isotope analysis. The spatial context (i.e. the island characteristics) and the chronological context (i.e. the improved seafaring technologies in the Late Iron Age which paved the way for increased mobility) proved crucial to understand the migration patterns that emerged in our case of Öland. This leaves us with a new approach to the Viking expansions, taking ground in the local Scandinavian mobility patterns, particularly those of the Baltic, rather than viewing them from the side of the "colonized". We argue that these expansions could initially be a reflection of a long established mobility pattern starting on a more local scale due to less developed seafaring technology. This would be closer to the argumentation by Svanberg (2003:201ff) in considering the mechanisms behind the Viking Age expansions as part of a long term development rather than instigated by very specific socio-economic factors as suggested by many other scholars (for example Barrett, 2008, 2010). It is also possible to seek an explanation in line with those proposed by Ashby (2015:102) emphasizing that "travel seems to have had a prestige value" which, on its own, could be incentive for increased migration. In the future we hope to subject the cremation graves from Iron Age Öland to Sr isotopic analysis also (c.f. Harvig et al., 2014; Snoeck et al., 2015) as this would allow adding an important part of the population. There is also a need to address the effect of the internal migration within Scandinavia in relation to the Viking expansions and the more specific push or pull factors and how they changed to increase and include external migration.

This approach to migration demonstrated some specific results for the case study, but is relevant to archaeology in a general sense as well. The recent surge in studies dealing with network analysis has shown this to be a powerful tool in approaching human interaction and mobility from a cultural perspective. Likewise, the expanding DNA methods open up for new questions on the same note, and interaction and mobility but from a biological perspective. The method presented here allows us to discuss migration while still on a population level, and is also adding a geological and spatial connection by being linked to both biology and culture. However, in order to get a more complete understanding of the variation and resolution of human migration patterns, it is imperative to develop the methodology and combine Sr with other isotopes reflecting geology. Sr apportionment by Bayesian mixing of human samples is a method used to investigate migration among others, but what makes it a unique contribution is that this approach also offers a way of connecting Sr values with the cultural dimensions of interaction and mobility, i.e. with the context. This approach's most significant contribution is, nonetheless, that it allows isotopic analysis to be fully integrated on a theoretical level and permits the posing of new questions based on the full potential of the method rather than subjecting it to old questions formulated before these methods emerged. This is a timely contribution in light of the current discussions about the role of "Archaeological Sciences" in archaeology at large (c.f. review in Martinon-Torres and Killick, 2015), acknowledging the theoretical aspects of this discussion in particular, and is therefore also of relevance beyond migration studies as an example of this practice.

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Appendix A. Human tooth enamel samples from Öland, chronology, and isotopic data.

Lab id	ID	Tooth (FDI)	Sr	δ13C	Period	SHM (grave field)	Grave number
F7866	1002	34	0.7107	−14.38	Early Iron Age	9754	25
F7867	1003	34	0.7127	−13.13	Early Iron Age	31890	8
F7868	1004	34	0.7117	−14.96	Early Iron Age	31890	11
F7869	1005	35	0.7184	−13.93	Early Iron Age	31890	18
F7870	1006	25	0.7089	−15.11	Early Iron Age	25570	2
F7871	1007	34	0.7123	−15.17	Early Iron Age	23981	35c
F7872	1008	24	0.7131	−12.81	Late Iron Age	24542	I undre
F7873	1009	34	0.7149	−12.96	Early Iron Age	23494	21
F7874	1010	14	0.7120	−13.56	Early Iron Age	25570	2
F7972	1011	14	0.7130	−13.24	Early Iron Age	23280	
F7973	1012	44	0.7318	−16.06	Late Iron Age	28549	
F7876	1013	44	0.7113	−15.51	Late Iron Age	27365	35
F7877	1014	44	0.7135	−13.94	Early Iron Age	28364	108 F231 III
F7878	1015	44	0.7110	−13.36	Early Iron Age	25153	
F7879	1016	34	0.7198	−15.13	Late Iron Age	25096	
F7881	1019	24	0.7119	−14.42	Early Iron Age	31890	25
F7882	1020	34	0.7159	−12.96	Early Iron Age	1785/67 Bårby	6
F7883	1021	34	0.7118	−14.05	Late Iron Age	26454	3
F7884	1022	35	0.7349	NA	Late Iron Age	26454	2?
F7885	1023	34	0.7113	−14.49	Late Iron Age	26454	1?
F7886	1024	25	0.7296	−14.64	Late Iron Age	25129	
F7887	1025	32	0.7133	−13.32	Early Iron Age	23981	35b
F7888	1026	34	0.7184	−14.76	Late Iron Age	19726	1
F7889	1027	44	0.7314	−14.52	Early Iron Age	19726	13
F7890	1028	34	0.7077	−13.25	Late Iron Age	22486	
F7891	1029	34	0.7128	−15.41	Early Iron Age	18521	
F7892	1030	25	0.7330	−14.51	Late Iron Age	25657	
F7893	1031	34	0.7118	−13.75	Early Iron Age	27768	
F7894	1032	45	0.7113	−14.39	Early Iron Age	27702	39
F7895	1033	44	0.7296	−14.30	Early Iron Age	27702	2
F7896	1034	44	0.7133	−13.88	Early Iron Age	25130	–
F7897	1035	44	0.7184	−13.89	Early Iron Age	22348	–
F7898	1036	44	0.7314	−12.47	Early Iron Age	23267	1
F7899	1037	44	0.7077	NA	Early Iron Age	27702	1
F8193	1038	45	0.7358	−13.92	Early Iron Age	28364	6
F7901	1039	34	0.7128	−14.88	Early Iron Age	27702	36
F7902	1040	34	0.7330	−12.99	Early Iron Age	28514	
F7903	1041	24	0.7116	−14.67	Early Iron Age	24544	5
F7904	1042	44	0.7115	−13.23	Early Iron Age	24544	2
F7905	1043	44	0.7121	−13.25	Early Iron Age	24847	3
F7906	1044	44	0.7258	−12.50	Early Iron Age	27764	
F7907	1045	44	0.7110	−12.16	Late Iron Age	29352	24
F7908	1046	14	0.7158	−14.05	Late Iron Age	22291	–
F7909	1047	44	0.7116	−12.89	Early Iron Age	23981	47
F7910	1048	14	0.7123	−13.60	Early Iron Age	23981	35a
F7913	1051	34	0.7246	−14.31	Early Iron Age	24846	1
F7914	1052	24	0.7125	−15.06	Early Iron Age	24846	2 (?)
F7915	1053	44	0.7148	−13.60	Early Iron Age	27702	90
F7916	1054	24	0.7120	−14.38	Early Iron Age	27702	140
F7917	1055	44	0.7104	−14.19	Late Iron Age	22231	4
F7918	1056	44	0.7113	−14.37	Early Iron Age	27125	
F7919	1057	45	0.7124	−13.96	Late Iron Age	29352	13
F7920	1058	34	0.7108	−14.47	Late Iron Age	28364	134
F7921	1059	44	0.7103	−14.32	Late Iron Age	23494	20
F7922	1060	45	0.7107	−13.10	Late Iron Age	23494	19
F7923	1061	24	0.7127	−13.81	Early Iron Age	24543	3
F7924	1062	24	0.7160	−13.99	Early Iron Age	19197	2?
F7925	1063	44	0.7116	−14.18	Early Iron Age	22126	
F7926	1064	44	0.7125	−14.59	Late Iron Age	22394	
F7927	1065	45	0.7391	−11.10	Late Iron Age	6393/75	3
F7928	1066	14	0.7120	−13.48	Late Iron Age	6393/75	10
F7929	1067	45	0.7180	−14.09	Late Iron Age	6393/75	20
F7930	1068	34	0.7265	−10.81	Late Iron Age	29352	18
F7931	1069	34	0.7105	−14.97	Early Iron Age	29764	–
F7932	1070	44	0.7125	−14.34	Early Iron Age	29764	Ind II
F7934	1071	14	0.7143	NA	Late Iron Age	27513	3
F7935	1072	44	0.7123	−15.36	Early Iron Age	12097	–
F7936	1073	44	0.7085	−15.47	Late Iron Age	27771	1
F7937	1074	44	0.7128	−13.89	Early Iron Age	25098	
F7938	1075	14	0.7113	−14.50	Late Iron Age	28364	164

(*continued*)

Lab id	ID	Tooth (FDI)	Sr	δ13C	Period	SHM (grave field)	Grave number
F7939	1076	44	0.7337	−14.04	Early Iron Age	28364	136
F7940	1077	35	0.7269	−14.53	Late Iron Age	22231	8
F7941	1078	44	0.7184	−15.59	Late Iron Age	21367	A5
F7942	1079	44	0.7115	−14.51	Early Iron Age	31890	12
F7943	1080	14	0.7134	−14.31	Early Iron Age	31890	5
F7944	1081	44	0.7106	−13.45	Early Iron Age	31890	6
F7945	1082	34	0.7110	−14.00	Early Iron Age	24543	2
F7946	1083	34	0.7209	−14.24	Early Iron Age	24543	1
F7947	1084	34	0.7090	−13.68	Late Iron Age	24542	25
F7948	1085	24	0.7108	−12.85	Early Iron Age	24866	G
F7949	1086	44	0.7087	−13.15	Late Iron Age	29352	25
F7950	1087	24	0.7112	−14.59	Early Iron Age	23267	2
F7951	1088	34	0.7140	−14.03	Late Iron Age	23267	3
F7952	1089	34	0.7122	−13.10	Early Iron Age	23267	4?
F7953	1090	34	0.7112	−15.35	Early Iron Age	27702	37
F8208	1091	24	0.7106	−13.85	Early Iron Age	29352	113
F7954	1092	44	0.7158	−13.08	Early Iron Age	12142	9 över?
F7955	1093	44	0.7158	−13.10	Early Iron Age	12142	9 under
F7956	1094	24	0.7116	−13.08	Early Iron Age	25132	
F7957	1095	34	0.7112	−13.95	Early Iron Age	25605	
F7958	1096	34	0.7133	−13.94	Early Iron Age	24813	II
F7959	1097	34	0.7090	−13.44	Late Iron Age	22763	–
F7960	1098	34	0.7117	−13.77	Early Iron Age	4186/73	3
F7961	1099	34	0.7131	−13.54	Early Iron Age	1785/67	5
F7962	1100	24	0.7310	−14.14	Early Iron Age	25021	
F7963	1101	44	0.7319	−14.54	Late Iron Age	21367	24
F7964	1102	36	0.7121	−13.82	Early Iron Age	23349	3 (?)
F7965	1103	14	0.7139	−13.70	Early Iron Age	21368	37 undre
F7966	1104	44	0.7129	−15.34	Early Iron Age	21368	37 övre
F7967	1105	34	0.7099	−15.62	Late Iron Age	28364	108:I:169
F7968	1106	44	0.7343	−13.70	Early Iron Age	28364	108:IV:282
F7880	1107	14	0.7131	−12.92	Early Iron Age	19765	13
F7970	1108	44	0.7110	−13.71	Late Iron Age	Sb	Individ I
F7971	1109	34	0.7109	−12.70	Late Iron Age	Sb	Individ 2
F8219	1110	44	0.7145	−13.29	Late Iron Age	26239/27121	29
F8220	1111	37	0.7155	−14.70	Early Iron Age	26733/26732	26
F8221	1112	47	0.7120	−13.63	Early Iron Age	27121	2
F8222	1113	47	0.7107	−14.17	Late Iron Age	26239	8
F8223	1114	48	0.7150	−11.35	Early Iron Age	26732	15

Appendix B. Faunal samples from Öland, chronology, and isotopic data

Lab id	Animal	Tooth	Sr	δ13C	Period
F8172	Dog	PM4 lower	0.7147	−11.46	Early Roman
F8173	Dog	M2 lower	0.7215	−12.27	Vendel
F8174	Pig	Enamel fragment molar/premolar	0.7120	−14.12	Early Iron Age
F8175	Pig	P3 dxt	0.7189	−12.90	Iron Age
F8176	Microfauna	Mandible/molars	0.7158	−13.81	Early Iron Age
F8177	Microfauna	Mandible/molars	0.7124	−12.60	Early Iron Age
F8178	Microfauna	Mandible/molars	0.7177	−14.49	Early Roman
F8179	Dog	I2 max sin	0.7164	−13.20	Early Roman
F8180	Microfauna	Enamel	0.7142	−11.20	Early Roman
F8181	Sheep/goat	M3 max sin. adult	0.7139	−13.28	Migration
F8182	Sheep/goat	M1 mand. subad./adult	0.7121	−12.56	Migration
F8183	Microfauna	dentes	0.7123	−13.67	Early Iron Age
F8184	Microfauna	dentes	0.7135	−12.39	Roman Iron Age
F8185	Dog	m1sin	0.7121	−14.21	Roman Iron Age
F8186	Microfauna	dentes	0.7118	−12.48	Viking
F8187	Dog	P3 max dxt	0.7204	−13.39	Vendel
F8188	Sheep/goat	M1 max	0.7116	−12.29	Early Roman
F8189	Dog	I3 max sin	0.7115	−13.96	Early Roman
F8190	Microfauna	dentes	0.7175	−14.24	Early Roman
F8191	Dog	Canine	0.7098	−12.38	Iron Age
F8192	Sheep/goat	P4 max sin	0.7127	−13.09	Roman Iron Age

Mikrofauna = mikromammalia. small mammal. rodent.

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PAPER III

Shifting diet, shifting culture? A bioarchaeological approach to island dietary development on Iron Age Öland, Baltic Sea

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Shifting diet, shifting culture? A bioarchaeological approach to island dietary development on Iron Age Öland, Baltic Sea

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ABSTRACT

Objectives

The diet and subsistence in Iron-Age Öland is debated as earlier studies and different archaeological sources seemingly provide conflicting interpretations. The objectives of this study are therefore to: (i) add new insights on diet and (ii) investigate the chronological variation in detail. It is common in studies of diet to investigate differences between datasets defined by archaeological periods (determined by artifact typology), but it is rare to explore whether these dietary changes are, in fact, well correlated with these temporal categories or not.

Materials and methods

Stable isotope analysis of 108 individuals and 25 animals was used to interpret diet in comparison to data from earlier studies. Different values of TLE (Trophic Level Effect) for $\delta^{15}N$ were compared for interpretations of diet. Of the 108 individuals, 42 were subjected to ^{14}C analysis in this study.

Results

The isotopes from Iron-Age animals on Öland indicate that the local, contemporary ecology is specific. The human isotope values show chronological development both when pooled in chronological groups by typology and by more specific ^{14}C chronology.

Discussion

The new samples of animals as well as the use of 5‰ TLE for $\delta^{15}N$ values results in the diet reinterpreted as mainly domesticate-based, with at least two shifts in diet occurring in the Iron Age. The use of ^{14}C dates in connection with the stable isotope results indicates a dietary transition occurring between 200BC to AD200, a date range that spans two typologically determined time periods.

1 INTRODUCTION

The one thing that archaeology demonstrates about humans is that nothing is constant—sooner or later the world changes. Understanding the timing of shifts in significant elements of human everyday life, such as subsistence and diet, is the first step that must be taken in order to investigate their motivation. The "when" and "what" comes before the "why". Human remains are the most direct link to human diet available in an archaeological context and all other sources (such as archaeozoological and paleobotanical assemblages, settlement patterns, artefacts, written sources) are by definition secondary. Investigation of diet by isotopic analysis of human remains, for example through the long established $\delta^{13}C$ and $\delta^{15}N$ in bone collagen, is thus a direct way to access large scale dietary patterns. Food practice and culture are closely linked and dietary shifts are often discussed as linked to cultural shifts. In archaeology a study of chronological variation in any material is often dependent on changes in material culture typology–relative chronology– assigning it to time periods defined regionally (such as for Scandinavia at large), due to its convenience and low cost. This method of dating burials allows to pool for example isotope results chronologically and investigate if there are any differences in isotope variation (diet) between these periods. However, it does not allow to pinpoint if a dietary shift was to occur within a time period. One way of avoiding a potentially circular argument is therefore to investigate a more specific chronology in tandem with the dietary isotopes, as is possible with ^{14}C from human bones. This approach could allow tracing if local dietary shifts would traverse the regional archaeological typology defined by material culture. Is shifting culture (i.e. archaeological typology) related to a shifting diet? Or is there simply no connection?

The island of Öland is situated adjacent to the Swedish mainland in the Baltic Sea (Fig. 1). With an area of 1,342 km2, it is the second largest island in Sweden. In Scandinavia, the Iron Age (500 BC–AD 1050) is defined regionally in two parts: the Early Iron Age (500 BC–AD 400) and the Late Iron Age (AD 400–1050) which in turn are further subdivided (Table 1). Öland is conceived of as having enjoyed a golden era of regional magnitude as well as enduring potential periods of crises in the Iron Age, not different from the rest of Southern Scandinavia during this time. The subsistence economy on Öland throughout the Iron Age is, at

	Period	Subperiod	Chronology
Early Iron Age (E IA)	Pre Roman Iron Age (PR IA)		500 BC-AD 0
	Roman Iron Age (R IA)	Early Roman Period	AD 0-200
		Late Roman Period	AD 200-400
Late Iron Age (L IA)	Migration Period		AD 400-550
	Vendel Period		AD 600-800
	Viking Age		AD 800- 1050

Table 1: Chronological definitions used in this study.

least for a part of the period (primarily AD 200–700), quite well understood from the secondary sources. The extensive partitioning of the landscape of pastures (virtually unprecedented in scale in northern Europe), stone house settlements, and the evidence from archaeozoology and paleobotany, as well as later historical sources, all reveal an island intensely focused on animal husbandry and grazing and likely suggest a diet high in animal protein. The chronology of these sources is patchy and does not cover significant parts of the Iron Age (Boessneck and Von den Driesh, 1979; Fallgren, 2006; Grabowski, 2011). The partitioning wall systems are interpreted in Öland as designed to accommodate sustaining an extensive population of grazers, either cattle or sheep. This landscape feature alone should therefore reflect a subsistence heavily relying on animal protein (meat and/or milk) (Stenberger, 1933; later Hagberg, 1967; Herschend, 1980; Fallgren, 2006). The initiation of this system is believed, by approximation to similar features elsewhere in Sweden, to have taken place sometime between AD 200–600 but the exact timing is debatable (discussions in Fallgren, 2006; see below).

Two previous isotopic studies including Iron Age human remains from Öland have been published recently (Eriksson et al., 2008; Howcroft et al., 2012). In contrast to other archaeological sources they conclude the diet was mainly dependent on freshwater fish. The latest study (Howcroft et al., 2012) focused on intra-individual dietary changes, with an emphasis on child isotope variation whilst the earlier study (Eriksson et al., 2008) was mainly comparing the Iron Age diet to that in earlier periods on Öland. The population level (more adults than children) and detailed chronology are so far unexplored, and only parts of the Iron Age have been investigated. A large number of graves from Öland are dated widely and only by a relative typology (grave form, not artefacts) and the grave-fields (and even a single stone cist) include burials from multiple subperiods of the Iron Age. A further complication is the extensive manipulation of the human remains (i.e. reopening, reburials and looting of burials) making it difficult to relate the artefacts (and thereby their dates) to the remains in many cases. An extensive campaign of ^{14}C- dating would therefore permit a more complete section of the population to be available as well as allowing the possibility to study dietary change in a more detailed level than before. This study is therefore the first of its kind, seeking out and sampling all periods of the Iron Age with the aim of sampling individuals from the entire chronological period rather than one subgroup.

The aim of this study is to investigate diet using the stable isotopes δ^{13}C and δ^{15}N and its chronological development on Öland on a population basis. Öland's specific island ecology is taken into account by investigating the local contemporary food web through isotopes. In this paper, new results from stable isotope analysis of δ^{13}C and δ^{15}N in bone collagen in the uncremated human remains of 109 individuals from Öland, dated by radiocarbon (n=47) and/or archaeological context (n=60), are presented and integrated with data from earlier studies. Alongside this, 26 new faunal samples are presented dating from Iron Age Öland. Using this new dataset, it will be investigated whether:

(i) any dietary shifts (isotopic shifts) occur during the Iron Age on Öland when comparing the subperiods defined by typological and relative chronology;

(ii) the chronology available from ^{14}C dates can give any new information relating to the timing of any dietary shifts or disprove shifts occurring at all;

(iii) it is possible to identify a diet with a high reliance on domesticates (grazers) and a high protein content that could correspond to the practice of animal husbandry indicated by the extensive partitioning systems. If so, does the chronology of the shift to this diet match any of the options for the archaeological chronology of the partitioning system, or does it suggest a new one?

Investigating these research questions will drive forward not only the understanding of Iron Age society on Öland, but will also provide a basis for an approach that combines isotopic analysis of diet and ^{14}C dating.

Fig. 1: The location of Öland in the Baltic Sea (left) and the distribution of the samples over the island (right). Esri, HERE, DeKorme, MapmyIndia, ©OpenStreetMap contributors and the GIS user community.

2 BIOARCHAEOLOGICAL BACKGROUND

2.1 The secondary evidence for Iron-Age diet

Historically, Öland has been characterized as relying on animal husbandry rather than crops and with an, at periods, significant fishing industry (mainly herring) in the Baltic Sea, especially so in the fifteenth century when the earliest written accounts of subsistence appear (Nordmark, 1949). This is likely a combination of Öland's specific island climate and a landscape and soils with limited potential for crop production in comparison to pastures for animal husbandry. This subsistence strategy, judging from the archaeological evidence detailed below, could well be dating back to the Iron Age.

The Iron Age diet can be approached from a variety of secondary sources but the chronological coverage is unclear and lacks detail. Despite this, archaeozoological, paleobotanical, and other archaeological evidence all indicate a subsistence relying heavily on animal husbandry. The archaeozoological assemblages from Öland in the Iron Age are quite coherent, perhaps a reflection of a controlled subsistence practiced within the forts (that most material is derived from) compared to ordinary settlements during the period AD 200–700. In the fort assemblages, besides the three most common domesticates—sheep/goat (Ovis aries/Capra hircus), cattle (Bos taurus), and pig (Sus scrofa domesticus) (Sellstedt, 1966; Boessneck and Von den Driesch, 1979; Hallström, 1979; Bäckström, 1986; Vretemark and Sten, 2008)—only domestic fowl (specifically chicken; Gallus gallus domesticus) is considered a potentially significant part of the diet (Vretemark and Sten, 2008). Fish (mainly herring) is also considered a potentially underestimated dietary source, though minutely significant compared to its importance in the medieval period in the very same sites (Hallström, 1979; Vretemark and Sten, 2008). The low representation of fish in assemblages is a question of taphonomy as their generally small size requires extensive sieving during excavation to retrieve them and they are also less likely to be well preserved. Fowling is also suggested as having some importance in Gråborg at least, although of less importance than the domestic fowl (Vretemark and Sten, 2008). The kill off patterns for sheep and cattle suggest that both milk and meat production were primary (Boessneck and Von den Driesh, 1979; Vretemark and Sten, 2008). Moreover, a recent study of the Eketorp ringfort involving DNA concluded a dominance of cows over bulls which was interpreted as revealing a high reliance on milk (more so than meat) in the Iron Age than in the later phase of occupation (Early Medieval) where fish also played a much greater part (Telldahl et al., 2011).

In addition to these assemblages covering circa AD 200–700, there are two later sites, non-forts, Östra Wannborga and Köpingsvik (AD 550–1050). These are summarized as having a greater proportion of pigs than the previously detailed assemblages, perhaps due to their slightly later date (including the Vendel period to the Medieval period) or potential urban connotations (discussion in Fallgren, 1994). Östra Wannborga probably dates mostly to the Vendel and Viking ages, although the specific dates of the bone material in particular are, to a minor extent, potentially compromised as stone age burials were also found within the site (Fallgren, 1994). The osteological report from Östra Wannborga (Bäckström, 1994) details a varied diet and subsistence, including fishing (both freshwater and marine species) and fowling, as well as use of the main domesticates (cattle, sheep/goats and pigs) and to a lesser extent, other domesticates (horses, domestic fowl, primarily geese) and wild game (seals, beavers, hares).

In conclusion, the material for interpreting diet from the archaeozoological assemblages is limited due to the few materials available and from the fact that not all periods of the Iron Age are represented in material culture, particularly the Pre Roman Iron Age. Judging from the Östra Wannborga and Gråborg assemblages, it is a possibility that the extent of fishing and fowling is significant at least during the middle and later parts of the Iron Age. The main focus, however, is clearly on the domesticates (mainly the two grazers cattle and sheep) as these are the most well-represented in the assemblages. How their representation compares is difficult to tell considering the greater extensive taphonomical loss of the more sensitive fish and bird bones.

There are 1302 house foundations (excluding those within the ring forts) in Öland and only 22 are excavated (Fallgren, 2006). The results from the excavations give dates for only 15 houses, spanning from the last centuries BC up to approximately AD 1300. Fallgren (2006) gives a generic date for the houses as AD 200- 1300 since this is what the artefactual typology supports (as the ^{14}C analyses giving older dates are all older than 1980 and may thus be unreliable). Three-aisled houses with a byre for stalling of animals are frequent on Öland during this period (Fallgren, 2006). Stalling of animals would facilitate access to milk as a dietary resource for humans. The division of the landscape was made using partitioning stone walls ("hägnadssystem") which appear to be more or less concurrent with the house foundations (Fig. 2), and which are dated by comparison to similar phenomena in Scandinavia, mainly to AD 0-700 (the Roman Iron Age through to the Vendel Period) (discussion in Fallgren, 2006). This means settlement remains clearly coincide chronologically with the archaeozoological assemblages but it is unclear whether they could date even further back, covering more of the earlier part of the Iron Age. The situation on the neighboring island of Gotland is very similar in terms of settlement, houses, and partitioning, and is dated mainly to AD 200–600 through typology (Carlsson, 1979). On the Swedish mainland, similar partitioning occurs at least as early as AD 100 but is roughly believed to cover the same period (discussion in Fallgren, 2006). In a

Fig. 2: The intensity of settlement structure on Öland. Left: the extent of house foundations (primarily Iron Age) of stone. Right: the extent of partitioning stone walls (primarily Iron Age). Data source: http://www.fmis.raa.se/cocoon/fornsok/search.html?utm_source=fornsok&utm_medium=-block&utm_campaign=ux-test, accessed 2nd October 2015, processed in ArcGIS by author

detailed inventory of the settlements on Öland, using multiple sources, Fallgren (2006) put forward the idea that in Öland the partitioning walls could be a later feature added to existing settlements during the Viking Age (AD 800–1050). Since then, partitioning was investigated in the southern part of Scandinavia, in Scania in particular. Already in the centuries around 0 AD (from 200 BC–AD 300), at the time when settlements appear to be focused in villages, the partitioning also seems to be established (e.g. Friman, 2008; Björhem and Skoglund, 2009). There are clearly many possibilities for the more specific chronology of the partitioning systems on Öland spanning almost a thousand years, an issue the isotopic results could potentially help further our understanding of.

Archaeobotanical analysis has shed some light on the local situation in Öland during the Iron Age (Königsson, 1967, Königsson, 1968; Hansson and Bergström, 2008; reviewed in Grabowski, 2011) but, the record is incomplete. In the Early Iron Age, barley was primarily grown with rye and oat being introduced at the end of the Roman Iron Age. During this period, C4-plants (specifically millet), that give higher $\delta^{13}C$ isotopic values (similar to a marine-based diet) are not likely to have been grown or imported to any significant extent in South Scandinavia. Indeed, there are only a few traces from the Early Iron Age and none from the Later (Grabowski, 2011). At Eketorp, the paleobotanical analysis was interpreted as indicating that the land was farmed to its maximum potential and that some cereal was also likely imported (Helbæk, 1979). Hansson and Bergström (2008) support the idea of import and emphasize that, at least to some extent, cereals probably had a high status on Öland. Further, Enckell et al. (1979), based on a combination of archaeobotanical and archaeological evidence, argue for an ecological collapse of the sensitive ecosystem in the Alvaret lime barren, probably due to overgrazing and overpopulation during the Roman period.

2.2 Stable isotope analysis and diet

Experimental studies have shown that the nitrogen in bone collagen derives from dietary protein while carbon can derive from carbohydrates and lipids (c.f. Ambrose and Norr, 1993; Warinner and Tuross, 2009). In paleodietary studies, the most commonly employed isotopes, $\delta^{13}C$ and $\delta^{15}N$, are measured from bone or dentine collagen; therefore they do not reflect the complete diet because collagen reflects the protein component of the diet (c.f. discussion in Van Klinken et al., 2000). The level of $\delta^{13}C$ reflects the proportion of terrestrial or marine/C4 plant resources in the diet and the level of $\delta^{15}N$ corresponds to the trophic level in the food chain and protein component. The first caveat is that because $\delta^{15}N$ only reflects the protein component in the diet, there can be the effect of “scrambling” of the isotopic signals when the protein component is insufficient and carbohydrates take its place, causing an offset between $\delta^{13}C$ and $\delta^{15}N$ dietary signals (Schwarcz, 1991 and discussion in Schwarcz and Schoeninger, 2011; Makarewicz and Sealy, 2015). Another caveat is that the isotope values measured in bone collagen, in multiple experiments, have been observed to be proportionally different than those in the bones of the animals (or plant tissues) eaten. This is usually referred to as the diet-tissue fractionation, or trophic level effect. As of yet, a specific mechanism has still to be attributed to this phenomenon (Schwarcz and Schoeninger, 2011) which makes it a significant factor impairing our understanding of paleodietary variation. Further, $\delta^{13}C$ and $\delta^{15}N$ are affected differently by fractionation which is why specific offsets for each are necessary. Experimental studies have suggested estimates for the offsets between animal bone isotope values and human bone values. The fractionation of $\delta^{15}N$ (human-diet spacing) has a variation between 1–6‰ (c.f. review in Hedges and Reynard, 2007; O’Connell et al., 2012). As pointed out recently by Bogaard and Outram (2013), isotope analysis is based on contemporary observations of cause and effect (i.e.

Binford's Middle Range Theory). This inherently means that our interpretations of archaeological data will have to change should the contemporary observations give new insights. Almost a decade ago, Hedges and Reynard (2007) suggested a fractionation of 4±1‰ should be considered. They recommended an emphasis on the higher values (i.e. 5‰), as this would better explain paleodiets due to the otherwise very high proportions of animal protein in archaeological populations' diets that actually surpass even the high-protein diets of humans today. Recent results from a controlled dietary study (O'Connell et al., 2012) also support an even higher level, presenting 6‰ as the most likely relevant level for humans. The TLE span chosen for the $\delta^{15}N$ has a huge significance for the interpretation of human diet with regards to animal protein reliance, as noted in particular by Hedges and Richards (2007) and O'Connell et al. (2012), and more recently by Reynard and Tuross (2015). Today, a TLE of 3–6‰ is recommended by Reynard and Tuross (2015) expanding the much-cited earlier version of 3–5‰ (Hedges and Reynard 2007).

2.2.1 Animal baseline

The $\delta^{13}C$ and $\delta^{15}N$ isotope values in human bone collagen are often compared with relevant animal (and plant) isotope values, in order to discuss human diet. An earlier study (Eriksson et al., 2008) sampled domesticates and fish from Öland using samples from sites dated to the Neolithic and/or Bronze Age. In other words, these samples could be several thousands of years older than the humans and animals sampled in this study. During these thousands of years leading up to the Iron Age, the climate at large changed, but most significantly the Baltic Sea changed from being a highly marine environment (included in the Atlantic) to the delimited brackish inland sea (cf. Emeis et al., 2003) that it remains as to this day. In this time span, there is also a probability for changes in animal husbandry practices which, along with the environmental change, make it potentially problematic to compare these animals to those from Iron Age data.

2.2.2 Salinity

The effect of changes in salinity level, at least documented to affect $\delta^{13}C$ in soil and plants but potentially also $\delta^{15}N$ (e.g. Van Groenigen and Van Kessel, 2002), is a factor to consider for both humans and animals in Öland. Recently, Danielsson et al. (2015) found considerable variation in both $\delta^{13}C$ and $\delta^{15}N$ in contemporary fish muscle tissue (collagen) within the same species in different regions of the Baltic Sea. They attribute this variation in both isotopes to salinity, outwash (rivers, sewage, manure), and the regional food web structures. Interestingly, they found a positive relationship between $\delta^{15}N$ and salinity, which is not possible to translate to bone collagen directly, of course, but is nonetheless an intriguing correlation. In c. AD 200, in the Baltic Sea and the nearby Gotland basin, paleoclimate changes in salinity shifted from a phase of low salinity to one of increasing salinity which is still present today (Emeis et al., 2003). It is a possibility that more temporary shifts in salinity could have had an effect also. The salinity effect would be very difficult to investigate without more complete chronologies in the archaeozoological assemblages and a larger sample of all species. Due to the current understanding of salinity with respect to paleodietary studies, this will have to remain a largely open issue also for this study.

2.3 Radiocarbon dates and the reservoir effect

A complex issue with radiocarbon dating is the reservoir effect; in aquatic environments the ^{14}C proportion in the plants and animals may be lower than the atmospheric ratio. A diet incorporating a significant proportion of either marine or freshwater resources could therefore result in misleading ^{14}C values in the human bone collagen. Understanding the diet of the individual is therefore vital when considering ^{14}C results and is why $\delta^{13}C$ and $\delta^{15}N$ collagen values for the individual are often discussed in comparison to ^{14}C dates (van der Sluis et al., 2015). The $\delta^{13}C$ and $\delta^{15}N$ values are interpreted for diet while taking multiple factors into consideration (see discussion above in 2.2). Estimations of the reservoir effect from diet estimated from $\delta^{13}C$ and $\delta^{15}N$ are thus inevitably resulting from multiple levels of interpretation.

A recent study published values from samples used to estimate local reservoir effects in the Baltic Sea with two sites close to Öland (numbers 13 and 19, cf. Lougheed et al., 2013). Their mean reservoir effect, the closest approximation for Öland currently, is roughly 200 years (236+-51 and 166 +-51, Lougheed et al., 2013). Consequently, a human on Öland with an almost totally marine-based diet (i.e. from the Baltic Sea) would generate a ^{14}C result indicating it to be 200 years older than is actually true. The estimation of the specific reservoir effect from freshwater resources is much less straightforward for Öland. There are no available pre-bomb ^{14}C freshwater fish samples with specific dates to my knowledge. In Denmark and Germany, some studies have been able to calculate reservoir effects from freshwater resources (e.g. Philippsen et al., 2013) yielding enormous variations in both earlier and later dates with up to hundreds, even thousands, of years of offset. An investigation in chronology from ^{14}C dates in Öland could therefore greatly benefit from a parallel investigation of diet. This parallel investigation of $\delta^{13}C$ and $\delta^{15}N$ and ^{14}C in the same individual could allow the use of diet as a means for discussing the reservoir effect in individual cases.

3 Materials and Methods

3.1 Materials

This study is based on the uncremated skeletal remains of 109 individuals found on Öland. The human remains sampled for dietary isotopes were selected by the criteria given in Wilhelmson and Ahlström (2015) and were selected to represent as complete a part of the population as possible, including contexts other than graves as well. The individuals sampled were over 7 years of age and included both sexes. The population level approach to dietary change is a necessity in order to be able to discuss general changes in diet throughout the entire Iron Age.

The dates of each burial/individual are, if not otherwise specified, based on information compiled for the burial in the four volumes summarizing the Iron Age graves on Öland by Beskow-Sjöberg and Arnell (1987), Beskow-Sjöberg and Hagberg (1991), Hagberg and Beskow-Sjöberg (1996), and Fallgren and Rasch (2001). The broadly defined typology used for the Iron Age graves on Öland makes a specific chronology difficult to approach and is somewhat dependent on the archaeologist that excavated each site. Grave form is believed to be significant and lime stone cists are commonly determined as Roman Iron Age when missing artefacts. Additionally, many of the cist graves are manipulated, that is subjected to reburials or looting/ritual, and in some cases the artefacts recovered could give a misleading date compared to the skeletal remains. If lacking artefacts in the grave the proximity to other graves and/or grave architecture is often used to infer a sensu lato date. Many graves are also left undated, simply assumed as Iron Age.

3.1.1 Previous isotope studies

The two previous studies of human isotope values from Öland by Eriksson et al. (2008) and Howcroft et al. (2012) had different scopes and aims compared to this study. Intra-individual (intra-tissue) isotopic variation was a major focus of these studies as well as sampling young children (especially Howcroft et al., 2012). The Eriksson et al. (2008) study involves a majority of manipulated graves (commingled and/or reopened and missing artefacts, cf. Holgersson, 1984 and Schulze, 1996). Both of these studies used graves mainly dated sensu lato from the Bjärby site.

Here, the samples from this study will only be compared with the isotope results based on the same material (bone collagen) and same age span (over seven years of age as this project only sampled those individuals; for details see Wilhelmson and Ahlström, 2015) from the other studies. This selection results in 21 individuals from the Eriksson et al. (2008) study and three individuals from the Howcroft et al. (2012) study available for comparison. All relevant details for these individuals are included in Supplement 1 for this specific comparison. One individual in the Eriksson et al. (2008) study and two from the Howcroft et al. (2012) study have ^{14}C dates. Both the studies interpret the isotope results using animal baselines distant in time (from the Neolithic period mainly, discussed in detail below) but local to Öland. These two studies concluded that the Iron Age diet had high $\delta^{15}N$ values and probably, to a large extent, consisted of freshwater fish or possibly suckling domesticates. The dates of the individuals sampled in these studies are reviewed here (see Supplement 1 and 4.3)

3.1.2 Radiocarbon subsample

In this project, 42 individuals were radiocarbon dated by the Lund University Radiocarbon Dating Laboratory covering graves dated sensu lato and individuals in other contexts than typical graves. A further five dates were available from earlier studies but not until now have they been coupled with stable isotope analysis. The cremation burials are excluded from this study as they currently cannot be analyzed using a similar methodology to that used on the uncremated remains in relation to diet. Cremation and inhumation are practiced simultaneously for most of the Iron Age on Öland but there appears to be a clear shift in burial customs circa AD 400–800 when cremation is almost exclusively practiced (Beskow-Sjöberg and Arnell, 1987; Beskow-Sjöberg and Hagberg, 1991; Hagberg and Beskow-Sjöberg, 1996; Fallgren and Rasch, 2001).

3.1.3 The two approaches: relative typology vs detailed chronology (^{14}C)

In this study the dietary development on Öland will be addressed based on the new data from this study while dividing the samples using two different chronological approaches: (i) general patterns for the relative archaeological typology and (ii) a more detailed chronology focused mainly on ^{14}C. The first (relative archaeological typology) will divide the samples in to three subsets of comparable timespans commonly used in archaeological contexts in general: the Pre-Roman Iron Age (500 BC–AD 0), the Roman Iron Age (AD 0–400) and the Late Iron Age (AD 400–1050). These periods will be discussed as each having separate diets if they show statistically significant differences in the isotope values. This is a more traditional approach to variation in diet where pooling the samples by relative chronology allows to investigate if the periods as such are different. The second part of the investigation will focus on using the ^{14}C dates for a more detailed chronology. This allows to investigate if there is variation in diet that can be related to specific chronology, for example if there is a dietary shift and, if so, when this occurs. Lastly, these two approaches for understanding isotope variation in a chronological perspective will be compared.

In addition to comparing these approaches, a new data set of local contemporary animals will provide a deepened ecological understanding as a base for interpretation of the dietary isotopes for Öland than before.

3.2 Stable isotope analysis

3.2.1 Sampling

Samples from 109 humans and 26 animals from Iron Age contexts on Öland were analyzed. In humans, the mandible was sampled in all cases where available, with a bone element of prominent cortical thickness (such as the cranium, femur, tibia, or humerus) as the substitute in a few cases (full details available in Supplements 2 and 3). The bone was generally of excellent preservation. The sampling strategy was designed to avoid bias in comparing different tissues with different turnover rates (that is, short term vs long term diet). When measuring $\delta^{13}C$ and $\delta^{15}N$ in bone collagen these reflect a diet during a specific time period depending on bone turnover (varying between elements, type of tissue, and metabolism). Bone turnover is quite poorly understood in detail (c.f. discussion in Hedges et al., 2007; and review in Jørkov et al., 2010). Cortical bone has a long turnover time (i.e. reflecting long-term dietary habits) and is chemically more robust so is less likely to suffer diagenetic change than more porous trabecular bone.

While sampling bones, an osteological examination was made to ensure the selected bones did not show any signs of osteomyelitis, healed fractures, or periostitis as these conditions have been demonstrated to correlate with changes in isotopic values, causing them not to reflect diet per se but catabolism (cf. Olsen et al., 2014; Reitsema, 2013; Katzenberg and Lovell, 1999). One individual had signs of bone remodeling most likely corresponding to hypertrophic pulmonary osteoarthropathy evident in most bones of the skeleton (confirmed by x-ray) (as the criteria are detailed in Ortner 2003 and Aufderheide et al., 1998). The bone remodeling was not manifest in the mandible where bone was sampled, however. This individual's isotope values could be compromiinsed because problems in bone formation is one symptom of this disease, and thus might reflect the disease process rather than indicating anything about diet. These values are therefore compared to those of the contemporary population to determine whether they are likely to be misrepresentative of diet. If so, they will be excluded from further analysis.

3.2.2 Sample preparation

For each sample, approximately 1g of compact bone was manually, mechanically cleaned with a drill as shavings, powder, or minor fragments. This was then ground to a fine powder with an agate pestle and mortar. The samples of approximately 0.25g of this powder were prepared for collagen extraction using a modified Longin method (Richards and Hedges, 1999) with Ezee filter and ultrafiltration, as recommended by Jørkov et al. (2007) in the following way. Each sample was demineralized by being placed in a 1M HCL solution until there was no further release of CO2, after which the sample was rinsed to neutral pH. The samples were gelatinized by adding HCL (until sample pH was 2.5) and heated to 70o for 24 hours. After this, the samples were filtered in two steps using Ezee mesh filters and then ultrafiltered. The ultrafiltered samples were freeze dried. All samples where then packed into ultra-clean tin capsules and weighed prior to being inserted in the mass spectrometer.

3.2.3 Isotopic instrumentation and analysis

The samples were analyzed with a Micromass Iso Prime Isotope Ratio Mass Spectrometer in the Stable Isotope Laboratory Department of Geosciences and Natural Resource Management at the University of Copenhagen. The work standard, GLTstd03, was calibrated for $\delta^{13}C$ to within 0.2‰ v. VPDB and for $\delta^{15}N$ to within 0.2‰ v. AIR. Duplicates were run for the samples (n=44) and analytical uncertainty for $\delta\ ^{13}C$ was determined to be 0.1‰ and for $\delta\ ^{15}N$ 0.2‰.

3.2.4 Diagenesis

There are a number of established criteria and methods to assess the possibility of contamination of collagen samples and this is an integral part of any analysis of which three are most commonly accepted in the field. One criteria used here is the yield which should be between 10–18% for $\delta^{15}N$ and 30–50% for $\delta^{13}C$ (Van Klinken, 1999). Another criteria is the C:N molar ratio, which should be between 2.9–3.6 according to the most widely cited and long used standard (DeNiro, 1985) in order to indicate that diagenetic alteration of the collagen is unlikely. These two criteria were deemed to hold the most significance as the third criterion, collagen yield (which should be above 0.5 wt%, Van Klinken, 1999), was recently concluded to be of lesser importance in determining diagenetic alteration of collagen (cf. Sealy et al., 2014) but will also be reported here.

3.2.5 TLE, Trophic Level Effect

The $\delta^{13}C$ and $\delta^{15}N$ values of human bone will be discussed and interpreted here primarily using the 5‰ levels of TLE but also taking the 3‰ level into account, an approach which has recently been frequently used (e.g. Basha et al., 2016; Nafplioti, 2016; Chen et al., 2015; Ciaffi et al., 2015; Fernandes et al., 2015; Halffman and Velemínský, 2015; Mörseburg et al., 2015; Richards et al., 2015; Schutkowski and Soltysiak, 2015). The offset in $\delta^{13}C$ is much smaller in human bone collagen when comparing to bones of animals likely consumed by humans (i.e. the trophic level enrichment, TLE) and is sometimes given as an interval of +0.8-1.3‰ (Bocherens and Drucker 2003), but mostly rounded off to the originally suggested +1‰ (DeNiro and Epstein, 1978) which is the value that will be employed in this study for the TLE. The human isotope values will be compared to suitable animal comparisons (with the TLE corrected) presented together in biplots.

3.2.6 The animal baseline and diet

In this study, animal samples that are both local (from graves and settlements on Öland, details in Supplement 4) and contemporary (Iron Age) were selected for isotopic analysis following the same methodology as the human samples. The fact that the animal assemblages overall have a small/uncertain overlap with the human samples (uncremated individuals) is a bias as changes in animal husbandry could occur also during the course of the Iron Age and affect the isotopic profiles of these animals. The animals sampled range from those which are most likely to be part of a human diet (n=17) and those which are less likely to be part of a human diet (n=9). The animals which are unlikely food sources (cat, dog, horse, seal) are used as a comparison for the animals more likely to be included in a human diet, as well as as a comparison to humans with regard to trophic level differences relating to being carnivores, omnivores, or herbivores. The most likely animal food sources are pigs, cattle, sheep/goats, chickens and fish judging from the archaeozoological assemblages (as discussed in detail in 2.1).

There are animal baseline values available from previous studies that are from relevant chronological and geographical contexts around the Baltic Sea. There are also animal values from archaeological Öland fauna (c.f. Eriksson et al., 2008) but that are several thousand years older. As the local ecology and animal husbandry practices may be different between all these subsets of samples, from different timespans or geography, the values per species (details in Supplement 4) will be compared to the animal values derived in this study. The results of this comparison will determine whether the animal baseline is relevant to Iron-Age Öland humans, as investigated with the 26 samples from this study, and whether it can be expanded to include any of these subsets of animal values.

3.3 Radiocarbon

3.3.1 Sampling

In 38 of the individuals also analyzed for stable isotopes in this study, the mandibles were sampled for ^{14}C analysis. A further four individuals were sampled using a rib and, one other using a finger phalanx (details in Supplement 5).

3.3.2 Sample preparation

Separate collagen extractions for the radiocarbon analysis (other than for the $\delta^{13}C$ and $\delta^{15}N$) were performed by the Lund University Radiocarbon Dating Laboratory. There, the bone samples were cleaned mechanically and pretreated with NaOH to remove any organic contaminants. Collagen was extracted in a slightly modified (demineralization with HCl in vacuum) version of the method described in Longin (1971), devised by Brock et al. (2010).

3.3.3 Diagnesis

The quality of the extracted collagen was determined following procedures outlined in Brock et al. (2012) using the C:N ratio.

3.3.4 Calibration

The radiocarbon dates were calibrated to calendric ages with associated 68% range, using the online software CalPal (http://www.calpal-online.de; CalPal-2007Hulu). All calibrations, conventional dates, and further details are available in Supplement 5. The details given here (in addition to those accounted per sample with the results in Supplement 5) follow the criteria for reporting ^{14}C results outlined by Millard (2014).

3.3.5 Reservoir effect

The individual $\delta^{13}C$ and $\delta^{15}N$ profiles for the humans, sampled separately in this study, could give some information with regards to the extent of use of freshwater and marine sources on the individual level (a potential cause of reservoir effect in human samples, as discussed in detail in 2.3) and will therefore be compared to the ^{14}C results. As mainly $\delta^{15}N$ levels are likely to indicate a high fish consumption these are primarily compared to the ^{14}C results here. The unknown magnitude of the reservoir effect in freshwater resources in Öland is especially problematic. In this specific case, another option could also be to compare the typological dates from artifacts in the individuals' graves to the ^{14}C results. Consequently, both $\delta^{15}N$ and typology will be compared on an individual level to the ^{14}C results to trace any reservoir effects.

4 RESULTS

4.1 Stable isotopes

All data concerning the $\delta^{13}C$ and $\delta^{15}N$ analysis are available in Supplements 2 (for the humans, n=109) and 3 (for the animals, n=26). The collagen yield was between 0.46–7.32 (3.49±1.78), so generally well above the lower limit set at 0.5 wt% (Van Klinken, 1999). The sample with the lowest value (0.5 wt%; ID 1031) had a C:N-ratio in the acceptable range (3.5; and $\delta^{13}C$-20.1‰ $\delta^{15}N$ 14.2‰) and is included since it is within the standards. The yield varied between 43.7–49.3% (47.0 ±1.1) for $\delta^{13}C$ and 13.7–18% (16.6±0.6) for $\delta^{15}N$. This is well within the given limits of 10–18% for $\delta^{15}N$ and 30–50% for $\delta\ ^{13}C$ (Van Klinken, 1999). The C:N molar ratios for all human and animal samples were between 3.2–3.8. The most widely used standard (DeNiro, 1985) would put only two samples outside of the accepted range for well-preserved collagen. The human sample ID 1066 (with C:N: 3.8, $\delta\ ^{13}C$ -20.0‰, $\delta^{15}N$ 11.9‰ and yield 0.7 wt%) and the animal sample 1210 which was taken from a seal (with C:N 3.7, $\delta\ ^{13}C$-16.2‰, $\delta^{15}N$ 16.2‰ and yield 1.7 wt%) are therefore excluded from further discussions as they are at risk of being diagenetically altered. All other samples are within the limits for acceptable ranges of molar C:N ratio and collagen yield and are therefore interpreted as diagenetically unaltered and included in the further analysis.

	$\delta^{13}C$, ‰ VPDB		$\delta^{15}N$, ‰ AIR		n
	Mean	**Std**	**Mean**	**Std**	
Pre Roman Iron Age (500 BC-AD 0)	-19.9	0.3	12.0	1.1	**21**
Roman Iron Age (AD 0-400)	-19.8	0.3	**13.7**	1.1	**48**
Late Iron Age (AD400-1050)	-19.4	**0.5**	12.7	1.0	**37**

Table 2: Sample mean and variation in the three main periods (Pre Roman, Roman, and Late Iron Age). One outlier in the Roman period excluded (ID 1005; $\delta^{13}C$ -20.3‰; $\delta^{15}N$ 8.0‰) from the calculations and the one dated Pre roman/Early roman (ID 1025;$\delta^{13}C$ 19.6‰; $\delta^{15}N$ 12.1‰) also as well as ID 1066 which did not meet collagen quality standards.

	F-value	Pre Roman vs Roman Iron Age	Pre Roman vs Late Iron Age	Roman vs Late Iron Age	Tukey HSD (alpha=0.05)
$\delta^{13}C$	16.47981	Non sign.	P<0.01	P<0.01	0.20559
$\delta^{15}N$	20.74919	P<0.01	P<0.05	P<0.01	0.64233

Table 3: Details of a one way ANOVA and post hoc Tukey HSD-test to the samples divided in subsamples for the three time periods. Non sign=non significant result.

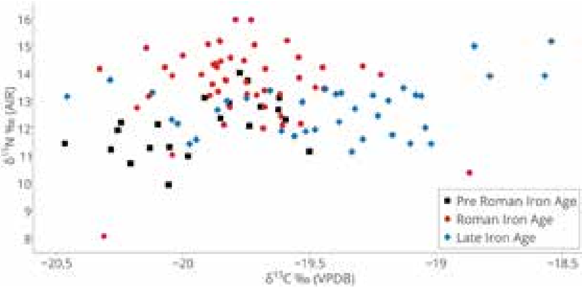

Fig. 3: The human $\delta^{13}C$ and $\delta^{15}N$ results divided by subperiods of the Iron Age, n=108. Pre Roman Iron Age (500 BC–AD 0), Roman Iron Age (0 AD–400), Late Iron Age (AD 400–1050).

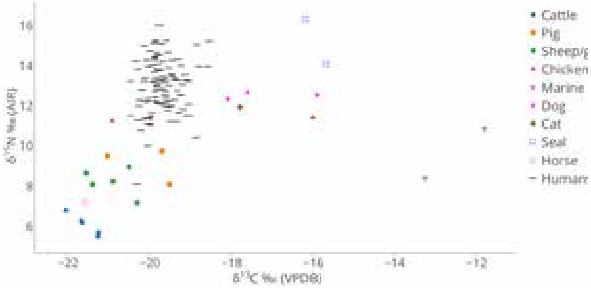

Fig. 4: Isotope values for all humans (n=108) and animals (n=25) sampled in this study. All are Iron Age and from Öland. Details available in Supplements 2 and 3.

4.1.1 The relative typology approach to dietary variation

The human samples can be pooled into three major chronological periods of comparable time spans—the Pre-Roman Iron Age (500 BC–AD 0), the Roman Iron Age (AD 0–400) and the Late Iron Age (AD 400–1050)—that with regards to isotope variation appear different (Table 2). Using simple robust statistics (ANOVA, Tukey HSD), there is a statistically significant difference between each of the periods as subsamples in their $\delta^{13}C$ ($P<0.01$ for both Pre and Roman samples vs Late Iron Age) and $\delta^{15}N$ values ($P<0.01$ for Pre Roman vs Roman and Roman vs Late Iron Age; $P<0.05$ for Pre-Roman vs Late Iron Age). The Roman Iron Age sample stands out in particular with a very high mean $\delta^{15}N$ (Table 3) as can also be visualized in Figure 3. The individual with hypertrophic pulmonary osteoarthropathy gave isotopic values of $\delta^{13}C$ -19.3‰ and $\delta^{15}N$ 12.4‰ which is almost exactly the mean for that period (the Late Iron Age, mean $\delta^{13}C$ -19.4‰ and $\delta^{15}N$ 12.7‰). Because of these results, it is unlikely that the disease had any influence, and so the sample will remain in discussions on diet.

The sampled (contemporary and local) animals show clear differences between herbivores, omnivores, and carnivores, as well as the marine species in Öland (Fig. 4). The results from the dog samples are most similar overall to the human diet suggesting they were largely eating the same food. Results from chicken and cat samples are also quite similar in $\delta^{15}N$ levels to humans indicating they too had a similar diet, although supplemented with other sources that were less significant parts of the human diet.

4.1.2 Animal samples

From this study, the isotope results of the specific animal types from Iron Age Öland contexts, most relevant to diet from archaeozoological assemblages (i.e. sheep/goat, cattle, pig, fish and chicken), can be compared to both local (but far from contemporary, several thousands of years older) and contemporary regionally similar values. The data that these comparisons are based on are available in Supplements 4 (the other studies) and 3 (this study).

Comparing the animal isotopic signatures from this study with the Eriksson et al. (2008) data is in essence a comparison of the same types of animals on Öland but thousands of years apart, with major changes in climate and animal husbandry potentially influencing the isotope signatures of the same species. There are differences in the faunal values (Table 4). The Neolithic pigs have lower $\delta^{13}C$ values and lower $\delta^{15}N$ values compared to those from the Iron Age. Both cattle and sheep show less variation in $\delta^{13}C$ and $\delta^{15}N$ during the Iron Age, possibly indicating a more controlled grazing in this period. A very similar mean $\delta^{13}C$ for each species in both samples suggests little change in ecological niches in both periods. The higher Iron Age $\delta^{15}N$ levels in all three animals could potentially indicate a more intense use of land (more animals) and/or controlled grazing, leading to more fertilization (manure) of the grazing areas. A more controlled, and potentially intensified, animal husbandry would correspond also to the extensive archaeological evidence of the agricultural landscape being strictly and extensively divided in the Iron Age.

The Eriksson et al. (2008) fish samples could coincide with the Littorina stage of the Baltic Sea, a completely different type of body of water (and ecology) than the Baltic Sea as outlined from circa 2500 BC. Despite this, the difference between these values and the two samples of Iron Age fish are relatively small although notable with higher $\delta^{15}N$ values and more negative $\delta^{13}C$ values. This indicates the ecological difference was either not so great, or that the samples are from the very end of the time period they are thought to represent. The fact that only two fish samples are representing the Iron Age is a potential bias. Since the older samples are differing, and are probably from a different biotope, they will not be used to interpret the Iron Age diet.

The Iron Age Öland animal samples from this study and selected contemporary regions are summarized in Figures 5A and B. The Danish cattle appear very similar to the values from Öland but the ones from Birka are considerably lower in $\delta^{15}N$. The pigs in Öland are slightly higher in $\delta^{13}C$ than in Denmark and those from Birka are very diverse in $\delta^{15}N$. The sheep appear different from both those of Denmark (with lower $\delta^{13}C$ and $\delta^{15}N$ values) and the one from Birka (with a very low $\delta^{15}N$ value). The chickens in Öland give an extremely wide span in $\delta^{13}C$, and smaller but still significant spans in Haithabu and Germany. The $\delta^{15}N$ values are diverse but generally high for all chickens, making their trophic level (likely dependent on human refuse) somewhat predictable in contrast to $\delta^{13}C$. The fish are more difficult to discuss as there is a big variation within the samples and between the regions, including both freshwater and marine fish (Fig. 5B). The two fish samples from Öland resemble the Danish marine fish most with a clearly marine signature. The Haithabu samples appear to be including fish with a more brackish (middle) $\delta^{13}C$ profile, probably due to the area's location in a fjord where freshwater from rivers could dilute the more saline sea water. The occurrence of more brackish values in Öland fish during the Iron Age is difficult to answer currently as the species tested here, which could live in a brackish environment, only gave a highly marine $\delta^{13}C$ signal. In an archaeological context, the variation in isotopic composition in cod in particular has been demonstrated as showing differences in both the west and the east of the Baltic Sea (Barrett et al., 2011). All these factors underline the potential complexity, so far undetected in the limited scope of the available isotopic measurements of animals from archaeological contexts on Öland.

In summary, although the Öland data from a previous study (Eriksson et al., 2008) are similar, there are some differences likely relating to changes in animal husbandry in the Iron Age when compared to the Neolithic period, but also possibly relating to climate changes. For this reason, the earlier animal data are unsuitable for comparison to the Iron Age human samples and will not be discussed further. Compared to the contemporary samples from Scandinavia, Öland is notable for some species and appears to possess an island-specific profile. The sheep in particular have high $\delta^{15}N$ values which are not fully matched in the other materials. This is likely primarily due to variations in local ecology and different animal husbandry practices in the different environments. Consequently, the best way to interpret the human isotope values from Iron Age Öland is to rely only on the animals that are both Iron Age and from Öland.

	$\delta^{13}C$ mean (VPDB) ‰	std	$\delta^{15}N$ mean (AIR) ‰	std	n
Cattle	-21.6	0.3	6.0	0.5	5
Cattle Eriksson et al. (2008)	-21.9	0.9	6.0	1.8	8
Pig	-20.1	0.8	9.0	0.9	3
Pig. Eriksson et al. (2008)	-21.3	0.5	5.8	1.7	13
Sheep/goat	-20.9	0.5	8.2	0.7	5
Sheep/goat. Eriksson et al. (2008)	-21.0	0.8	6.9	1.0	9
Marine fish	-12.5	1.0	9.6	1.7	2
Marine fish. Eriksson et al. (2008)	-14.0	1.7	11.2	1.3	13

Table 4: Isotopic values for fauna from different periods, all excavated on Öland. If not specified the values are derived from this study (Iron Age only). The Eriksson et al. 2008 data are from mainly Neolithic/ Bronze Age dated assemblages on Öland.

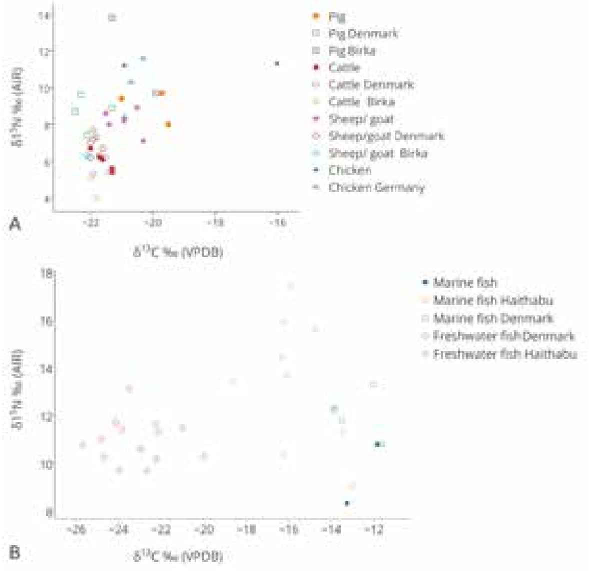

Fig. 5. The variation in animal sample values from the selected sites compared to this study. Chart A shows the domesticated species and chart B shows the fish. The animal samples are from this study unless otherwise specified. For chickens, the samples marked "Germany" are from Hakenbeck et al. (2010) and Knipper et al. (2013). Other sources of data are Denmark (Jørkov, 2007), Birka (Linderholm et al., 2008), and Haithabu (Doppler et al., 2010). Details available in Supplement 4.

4.2 Radiocarbon results and the reservoir effect

Here, only the results from the ^{14}C analysis are presented along with the archaeological typology for the individuals analyzed with $\delta^{13}C$ and $\delta^{15}N$ in this study. In the discussion, the ^{14}C results will be compared to the dietary results (from $\delta^{13}C$ and $\delta^{15}N$) in order to assess the potential reservoir ef-

Date typology	**^{14}C -dates LU 2013/2014**					
	(PR IA) *Pre Roman Iron Age*	**(R IA)** *Early Roman Period*	*Late Roman Period*	**L IA** *Vendel Period*	*Viking Age*	***n***
Iron Age?/Early Iron Age?	9	6			7	***23***
Early Roman Period	1	6			1	***6***
Roman Iron Age	1	3			1	***5***
Late Roman Iron Age		1				***1***
Viking Age?				1	5	***6***
Total	***11***	***16***		***1***	***14***	***42***

Table 5: Typological date from grave type and/or artefacts, compared to ^{14}C -dates of human skeletal remains in the same graves. For chronological definitions see Table1.

Id	**Artefacts**		**Typology**		**^{14}C - Calibrated (68%, CalPal)**	**Arch. date years (AD)**	**δ^{13}C**	**δ^{15}N**	**Comment**
	match	**no match**	**match**	**no match**					
1028	x				885 ± 69	800-1050	-19.3	11.6	good match ^{14}C -artefacts, typology
1094	x				125 ± 62	70-200	-19.8	15.9	Prefect fit ^{14}C and artefact (B2/C1a)
1004	*x*				*112 ± 116 **	*0-40*	*-19.7*	*13.4*	*(0-40 AD; IV:1,14C very wide, due to old?*
1096	x				25 ± 47	0-40	-19.4	13.4	IV:1, very good fit ^{14}C and typology
1059	x				847 ± 65	800-1050	-18.6	13.9	Multiple burials, ^{14}C supported by artefact. Excavation report mentions bone comb (VA) why ÖJG summary (RIA, 0-400) is wrong
1071	x				716 ± 44	550-800 AD (or 100? BC -40 AD)	-19.5	11.9	unsual combination artefacts, appears in situ on body-not commingling (wth an infant), details in Supplement 5 Table 1
1008			**x**		847 ± 65	800-1050?	-19.1	11.4	
1086			x		799 ± 68	800-1050?	-19.6	11.9	date from burials close by
1089			**x**		125 ± 57	0-200?	-19.5	13.5	
1036			**x**		103 ± 54	0-400	-19.2	13.9	
1062			**x**		88 ± 57	0-400	-19.9	14.3	
1074			**x**		30 ± 48	0-200	-19.9	14.3	
1034			**x**		3 ± 46	500 BC-400 AD	-19.7	13.2	
1047			**x**		3 ± 46	0-400	-19.8	14.4	
1042			**x**		191 ± 95 BC	500 BC-0 AD	-19.6	12.3	
1052			**x**		386 ± 80 BC	500 BC-0 AD	-20.3	11.2	
1063			**x**		576 ± 130 BC	500 BC-400 AD?	-19.7	12.1	
1106		x			91 ± 61 BC	0-200	-19.9	13.1	Multiple burials, commingling of artefacts? This is an early burial without artefacts?
1084		x			1122 ± 63	800-1050	-19.2	13.0	Slightly younger than typology (comb). Late burial?
1105				x	853 ± 71	0-200	-20.0	11.6	^{14}C likely correct, last burial in cist (first is id 1106 Pre Roman in c14)
1015				x	130 ± 57	800-1050	-19.6	15.2	Commingled, looted. No datable artefacts, other burials close by are Viking age.
1072				x	119 ± 56	200-400	-19.9	14.4	Commingling, looted. LR date only in ÖJG, old excavation (1928) artefacts resembling E or L Roman period. 14C likely correct
1027				x	575 ± 129 BC	500 BC-0 AD	-19.5	11.1	Most graves in this grave field dated with artefacts are Viking Age, only 1 LR 1 E/L Roman. Date: only due to a cists (despite most graves Viking age)

Table 6. Detailed comparison of the individuals with more specific typological/and or artefact dates, the same dataset as used for Fig 6.

fects. A further eight radiocarbon dates (three are for individuals with $\delta^{13}C$ and $\delta^{15}N$ measured in earlier studies) were also available from earlier studies and will be included in this analysis, comprising 50 radiocarbon dated individuals in total. All the details are supplied in Supplements 1 and 5.

The vast majority of the calibrated ^{14}C dates fall somewhere between 400 BC–AD 200 and AD 700–1000, yielding more burials, especially in the earliest and latest parts of the Iron Age than what could previously be assumed by chronology alone. This sample is clearly biased, lacking dates from circa AD 187–611 despite an intense sampling of graves dated sensu lato to be able to catch any uncremated human remains from this period. The cremation practice during this period is probably the major cause of this bias as these individuals cannot be used for comparable stable isotope analysis. When comparing to the Intcal 13 calibration curve for ^{14}C dates in Reimer et al. (2013) (available on http://www.radiocarbon.org/IntCal13.htm), the lack of data from the middle Iron Age shows no correspondence with the wiggles or plateaus in the curve.

For 23 individuals, a more specific archaeological date (using artefacts) or a less specific archaeological date (using grave forms) could be compared to the ^{14}C result (Fig. 6, details in Table 5 and Supplement 5). The majority (17 of 23) of the dates given to the individuals clearly concur with the ^{14}C dates. Of these, two deserve special mentioning as they are exceptionally detailed and appear to be very accurate. The first individual, ID 1096, is dated to AD 0–40 (Period IV:1) using artefacts and has a ^{14}C date of 22BC-AD72. The second, ID 1094, has a wider date range of AD 70–200, established using one artefact, and the ^{14}C date is virtually the same (AD 63–187). In six cases, the ^{14}C and archaeological date do not concur. For all but one of these, it is more likely that the ^{14}C date is correct due to sensu lato archaeological typology and/or commingling. For ID 1084, the ^{14}C date is late, although very close in the total range in comparison to the archaeological date.

The reservoir effect, as mentioned earlier, is especially likely to be a problem for individuals with a diet high in marine or freshwater sources. The ^{14}C results both corresponding well with, and not corresponding well with, archaeological dates are compared to individual diet, i.e. $\delta\ ^{13}C$ and $\delta^{15}N$, in Figure 6. If we assume that the individuals with the highest $\delta^{15}N$ (regardless of $\delta^{13}C$) are those who are comparably most likely to have been consuming a lot of fish, then these are by definition the most likely to also show a significant reservoir effect. When comparing typological and ^{14}C dates for individuals with high $\delta^{15}N$ (Table 6), it is clear there is no such correspondence. On the contrary, those with best fit of the archaeological and ^{14}C dates in the Early Iron Age have very high $\delta^{15}N$ values and low $\delta^{13}C$ (IDs 1094 and 1096), indicating a possibility of freshwater fish consumption. An individual who is more likely to have a marine-based diet (ID 1059) also has a good correspondence between ^{14}C and the archaeological date. This is not, however, unexpected as a marine reservoir effect would affect the number of years only to a small degree locally for Öland (as discussed under section 3.3.5). From the data at hand, it is hard to find conclusive evidence supporting that the reservoir effect has influenced the results of the ^{14}C samples of humans from Öland. These results could either mean that there is only a small reservoir effect (regardless of marine or freshwater) or that these individuals were not consuming any large quantities of either freshwater or marine fish. In the further discussions, the ^{14}C dates, due to lack of evidence to the contrary, are considered to be reliable and likely uncompromised by any reservoir effect, both marine (i.e. the Baltic Sea) and freshwater.

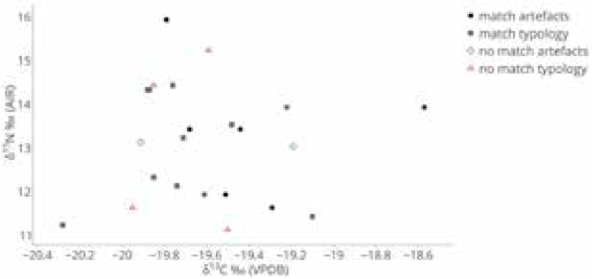

Fig. 6. The $\delta^{13}C$ and $\delta^{15}N$ values of samples with both ^{14}C and more specific chronological dates from either artefacts or typology n=23. Details in Supplement 5. Match artefact/typology means the ^{14}C date corresponds perfectly to artefact and/or typology (= grave form) date. No match artefact/typology means the ^{14}C date does not correspond perfectly to the artefact/typology date.

4.2.1 A detailed chronology

The archaeological dates for each of the individuals and ^{14}C results are detailed in Supplement 5, and range from detailed (due to specific artefacts) to general sensu lato (a grave form, for example a cist). In the cases where dates were specified from specific artefacts, or by similar burials close by, albeit dated securely (i.e. there was no ambiguity such as commingling or reopening of the grave), ^{14}C was rarely performed. The results of the 42 individual ^{14}C analyses performed in this study yielded results indicating that the typological dates based on artefacts are likely correct (as discussed for a subset of 17 samples above in 4.2). On the contrary, the sensu lato defined typology used on Öland is not reliable as these individuals got more varied ^{14}C dates, likely indicating a much longer and more frequent use of graves than previously thought (due to the lack of artifacts in these burials (cf. Table 5, details in Supplement 5). In one cist, for example, multiple consecutive burials could be identified in stratigraphy where the top burial had a ^{14}C date in the Viking Age and the bottom burial had a Pre-Roman date (IDs 1105 and 1106, details in Supplements 2 and 5), while the artefacts were Roman Iron Age and most likely associated with the more fragmented human remains in that

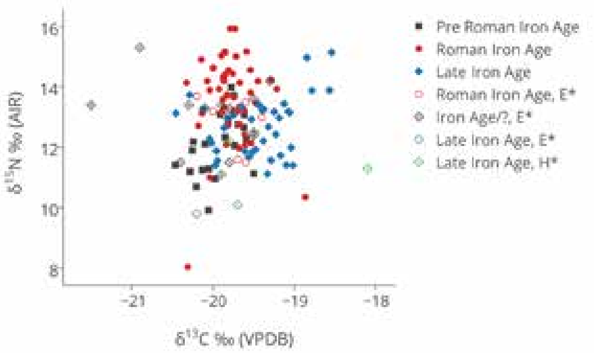

Fig. 7: The $\delta^{13}C$ and $\delta^{15}N$ values (from bone collagen only) from Eriksson et al. (2008) (E*) and Howcroft et al. (2012) (H*) in comparison to the values from this study (the same data set as in Fig. 3). Detailed data available in Supplements 1 and 2.

layer. Those remains that have been reburied, or that have been placed in the same cists or pits but which lack artefacts have previously been assumed to be contemporary with the other human remains in the same burial which had associated artefacts. This can now be demonstrated as a clearly inappropriate approach considering the specific complexity in reburials in Öland. The very same type of burials (north-south oriented cists) believed to be common in the Early Iron Age are now established as primary burials in the Viking Age by ^{14}C to a much larger extent than previously assumed.

4.3 Integration with earlier stable isotope studies

The values of bone collagen $\delta^{13}C$ and $\delta^{15}N$ for Iron Age individuals available from earlier studies have some chronological information attached to them. The Howcroft et al. (2012) data (three samples) are dated in detail by relative chronology and ^{14}C, as is one sample from Karlevi with a ^{14}C value in the Eriksson et al. (2008) data. The rest of the samples in the Eriksson et al. (2008) data set are given as Roman Iron Age, which deviates from the wider chronology given in the most recent report of the grave field (Schulze, 1996; detailed in Supplement 1). In addition to this, the results of the ^{14}C dating of graves of similar character (no artefacts, lime cists, north-south oriented) in this study (compare discussion in 4.2) suggest that the individuals in the graves dated by the sensu lato typology to the Roman Iron Age by Schulze (1996) should instead be defined more accurately as Iron Age (i.e. 500 BC–AD 1050) in some cases (Supplement 1) when lacking artefacts. Revising the dates from Eriksson et al. (2008) accordingly gives a chronology that allows comparison to this study (summarized in Supplement 1 along with the Howcroft et al. (2012) data set).

The data from earlier studies fit well with the Iron Age sample from this study (Fig. 7). When viewing the Eriksson et al. (2008) isotope results the majority of the sensu latu dates seem to fit better with the Pre Roman and Late Iron Age samples in this study rather than the Roman Iron Age. This makes it problematic to compare the sensu lato part of the earlier data set with this study. The Eriksson et al. (2008) data for the Roman Iron Age (not dated sensu lato) fit very well in $\delta^{13}C$ values with this study's Roman Iron Age samples, but the $\delta^{15}N$ values are slightly lower (Fig. 7). The samples from Eriksson et al. (2008) from the Roman Iron Age are, however, very few (six compared to 48 from this study) and this difference is therefore not considered to be important.

The overall pattern in isotope variation in the Iron Age is clearly coherent between the three studies. When adding the data from the earlier studies to the values from this study, this does very little to help expand the chronological understanding. Only 10 samples from the earlier studies have specific chronology which is comparable to the 108 samples from this study. Still, three individuals in the earlier data sets are clear outliers, of which two have considerably lower $\delta^{13}C$ from the Eriksson et al. (2008) data set, and one has considerably higher $\delta^{13}C$ from the Triberga data set. This shows that a greater variation could be possible than is found in this study alone.

5 DISCUSSION

5.1 Interpreting diet

5.1.1 The relative typology approach to dietary variation

The results of the stable isotope analysis in this study showed small, albeit statistically significant differences in the $\delta^{13}C$ and $\delta^{15}N$ for the chronological subsets: the Pre Roman Iron Age, the Roman Iron Age, and the Late Iron Age (Table 3). As a basis for interpretation, the human values are presented with the most likely type of food source (animals) shown with a TLE of +5‰ for $\delta^{15}N$ and +1‰ for $\delta^{13}C$ in Figures 8A–C (note: not the measured values for the animals, only the TLE corrected values are shown). The human diet is divided into the three major time periods in discussion, rather than as individual diets.

The diet in the Pre Roman Iron Age could be explained as being reliant on domesticates, probably the sheep/goats and cattle, which fit well with both the $\delta^{13}C$ and $\delta^{15}N$ data (Fig. 8A). One other possibility would be a freshwater fish diet combined with a heavy reliance on plant protein, thus lowering the $\delta^{15}N$.

The Roman Iron Age values are heterogeneous in $\delta^{15}N$, with some very high values, but comparably homogenous $\delta^{13}C$ (Fig. 8B). For this period in particular, there are a number of options that need to be considered. Overall, these values are probably indicating an intense use of domesticates, more likely the sheep, pigs, and chickens rather than cattle. It is also a possibility that a mix of both freshwater and marine fish could be causing the higher $\delta^{15}N$ levels while maintaining a middle ground $\delta^{13}C$, although the low diversity in $\delta^{13}C$ compared to the $\delta^{15}N$ is harder to explain using such an interpretation. Another possibility is that scrambling is causing the nonconforming $\delta^{13}C$ values and high $\delta^{15}N$ values for freshwater or marine fish. In other studies, similarly high human $\delta^{15}N$ values coupled with $\delta^{13}C$ values that are "middle ground" (in other words, neither particularly marine nor freshwater/terrestrial) have been interpreted differently by different authors. Earlier, they were interpreted as indicating a mixed freshwater-, terrestrial- and marine-based diet (Müldner and Richards, 2005) or freshwater fish and/or manuring (McManus et al., 2012) on the coast of Scotland. However, more recently, the interpretation has shifted away from a fish-based diet towards a diet of grazers reared in a brackish environment, in the coastal Netherlands (McManus et al., 2012), established using comparison to local contemporary animal samples. The specific isotopic profiles of grazing domesticates in estuarine environments have received increasing attention (c.f. McManus et al., 2012; Richards et al., 2006; Britton et al., 2008) and an extensive study of faunal isotopic variation in such an environment was recently presented by Müldner et al. (2014). The values for cattle in Öland, particularly sheep, correlate very well to those defined as estuarine grazers in the studies mentioned above. The Müldner et al. (2014) extensive data set shows an interesting temporal variation and complexity not possible to capture in the currently available data from Öland. Considering the animal samples from Öland alongside the 5‰ TLE and the studies mentioned above, I argue that the diet in the Roman Iron Age is largely reflecting an intense use of domesticates, potentially primarily sheep/goats due to the narrow variation in $\delta^{13}C$ and higher $\delta^{15}N$. If the higher value for variation in TLE (i.e. 6‰) for $\delta^{15}N$ is used, that level would make this diet even more probable. This subsistence is also supported in the archaeozoological assemblages where domesticates are the most common, and sheep are clearly the dominant taxa. Moreover, milk (also in the form of sour or fermented products) from sheep and cattle could constitute an even larger proportion of the diet that would not leave much evidence in the bone assemblages. It is therefore quite possible that the introduction of partitioning systems along with the houses with specific byres could be linked to this specific isotopic shift. This would mean this settlement pattern could be older than AD 200, which is the earliest date discussed for Öland so far. In theory, it could date back as far as AD 0 which is the chronological definition of the start of the Roman Iron Age. This possibility will be discussed in more detail below in relation to the more specific chronology to see whether the ^{14}C dates can establish individuals with this diet earlier in the Iron Age as in the very start of the Roman Iron Age.

In the Late Iron Age (Fig. 8C), there is a shift in $\delta^{13}C$ to include both less-negative values and an overall increased diversity compared to the two earlier periods. This is likely indicative of an addition of marine dietary components in some individuals. Since the $\delta^{15}N$ is not increasing proportionally, this is possibly coupled with an increase of other lower $\delta^{15}N$ dietary sources, or fish with lower trophic levels, compared to the results from the Roman Iron Age. The Late Iron Age archaeozoological assemblage, Östra Wannborga, showed a varied subsistence including fish and fowl which corresponds remarkably well to the diversity in $\delta^{13}C$ for the Late Iron Age individuals. It is, however, difficult to establish whether the specific timing of this dietary shift really does occur around AD 400 which is the typological definition of the relative chronology.

The effect of salinity changes in the Baltic Sea during the Iron Age on the paleodietary isotopes is very difficult to address for Öland with the data presently at hand, as discussed earlier. The gradual mean decrease in human $\delta^{13}C$ over time is a peculiar effect on Öland. It is a tantalizing notion that this might be corresponding to a change (increase) in salinity level through time, but it could also simply be a coincidence. The paleoclimate data support an increase in salinity from circa AD 200 in the Öland region of the Baltic Sea (Emeis et al., 2003) so it is at least a possibility that changing salinity levels might explain some of the chronological human isotope variation. With the data at hand, it cannot be conclusively proven, but only proposed as a possibility.

Should a lower TLE be applied to the $\delta^{15}N$ data, say 3‰, then the interpretation of the diets in the three periods would mean a higher reliance on fish in all periods and an extremely high level of freshwater fish in the Roman Iron Age. It is a possibility that the significance of fish in general would be underestimated in the archaeozoological assemblages, which also do not cover the entire period. However, it is unlikely that freshwater fish specifically should be so very poorly represented in comparison to marine fish. This scenario would make little sense with regards to the partitioning system and a domesticate-based subsistence at least practiced at some point in the Iron Age. Considering that fish vary in their $\delta^{13}C$ and $\delta^{15}N$ values, the relatively limited variance in $\delta^{13}C$ (for the Pre Roman and Roman Iron Age) or $\delta^{15}N$ (for the Late Iron Age) for the population would further be unexpected. Of the two options for interpreting diet from the isotope samples, I argue the first one, which uses a 5‰ TLE, is far more likely to be relevant, especially when taking the estuarine effect into account. The 6‰, the current maximum, as discussed in the earlier sections of the paper, would also be relevant and result in a similar interpretation.

The interpretation of Iron Age diets presented here clearly differs from that in the two earlier studies (Eriksson et al., 2008; Howcroft et al., 2012) where diet was interpreted as mainly consisting of freshwater fish during the Iron Age.

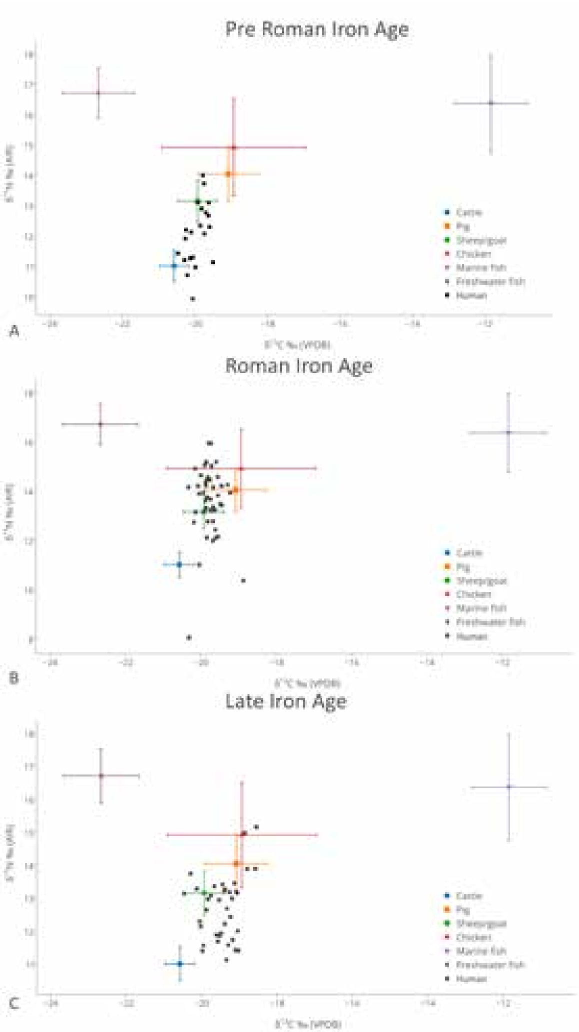

Fig. 8. The human samples from PreRoman Iron Age (500BC–AD 0) (chart A), Roman Iron Age (AD 0–400) (chart B) and Late Iron Age (AD 400–1050) (chart C). Iron Age samples are shown in a biplot with the TLE corrected animal samples from the most likely animal food sources. For each animal type, the standard deviation and mean of δ^{13}C was calculated while adding +1‰ for TLE. and the δ^{15}N is the mean and standard deviations calculated using the 5‰ TLE. The animal samples are from this study unless otherwise indicated. Marine fish is including values from Denmark (Jørkov, 2007), freshwater fish is only values from Denmark (Jørkov, 2007).

The isotopic values from all studies are on the other hand clearly similar (cf. Figs. 7 and 4.3). The interpretation of diet argued here differs from the earlier interpretations due to three particular factors: (i) this study uses contemporary relevant animal samples (including for example chickens); (ii) this study utilizes a stricter chronology; and (iii) this study applies a higher TLE for δ^{15}N as has recently been widely accepted. It is thus important to bear in mind that it is not the human isotope values that differ between these three studies, only the chronological organization (that will be discussed in detail below) and interpretation.

5.2 Chronology-relative typology or detailed chronology (radiocarbon)?

Dividing the sample from this study into three chronological periods (Pre Roman, Roman and Late Iron Age) showed statistically significant differences in the stable isotope variation. The actual timing of these isotopic (i.e. dietary) shifts are, however, very difficult to pinpoint when comparing them only with typological chronology. Since it was possible to conclude that the ^{14}C dates in Öland are unlikely to be compromised by the reservoir effect, these data can be used for a more detailed chronological discussion. The chronology for the two other studies involving human bone collagen for δ^{13}C and δ^{15}N allows some expansion of the sample size.

The results provided from the individuals dated by ^{14}C in all three studies (Figs. 9A, B) indicate a dietary shift taking place sometime in the two last centuries BC. This is expressed as a new level of higher δ^{15}N and the proportion of the lowest δ^{13}C values (-20‰ and lower) disappear. This result can be interpreted as the dietary transition appearing to be traversing the 0 AD boundary separating the two archaeological periods (the Pre Roman and the Roman Iron Age). In effect, the relative chronology in the case of Öland, at least, could be hindering the pinpointing of an actual dietary transition which could be potentially misleading. The ^{14}C dates comprise less than half the sample and when they are combined with the samples with a more specific chronological date (not just the general subperiods), the sample is large (Figs 9A, B). There is only one individual with δ^{15}N over 13‰ that has a potentially earlier chronological date than the other samples, but the date could also fall just on the mark (i.e. 200 BC). However, it is clear that the spectrum of δ^{15}N in the period AD 0–400 also includes individuals with very low δ^{15}N values. Consequently, a very wide range of N-values (from 16–10‰, with one outlier at 8‰) is not as apparent when viewing only the ^{14}C subsample where the average is higher. With the addition of the relative chronology data it seems that this diet could be lasting into at least the second century AD, and possibly even the third (Fig. 9B).

Considering the interpretation of diet proposed in this study, that of an animal-based subsistence, the partitioning system on Öland could be much older than currently assumed, even up to 400 years older. Due to the imprecise nature of both ^{14}C dates (despite a significant reservoir effect being an unlikely bias in this case) and relative chronology, it is risky to give an exact timeframe for the dietary transition occurring at the end of the Pre Roman Iron Age. An early potential date of partitioning systems in Scandinavia, however, outside of Öland, was recently determined as possibly including the last centuries BC (Friman, 2008;

Björhem and Skoglund, 2009). Thus, I suggest, based on the interpretation of the dietary isotopes, that the shift in diet and subsistence (to pastoralist) occurred on Öland much earlier than previously supposed.

During the seventh century and onwards, there was a variation in $\delta^{15}N$ that is more clearly detectable when including the non-^{14}C dated subsample. The high $\delta^{15}N$ levels in the Late Iron Age (and specifically in the two samples around AD 500) with corresponding higher $\delta^{13}C$ are probably indicative of a more substantially marine-based diet (c.f. Fig. 9). Since there are very few data points in the time span of AD 200–700, the dietary transition that appears to take place at some point in that span cannot be pinpointed or discussed in any detail at this stage. It could be a comparably swift change (like the one in the last centuries BC), perhaps even occurring simultaneously with the other great societal changes in burial practice (around AD 200), or a slow change appearing sometime within the 500 years. This transition does not seem to correspond to the introduction of the partitioning system, rather indicating the opposite by the diet being more diversified.

Based on the current information available, it can be concluded that a reliance on domesticates was probably apparent already in the earliest Iron Age. In the centuries leading up to AD 0, this had transitioned into the spectacularly organized partitioning system. This system, as assumed here from the isotope interpretation, coincides with a more intense use of the grazers, primarily sheep, which is a conclusion supported further by later archaeozoological assemblages and which consequently appears to have prevailed for many centuries. At some point in the centuries surrounding the middle of the first millennium AD, the subsistence becomes more varied. This does not necessarily mean that the partitioning system would be abandoned, only that it was at least supplemented with other resources giving a more varied diet. At around AD 800, the inhumation burials were also becoming increasingly varied with respect to orientation and types, signaling a change in culture as well. In the case of Öland, and probably elsewhere, it is important to attempt to shed the typological definitions of chronology to some extent, at least, and also to investigate chronology with methods such as ^{14}C in order to trace actual local dietary and cultural shifts with accuracy.

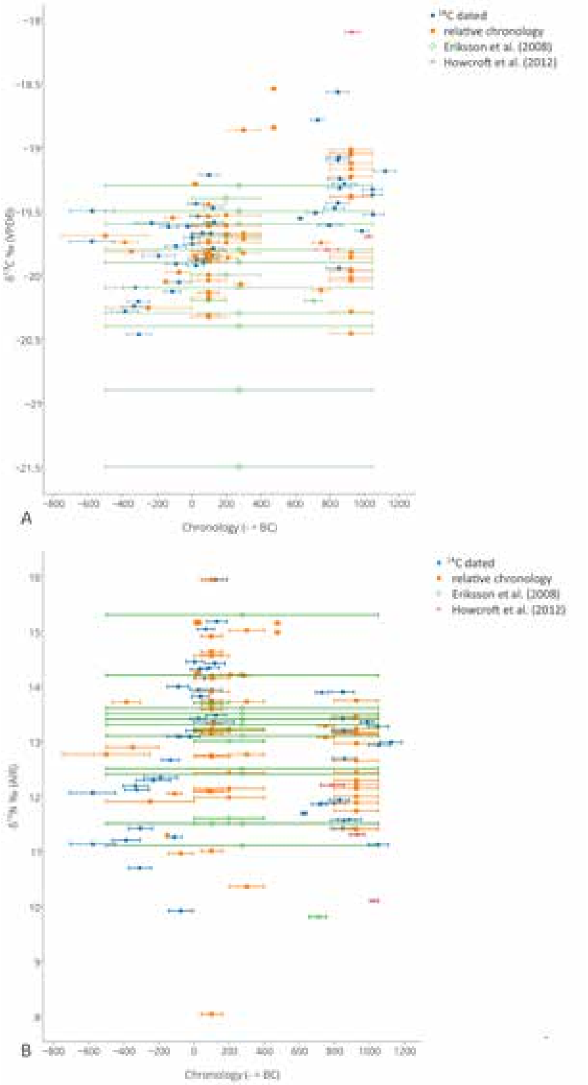

Fig. 9. The $\delta^{13}C$ (chart A) and δ^{15} N (chart B) values of the individuals specified as either with an individual ^{14}C or if dated by archaeological criteria (typology and/or artefact) and/or shared context to individual with ^{14}C. The data sets labeled "^{14}C dated" above also include ^{14}C dated individuals from the two previous isotopic studies (Eriksson et al., 2008; Howcroft et al., 2012) as specified in Supplement

6 CONCLUSION

Throughout the Iron Age, isotopic differences, here interpreted as corresponding dietary shifts, could be determined. The first shift appears to have occurred in the last two centuries BC, established by ^{14}C dates, but the second shift could not be determined with any similar precision. The timing of the first shift appeared to correspond to the transition from the Pre Roman Iron Age into the Roman Iron Age around AD 200 without taking the ^{14}C dates into account (i.e., an erroneous result was achieved if only relying on regional relative chronology). This is an important result, that using a specific chronology from ^{14}C not only showed when a dietary transition occurred but also that it did not fit nicely with the regional time periods. Such an approach should therefore be considered in other paleodietary studies seeking to pinpoint, and explain, dietary transitions. Moreover, the possibility that relative chronology alone is insufficient to answer such questions should be carefully considered in designing paleodietary studies– whether based on isotopes or other sources, or in combination as here.

Considering the local contemporary animal samples and the estuary aspect, the diet was concluded to be going through two major transitions. The first was a shift to a more intense domesticate subsistence, likely relying heavily on sheep but also pigs and chickens, with less reliance upon cattle than seen previously. The second shift was to a more varied diet than eaten during the Iron Age. These interpretations correspond well to the archaeozoological assemblages in particular. The first shift is concluded to be of the greatest relevance in relation to the introduction of the extensive partitioning system on Öland. By consequence, this would indicate that the partitioning system is older than assumed and possibly parallel to the earliest finds recently excavated in South Scandinavia. Overall, this study has shown, as have many others, that there is great potential for increasing our understanding of past subsistence and diet by investigating a primary source—the humans. Moreover, it was also demonstrated how not simply relying on regional relative archaeological chronology is imperative to further our understanding and can even provide new insights into both dietary and cultural change on a local scale. Instead of asking whether shifting culture equates to a shifting diet, I argue that we need to view the problem from the opposite perspective: what does the shifting diet mean for our understanding of cultural shifts on the local scale?

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SUPPLEMENT 1: The human stable isotope results used from earlier studies

	Schulze 1996:159ff (148-162)				Data from Eriksson et al., 2008					
grave	**Date**	**Artefacts****	**Dated by**	**Date used here**	**$\delta^{13}C$ (VPDB) ‰**	**$\delta^{15}N$ (AIR) ‰**	**sampled bone**	**Date**	**Age***	**Looting**
Bjärby 41	Iron Age?			Iron Age?	-21.5	13.4	femur	Roman Iron Age		Yes
Bjärby 38	Iron Age	iron , flint	artefact	Iron Age	-20.9	15.3	mandible	Roman Iron Age	28-37	Yes
Bjärby 2	Roman Iron Age		Relative grave chronology?	Iron Age?	-20.4	11.5	mandible	Roman Iron Age		Yes
Bjärby 72	Iron Age?			Iron Age?	-20.3	13.4	mandible	Roman Iron Age	20-35	No
Bjärby **40**	Early Roman Period	knife, beltfitting etc	artefact	R IA	-20.2	13.7	mandible	Roman Iron Age	20-30	Yes
Bjärby 86	not specified			Iron Age?	-20.1	13.3	mandible	Roman Iron Age	10-24	No
Bjärby 36	Roman Iron Age	knife, ceramic	artefact	R IA	-20.0	13.2	humerus	Roman Iron Age	20	Yes
Bjärby 10	Roman Iron Age	iron fragm, resin	Relative grave chronology?	Iron Age?	-19.9	11.1	femur	Roman Iron Age		Yes
Bjärby 85	Iron Age?			Iron Age?	-19.9	13.4	mandible	Roman Iron Age	20-35	No
Bjärby 101	Roman Iron Age		Relative grave chronology?	Iron Age?	-19.8	13.3	frontale	Roman Iron Age	adult	No
Bjärby 27	Iron Age?			Iron Age?	-19.8	13.1	mandible	Roman Iron Age	23-40	Yes
Bjärby 39	Iron Age?			Iron Age?	-19.8	11.5	mandible	Roman Iron Age	25-35	Yes
Bjärby 100	Roman Iron age	knife	artefact	R IA	-19.7	11.6	humerus	Roman Iron Age	juvenile/adult	Yes
Bjärby 89	Roman Iron Age	knife, resin		R IA	-19.6	13.5	femur	Roman Iron Age	15-20	No
Bjärby **99**	Early Roman Period	half moon knife etc	artefact	R IA	-19.6	11.5	fibula	Roman Iron Age	adult	No
Bjärby 35	Roman Iron Age	ceramics	artefact	Iron Age? (due to extensive looting)	-19.5	13.6	femur	Roman Iron Age	25-35y	Yes
Bjärby 8	Iron Age?			Iron Age?	-19.5	12.4	frontale	Roman Iron Age		Yes
Bjärby 77	Iron Age			Iron Age?	-19.5	12.5	mandible	Roman Iron Age	adult	No
Bjärby 25	Roman Iron Age	ceramics, resin	artefact	R IA	-19.4	13	radius	Roman Iron Age	40-50	Yes
Bjärby 18	not specified	resin	artefact	Iron Age?	-19.3	14.2	long bone	Roman Iron Age	7-10	No
Karlevi	-	?	^{14}C	L IA (AD 706 ± 49****)	-20.2	9.8	mandible	Iron Age		
					Data from Howcroft et al. 2012					
Triberga, A1	Early 11th century	Pearl, jewellry	artefact	L IA (AD 1000-1050)	-19.7	10.1	femur	Vendel –Viking Age	40-50	No
Triberga, A5	AD 786± 66	Knife	^{14}C	L IA (AD 786± 66)	-19.8	12.2	femur	Vendel –Viking Age	20-24	No
Triberga, A6	AD 930 ± 40	knife	^{14}C	L IA (AD 930 ± 40)	-18.1	11.3	femur	Vendel –Viking Age	45-45	no

Table 1. The other samples (of relevance to this study) from Öland, as presented in earlier studies. Only individuals over 7 years of age and with bone collagen sampled are included. Individuals from Bjärby and one from Karlevi (in Eriksson et al., 2008) and Triberberga (Howcroft et al., 2012). The samples where the dates are interpreted differently in this study compared to Eriksson et al. (2008) are marked in darker fields.

* Data from Holgersson (1984)

** none if not specified

*** this date takes into account the factor of graves without artefacts, routinely dated to the Roman Period on Öland, in this study have been ^{14}C-dated usually to either the Pre Roman Period or the Viking Age (i.e. the typology is only relative to Iron Age in a wide sense, not specifically the Roman Iron Age).

****= this date is calibrated with Cal Pal (same as those from this study), conventional age 1325± 55 BP according to Eriksson et al. (2008) (referring to an unpublished MA thesis; Kanstrup, (2004)). Since it is not specified which burial (there is no burial 1) in the Karlevi grave field (including multiple burials all dated to relative chronology as Viking Age) no further details, for example relative chronology, is available.

The two - from Triberga, are calibrated with Cal Pal (same as those from this study), values from Petersson (2006): conventional age for A5: 1225 ± 40 and A6: 1110± 40 BP.

SUPPLEMENT 2: Human stable isotope results

ID	SHM (grave field)	Grave number	δ13C (VPDB) ‰	δ15N (AIR) ‰	Bone	mg (sample)	mg collagen	Yield (mg/g) %	C%	N%	C/N ratio
1002	9754	25	-20.2	12.7	mandible	150.4	2.6	1.73	48.4	16.9	3.3
1003	31890	8	-19.6	12.4	mandible	150.5	4.3	2.86	49.0	17.8	3.2
1004	31890	11	-19.7	13.4	tibia	150.5	8.4	5.58	49.0	18.0	3.2
1005	31890	18	-20.3	8.0	humerus	150.4	2.6	1.73	46.9	16.8	3.3
1006	25570	2	-19.7	12.8	cranium	150.7	1.0	0.66	49.3	17.7	3.3
1007	23981	35c	-19.8	14.0	mandible	150.3	1.8	1.20	47.0	16.4	3.3
1008	24542	I undre	-19.1	11.4	femur	150.4	2.4	1.60	48.6	17.2	3.3
1009	23494	21	-19.5	12.1	mandible	150.3	7.7	5.12	48.1	17.2	3.3
1010	25570	2	-19.6	12.3	mandible	150.4	9.3	6.18	46.8	16.7	3.3
1011	23280		-18.9	10.4	mandible	150.7	2.4	1.59	48.7	17.1	3.3
1012	28549		-19.9	12.6	mandible	151.5	5.2	3.43	48.1	17.1	3.3
1013	27365	35	-19.4	12.2	mandible	150.6	2.1	1.39	49.2	17.1	3.4
1014	28364	108 F231 III	-19.8	12.7	mandible	150.2	2.6	1.73	47.5	16.9	3.3
1015	25153		-19.6	15.2	mandible	149.9	1.9	1.27	48.0	16.9	3.3
1016	25096		-19.8	13.0	mandible	150.6	4.3	2.8552457	48.1	17.4	3.2
1019	31890	25	-19.9	13.6	humerus	150.1	1.1	0.7328448	46.9	16.2	3.4
1020	1785/67 Bårby	6	-19.7	15.9	mandible	150.6	6.6	4.38	48.6	17.6	3.2
1021	26454	3	-20.3	13.7	mandible	150.3	3.3	2.20	47.5	16.6	3.3
1022	26454	2?	-20.0	12.1	mandible	151.5	3.9	2.57	47.5	16.8	3.3
1023	26454	1?	-20.0	12.3	mandible	150.3	2.9	1.93	46.4	16.2	3.4
1024	25129		-19.3	11.1	mandible	150.5	3.3	2.19	47.4	16.9	3.3
1025	23981	35b	-19.6	12.1	cranium	150.7	4.3	2.853351	46.8	16.8	3.3
1026	19726	1	-19.7	13.4	mandible	150.8	8.5	5.64	47.0	16.9	3.2
1027	19726	13	-19.5	11.1	mandible	150.0	2.4	1.60	46.4	16.3	3.3
1028	22486		-19.3	11.6	mandible	150.3	9.3	6.19	47.0	17.0	3.2
1029	18521		-20.1	12.1	mandible	150.8	1.7	1.13	47.4	16.6	3.3
1030	25657		-20.5	13.1	cranium	150.6	2.1	1.39	46.0	15.8	3.4
1031	27768		-20.1	14.2	mandible	151.2	0.7	0.46	46.8	15.7	3.5
1032	27702	39	-20.1	13.1	humerus	150.2	5.3	3.53	46.7	16.4	3.3
1033	27702	2	-20.0	11.0	mandible	150.4	7.1	4.72	47.0	16.7	3.3
1034	25130	-	-19.7	13.2	mandible	150.5	8.7	5.78	47.7	17.2	3.2
1035	22348	-	-19.6	13.2	mandible	150.4	6.1	4.06	47.9	17.4	3.2
1036	23267	1	-19.2	13.9	mandible	151.2	6.5	4.30	45.3	16.4	3.2
1037	27702	1	-19.8	14.6	mandible	149.8	3.4	2.27	46.1	16.2	3.3
1038	28364	6	-19.9	13.2	humerus	151.2	3.0	1.98	46.1	16.1	3.3
1039	27702	36	-19.9	15.2	cranium	150.9	4.1	2.72	47.6	17.1	3.3
1040	28514		-20.2	12.2	mandible	150.2	3.0	2.00	46.5	16.2	3.4
1041	24544	5	-20.3	11.9	cranium	150.4	4.1	2.73	46.5	16.2	3.3
1042	24544	2	-19.9	12.3	mandible	150.7	2.1	1.39	45.0	15.3	3.4
1043	24847	3	-19.8	12.9	mandible	150.3	5.8	3.86	47.3	16.7	3.3
1044	27764		-19.5	14.2	mandible	150.7	9.2	6.10	45.9	16.4	3.3
1045	29352	24	-19.0	11.4	mandible	150.8	10.3	6.83	46.9	16.9	3.2
1046	22291	-	-19.4	13.4	mandible	150.7	2.4	1.59	45.8	15.5	3.4
1047	23981	47	-19.8	14.4	mandible	150.0	7.6	5.07	47.0	16.9	3.2
1048	23981	35a	-19.9	13.9	mandible	150.9	2.2	1.46	46.6	16.1	3.4
1051	24846	1	-19.7	13.7	mandible	150.7	9.1	6.04	48.1	17.2	3.3
1052	24846	2 (?)	-20.3	11.2	mandible	150.4	6.6	4.39	43.7	15.7	3.2
1053	27702	90	-20.0	13.9	mandible	150.6	3.8	2.52	45.8	16.1	3.3
1054	27702	140	-20.3	14.1	humerus	150.7	2.9	1.92	47.0	16.1	3.4
1055	22231	4	-20.1	13.3	mandible	151.0	4.9	3.25	48.0	16.4	3.4
1056	27125		-19.6	13.1	mandible	150.9	7.9	5.24	46.1	16.4	3.3
1057	29352	13	-19.2	11.7	mandible	150.3	8.1	5.39	46.9	16.9	3.2
1058	28364	134	-19.4	13.3	mandible	150.9	4.2	2.78	46.4	16.6	3.3
1059	23494	20	-18.6	13.9	mandible	150.5	4.1	2.72	47.6	17.2	3.2
1060	23494	19	-20.0	11.4	mandible	150.9	5.0	3.31	46.5	16.5	3.3
1061	24543	3	-19.7	15.0	mandible	151.4	7.6	5.02	47.9	17.3	3.2
1062	19197	2?	-19.9	14.3	mandible	148.8	6.7	4.50	47.3	17.1	3.2
1063	22126		-19.7	12.1	mandible	150.9	5.2	3.45	45.8	16.3	3.3
1064	22394		-19.3	12.7	mandible	150.0	6.7	4.47	45.2	16.4	3.2
1065	6393/75	3	-19.4	13.2	mandible	150.9	9.0	5.96	46.8	16.9	3.2
~~1066~~	~~6393/75~~	~~10~~	~~-20.0~~	~~11.9~~	~~mandible~~	~~150.6~~	~~1.1~~	~~0.73~~	~~44.7~~	~~13.7~~	~~3.8~~
1067	6393/75	20	-19.1	13.5	mandible	151.1	9.4	6.22	47.0	16.9	3.2
1068	29352	18	-19.1	13.2	mandible	150.8	1.7	1.13	46.9	15.9	3.4
1069	29764	-	-20.1	9.9	mandible	150.9	5.1	3.38	49.0	17.4	3.3
1070	29764	Ind II	-20.0	11.0	mandible	150.4	6.0	3.99	48.3	17.0	3.3
1071	27513	3	-19.5	11.9	humerus	149.9	2.8	1.87	47.6	16.8	3.3
1072	12097	-	-19.9	14.4	mandible	151.1	9.3	6.15	45.4	16.4	3.2
1073	27771	1	-19.5	11.9	mandible	150.5	2.3	1.53	44.9	16.0	3.3
1074	25098		-19.9	14.3	mandible	150.7	5.2	3.45	46.7	16.9	3.2
1075	28364	164	-19.1	13.2	mandible	150.3	1.8	1.20	44.9	15.8	3.3
1076	28364	136	-19.9	14.2	mandible	150.6	8.8	5.84	47.2	17.1	3.2
1077	22231	8	-19.8	13.1	Radius	150.1	6.2	4.13	48.0	17.6	3.2
1078	21367	A5	-19.0	12.0	mandible	150.8	7.7	5.11	46.5	16.8	3.2
1079	31890	12	-19.8	13.7	mandible	151.5	2.3	1.51	46.3	16.4	3.3
1080	31890	5	-19.8	13.7	tibia	150.0	8.3	5.53	46.2	16.9	3.2
1081	31890	6	-19.9	15.1	mandible	150.4	2.9	1.93	47.1	16.7	3.3
1082	24543	2	-19.9	15.0	mandible	150.5	7.9	5.25	47.8	17.2	3.2
1083	24543	1	-19.7	12.0	mandible	150.4	6.1	4.06	47.4	17.1	3.2
1084	24542	25	-19.2	13.0	mandible	150.5	8.8	5.85	48.2	17.5	3.2
1085	24866	G	-19.6	12.1	mandible	151.2	7.3	4.83	46.0	16.6	3.2
1086	29352	25	-19.6	11.9	mandible	149.9	9.5	6.34	47.8	17.2	3.2
1087	23267	2	-19.5	13.8	mandible	151.2	3.3	2.18	44.8	15.8	3.3
1088	23267	3	-19.3	13.2	mandible	150.2	4.8	3.20	45.8	16.2	3.3
1089	23267	4?	-19.5	13.5	mandible	150.2	4.5	3.00	45.3	16.2	3.3
1090	27702	37	-20.0	14.6	mandible	150.5	4.0	2.66	46.5	16.3	3.3
1091	29352	113	-19.3	14.2	mandible	150.3	5.1	3.39	47.0	16.8	3.3
1092	12142	9 över?	-19.5	14.6	mandible	151.2	2.9	1.92	46.3	16.3	3.3
1093	12142	9 under	-20.1	14.9	mandible	150.8	4.8	3.18	45.5	16.2	3.3
1094	25132		-19.8	15.9	mandible	150.7	3.3	2.19	46.6	16.3	3.3
1095	25605		-20.5	11.4	mandible	149.9	5.1	3.40	47.8	16.9	3.3
1096	24813	II	-19.4	13.4	mandible	150.4	8.8	5.85	48.2	17.3	3.2
1097	22763	-	-19.5	12.9	mandible	150.4	6.9	4.59	46.9	16.8	3.3
1098	4186/73	3	-20.1	11.3	mandible	151.1	2.6	1.72	47.0	16.2	3.4
1099	1785/67	5	-19.8	13.7	mandible	150.1	8.0	5.33	46.6	16.7	3.3
1100	25021		-19.7	14.1	mandible	153.2	3.2	2.09	46.5	16.6	3.3
1101	21367	24	-19.2	12.4	mandible	152.0	5.9	3.88	47.6	17.1	3.2
1102	23349	3 (?)	-19.8	13.2	mandible	72.3	3.9	5.39	47.9	17.4	3.2
1103	21368	37 undre	-19.9	13.3	mandible	150.6	4.8	3.19	47.3	16.8	3.3
1104	21368	37 övre	-19.8	12.1	mandible	150.4	4.6	3.06	46.1	16.5	3.3
1105	28364	108:I:169	-20.0	11.6	mandible	150.1	3.0	2.00	48.8	17.3	3.3
1106	28364	108:IV:282	-19.9	13.1	mandible	150.6	4.3	1.73	47.4	17.0	3.3
1107	19765	13	-19.7	12.8	mandible	150.2	2.6	2.86	46.5	16.3	3.3
1108	Sb	Individ I	-18.9	15.0	mandible	150.3	3.6	2.40	47.3	16.4	3.4
1109	Sb	Individ 2	-18.5	15.2	mandible	150.2	2.3	1.53	47.4	16.5	3.3
1110	26239/27121	29	-19.6	11.7	mandible	107.2	6.1	5.69	47.2	17.0	3.2
1111	26733/26732	26	-20.1	11.3	mandible	102.7	4.7	4.58	47.4	16.9	3.3
1112	27121	2	-19.6	12.7	mandible	100.2	6.8	6.79	47.4	17.1	3.2
1113	26239	8	-18.8	13.9	mandible	102.5	3.8	3.71	47.4	17.1	3.2
1114	26732	15	-20.2	10.7	mandible	105.2	7.7	7.32	47.5	16.8	3.3

SUPPLEMENT 3: Animal stable isotopes results

Id	Species	Site (SHM)	Subperiod	Bone element	δ¹³C (VPDB) ‰	δ¹⁵N (AIR) ‰	mg (sample)	mg (collagen)	Yield (mg/g) %	C%	N%	C:N
1223	Cattle	27362	EIA	Malleolar, R	-22.0	6.7	151.1	10.4	6.88	46.2	16.9	3.2
1225	Cattle	28361	IA (Roman Iron Age-Vendel period)	Maxilla	-21.7	6.2	150.3	5.3	3.53	45.7	15.9	3.3
1246	Cattle	Sandby borg	LIA (Migration period)	Humerus, R	-21.6	6.1	150.2	2.2	1.46	45.6	16.1	3.3
1244	Sheep/ goat	23280	EIA (Late Roman period)	Astragalus, L	-21.5	8.6	150.1	1.3	0.87	43.7	15.0	3.4
1235	Sheep/ goat	27702	EIA (Early Roman period)	Astragalus, R	-21.4	8.0	150.2	4.1	2.73	46.8	16.4	3.3
1230	Cattle	27362	EIA	Frontal	-21.3	5.4	150.9	7.8	5.17	45.5	16.4	3.2
1204	Cattle	27702	EIA (Early Roman period)	Astragalus, L	-21.3	5.6	150.3	1.1	0.73	45.6	15.9	3.3
1245	Pig	27362	EIA	Metacarpal V, L	-21.0	9.4	150.4	8.4	5.59	48.9	17.6	3.2
1241	Chicken	23280	EIA (Late Roman period)	Humerus , L	-20.9	11.2	150.5	2.8	1.86	46.0	15.7	3.4
1216	Sheep/ goat	27362	E I A	Atlas	-20.9	8.2	150.5	6.7	4.45	47.6	17.1	3.3
1224	Sheep/ goat	27362	E I A	Calcaneum	-20.5	8.9	150.9	10.5	6.96	46.5	16.8	3.2
1238	Sheep/ goat	10302	IA	Phalanx I	-20.3	7.1	149.9	6.4	4.27	47.3	16.9	3.3
1214	Pig	31597	IA	Canine	-19.7	9.7	150.8	6.9	4.58	48.0	17.4	3.2
1242	Pig	10302	IA	Humerus, L	-19.5	8.0	150.6	3.4	2.26	46.9	16.4	3.3
1205	Chicken	25570	IA	Humerus, R	-16.0	11.3	151.7	6.2	4.09	48.2	17.3	3.2
1213	Flounder	31597	IA	Anal	-13.3	8.3	110.9	3.3	2.98	46.9	16.6	3.3
1211	Pike	27362	EIA	Vertebrae	-11.8	10.8	107.8	3.4	3.15	46.5	16.4	3.3
1231	Cat	31597	IA	Humerus, L	-17.8	11.9	150.3	7.8	5.19	45.8	16.3	3.3
1201	Dog	12142	EIA (Early Roman period)	Mandible	-18.1	12.3	150.6	1.8	1.20	47.5	16.5	3.4
1202	Dog	22231	LIA (Vendel period)	Mandible	-19.8	12.1	150.5	5.1	3.39	48.8	17.2	3.3
1237	Dog	27702	EIA (Early Roman IA)	Mc2, L	-20.0	11.3	150.3	1.1	0.73	46.6	17.0	3.2
1239	Dog	10302	IA	Radius, R	-15.9	12.5	150.4	3.8	2.53	48.2	17.2	3.3
1247	Dog	Sandby borg	LIA (Migration period)	Ulna ,L	-17.6	12.6	150.9	9.2	6.10	48.1	17.1	3.3
1222	Horse	28549	LIA (Viking Age)	Petrous portion, L	-21.6	7.1	150.8	1.8	1.19	46.7	15.6	3.5

Table 1. IA (Iron Age), EIA (Early Iron Age) LIA (Late Iron Age) for further definition of chronology see table 5 below.

	Period	Subperiod	Chronology
Early Iron Age (EIA)	Pre Roman Iron Age		500 BC-AD 0
	Roman Iron Age	Early Roman Period	AD 0-200
		Late Roman Period	AD 200-400
Late Iron Age (LIA)	Migration Period		AD 400-550
	Vendel Period		AD 600-800
	Viking Age		AD 800- 1050

Table 2. Chronological definitions

SUPPLEMENT 4: Animal isotopes comparative background

δ^{13}C (VPDB) ‰	δ^{15}N (AIR) ‰	
-23.4	4.5	cattle
-23.1	3.8	cattle
-21.9	6.5	cattle
-21.3	8.1	cattle
-21.5	4.4	cattle
-21.3	7.3	cattle
-20.9	8.2	cattle
-21.5	4.9	cattle
-20.7	4.5	pig
-20.7	7.2	pig
-20.8	3.4	pig
-21.9	5.4	pig
-20.5	5.5	pig
-21.5	5.4	pig
-22. 0	9.5	pig
-21.1	4.3	pig
-21. 0	4.0	pig
-21.7	7.5	pig
-20.9	5.3	pig
-22.0	6.3	pig
-22.1	6.5	pig
-21.0	7.6	sheep/goat
-21.0	6.7	sheep/goat
-20.5	6.1	sheep/goat
-21.3	9.1	sheep/goat
-19.8	6.5	sheep/goat
-20.9	6.6	sheep/goat
-20.1	6.2	sheep/goat
-21.5	7.4	sheep/goat
-22.5	5.6	sheep/goat
-14.2	9.8	fish
-15.1	8.8	fish
-10.8	12.4	fish
-12.7	12	fish
-11.0	11.3	fish
-15.1	12.8	fish
-14.5	10.6	fish
-16.6	9.3	fish
-15.4	10.7	fish
-15.3	12.7	fish
-13.7	12.1	fish
-13.7	11.5	fish
-13.8	12.0	fish

Table 1. Neolithic/Bronze Age animal values, from Eriksson et al. 2008 for Öland.

δ^{13}C (VPDB) ‰	δ^{15}N (AIR) ‰	Animal	Place	Source
-22.1	11.3	Carp	Denmark	Jørkov 2007
-23.8	11.4	Carp	Denmark	Jørkov 2007
-23.5	13.1	Pike	Denmark	Jørkov 2007
-24.8	11.0	Pike	Denmark	Jørkov 2007
-24.1	11.7	Roach	Denmark	Jørkov 2007
-13.9	12.3	Garfish	Denmark	Jørkov 2007
-13.8	12.2	Garfish	Denmark	Jørkov 2007
-13.5	11.8	Garfish	Denmark	Jørkov 2007
-12.0	13.3	Cod	Denmark	Jørkov 2007
-11.6	10.8	Perch	Denmark	Jørkov 2007
-13.3	8.3	Flounder	Öland	this study
-11.8	10.8	Pike	Öland	this study
-13.0	9.0	perch	Haithabu	Doppler et al. 2010
-13.5	11.3	perch	Haithabu	Doppler et al. 2010
-14.7	15.6	cod	Haithabu	Doppler et al. 2010
-16.0	17.4	cod	Haithabu	Doppler et al. 2010
-16.1	13.7	cod	Haithabu	Doppler et al. 2010
-16.2	10.4	perch	Haithabu	Doppler et al. 2010
-16.2	15.9	cod	Haithabu	Doppler et al. 2010
-16.3	14.4	pike	Haithabu	Doppler et al. 2010
-18.6	13.4	pike	Haithabu	Doppler et al. 2010
-20.0	10.3	sander	Haithabu	Doppler et al. 2010
-21.0	11.5	sander	Haithabu	Doppler et al. 2010
-22.2	10.2	sander	Haithabu	Doppler et al. 2010
-22.2	11.6	pike	Haithabu	Doppler et al. 2010
-22.7	9.7	sander	Haithabu	Doppler et al. 2010
-23.0	10.6	sander	Haithabu	Doppler et al. 2010
-24.0	9.7	perch	Haithabu	Doppler et al. 2010
-24.7	10.3	pike	Haithabu	Doppler et al. 2010
-25.7	10.8	pike	Haithabu	Doppler et al. 2010
-21.3	5.6	Cattle	Öland	this study
-22.0	6.7	Cattle	Öland	this study
-21.7	6.2	Cattle	Öland	this study
-21.3	5.4	Cattle	Öland	this study
-21.6	6.1	Cattle	Öland	this study
-21.9	5.3	cattle	Denmark	Jørkov 2007
-21.4	5.4	cattle	Denmark	Jørkov 2007
-21.5	6.2	cattle	Denmark	Jørkov 2007
-22	5.1	cattle	Birka	Linderholm et al. 2008
-21.8	4	cattle	Birka	Linderholm et al. 2008
-19.7	9.7	Pig	Öland	this study
-19.5	8.0	Pig	Öland	this study
-21.0	9.4	Pig	Öland	this study
-22.3	9.6	pig	Denmark	Jørkov 2007
-22.5	8.7	pig	Denmark	Jørkov 2007
-22.1	7.4	pig	Denmark	Jørkov 2007
-21.3	8.9	pig	Denmark	Jørkov 2007
-21.3	13.8	pig	Birka	Linderholm et al. 2008
-19.9	9.7	pig	Birka	Linderholm et al. 2008
-20.9	8.2	Sheep/goat	Öland	this study
-20.5	8.9	Sheep/goat	Öland	this study
-21.4	8.0	Sheep/goat	Öland	this study
-20.3	7.1	Sheep/goat	Öland	this study
-21.5	8.6	Sheep/goat	Öland	this study
-21.9	7.7	sheep	Denmark	Jørkov 2007
-22	7.0	sheep	Denmark	Jørkov 2007
-21.9	7.2	sheep	Denmark	Jørkov 2007
-21.7	6.3	sheep	Denmark	Jørkov 2007
-21.6	6.7	sheep	Denmark	Jørkov 2007
-21.8	7.3	sheep	Denmark	Jørkov 2007
-22	6.2	sheep	Denmark	Jørkov 2007
-22.1	6.3	sheep	Birka	Linderholm et al. 2008
-16.0	11.3	Chicken	Öland	this study
-20.9	11.2	Chicken	Öland	this study
-20.3	11.6	Chicken	Germany	Hakenbeck et al. 2010
-20.7	10.3	Chicken	Germany	Knipper et al. 2012
-20.9	8.4	Chicken	Germany	Knipper et al. 2012

Table 2. Iron Age animal values, regional and from Öland. Jørkov, 2007 is Iron Age Eastern Denmark and Doppler et al., 2010 and Linderholm et al., 2008 are the Viking Age coastal trade centers in Haithabu in Germany and Birka in Sweden respectively.

Table 3. Overview of the geographical origin of the animal samples selected to represent the ecologically most similar isotopic signals to Öland. The values of these samples will be compared directly to the animal values from Öland. Note: for chicken: 3 more samples were added from more distant contexts (Hakenbeck et al., 2010; Knipper et al., 2013). Local contemporary data from: East Denmark (Jørkov 2007), Birka (Linderholm et al. , 2008) and Haithabu (Doppler et al., 2010).

	Öland	East Denmark	Birka	Haithabu	Total
Cattle	5	3	2	-	10
Sheep/goat	5	7	1	-	13
Pig	3	4	2	-	9
Chicken	2	-	-	4	9
Freshwater fish	-	5	-	9	14
Marine fish	2	5	-	9	16

SUPPLEMENT 5: Radiocarbon

ID	Date, typology and 14C	^{14}C conventional age, BP	^{14}C calib.	LuSNo	Collagen, mg	Date, typology as given in ÖJG	Comment/ details	Bone sampled in this study
1002	R IA (Early Roman Period)					Early Roman Period		
1003	R IA (Roman Iron Age)					Roman Iron Age		
1004	R IA (Early Roman Period)	1895 ± 100	112 ±1 16 AD	See -		Early Roman Period IV:1	IV:1	-
1005	R IA (Early Roman Period)					Early Roman Period IV:2	IV:2	
1006	PR IA (Pre Roman Iron Age)					Pre Roman Iron Age		
1007	PR IA (Pre Roman Iron Age)	2065 ± 45	91 ± 61 BC	10535	2,2	Iron Age?		Mandible
1008	L IA (Viking Age)	1180 ± 45	847 ± 65 AD	10536	0,9	Viking Age?		Mandible
1009	R IA (Roman Iron Age)					Late Roman Period		
1010	PR IA (Pre Roman Iron Age)	2155 ± 45	232 ± 98 BC	10537	4,4	Iron Age?		Mandible
1011	R IA (Late Roman Period)					Late Roman Period		
1012	L IA (Viking Age)					Viking Age		
1013	L IA (Viking Age)					Viking Age		
1014	R IA (Early Roman Period)					Early Roman Period		
1015	R IA (Early Roman Period)	1885 ± 45	130 ± 57 AD	10538	1,9	Early Roman Period	commingled, looted. No datable artefacts, other burials close by are Viking age	Mandible
1016	L IA (Viking Age)					Viking Age		
1019	R IA (Roman Iron Age)					Roman Iron Age (IV:2/V:I)		
1020	R IA (Early Roman Period)					Roman Iron Age per IV:2		
1021	L IA (Viking Age)					Viking Age		
1022	L IA (Viking Age)					Viking Age		
1023	L IA (Viking Age)					Viking Age		
1024	L IA (Viking Age)	1005 ± 45	1049 ± 58 AD	10539	0,8	Iron Age?		Mandible
1025	- (Pre Roman/ Early Roman Period)					Iron Age?	Burials next to are: ID 1007 (91± 61 BC) and ID 1048 (25 ± 47AD).	
1026	L IA (Viking Age)	1035 ± 45	986 ± 38 AD	10540	1,9	Iron Age?		Mandible
1027	PR IA (Pre Roman Iron Age)	2425 ± 45	575 ± 129 BC	10664	0,8	Roman Iron Age	RIA only due to a cists (despite most graves Viking age in the grave field)	Mandible
1028	L IA (Viking Age)	1140 ± 50 BP	885 ± 69 AD	10267	5,2	Viking Age	See table 3	Mandible
1029	PR IA (Pre Roman Iron Age)	2295 ± 45	326 ± 70 BC	10541	0,4	Iron Age?		Mandible
1030	L IA (Viking Age)					Viking Age		
1031	R IA (Late Roman Period)					Late Roman period (C2)		
1032	R IA (Early Roman Period)					Early Roman period (IV:2)		
1033	R IA (Early Roman Period)					Early Roman period (IV:2)		
1034	R IA (Early Roman Period)	1990 ± 45	3 AD ± 46	10542	1,8	Early Iron Age		Mandible
1035	R IA (Early Roman Period)					Early Roman Period		
1036	R IA (Early Roman Period)	1905 ± 45	103 ± 54 AD	10543	1,9	Roman Iron Age		Mandible
1037	R IA (Early Roman Period)					Early Roman Period		
1038	R IA (Early Roman Period)					Early Roman Period		
1039	R IA (Early Roman Period)					Early Roman Period (IV:1)		
1040	PR IA (Pre Roman Iron Age)	2315 ± 45	344 ± 71 BC	10544	0,7	Iron Age		Mandible
1041	PR IA (Pre Roman Iron Age)					Pre Roman Iron Age		
1042	PR IA (Pre Roman Iron Age)	2125 ± 45	191 ± 95 BC	10545	1,1	Early Iron Age		Mandible
1043	PR IA (Pre Roman Iron Age)					Pre Roman Iron Age (per. I)		
1044	R IA (Early Roman Period)					Early Roman Period		
1045	L IA (Viking Age)					Viking Age		
1046	L IA (Viking Age)	1180 ± 45	847 ± 65 AD	10546	0,9	Viking Age		Mandible
1047	R IA (Early Roman Period)	1990 ± 45	3 ± 46 AD	10665	2,3	Roman Iron Age		Mandible
1048	R IA (Early Roman Period)	1965 ± 45	25 ± 47 AD	10547	1,7	Iron Age?		Mandible
1051	PR IA (Pre Roman Iron Age)					Iron Age	dated by burial next to id 1052	
1052	PR IA (Pre Roman Iron Age)	2325 ± 45	386 ± 80 BC	10550	2,7	Early Iron Age		Mandible
1053	R IA (Early Roman Period)					Early Roman Period		
1054	R IA (Early Roman Period)					Early Roman Period		
1055	L IA (Vendel Period)					Circa AD 700		
1056	PR IA (Pre Roman Iron Age)	2010 ± 45	22 ± 55 BC	10551	3,1	Iron Age?		Mandible
1057	L IA (Viking Age)					Viking Age		
1058	L IA (Viking Age)	1005 ± 45	1049 ± 58 AD	10552	2,8	Iron Age?	See table 3	Mandible
1059	L IA (Viking Age)	1180 ± 45	847 ± 65 AD	10553	3,2	Roman Iron Age		Mandible
1060	L IA (Viking Age)					Viking Age		
1061	R IA (Late Roman Period)					Late Roman Period		
1062	R IA (Early Roman Period)	1915 ± 50	88 ± 57 AD	10274	4,2	Roman Iron Age		Mandible
1063	PR IA (Pre Roman Iron Age)	2425 ± 50	576 ± 130 BC	10273	4	Early Iron Age?		Mandible
1064	L IA (Viking Age)	1170 ± 45	858 ± 68 AD	10270	5,2	Iron Age?		Rib
1065	L IA (Viking Age)					Viking Age		
1066	L IA (Viking Age)					Viking Age		
1067	L IA (Viking Age)					Viking Age		
1068	L IA (Viking Age)					Viking Age		
1069	PR IA (Pre Roman Iron Age)	2050 ± 50	75 ± 69 BC	10269	4,8	?		Mandible
1070	PR IA (Pre Roman Iron Age)					?	same specific context, as 1069	
1071	L IA (Vendel Period)	1300 ± 45	716 ± 44 AD	10555	2,4	Pre Roman Iron Age (III) – Early Roman Period (IV:1) or Vendel Period	See below under ****	first phalange (hand)
1072	R IA (Early Roman perid)	1895 ± 45	119 ± 56 AD	10556	1,8	Late Roman Period	See table 3	Mandible
1073	L IA (Viking Age)	1190 ± 45	829 ± 57 AD	10557	1,6	Iron Age?		Mandible
1074	R IA (Early Roman Period)	1960 ± 45	30 ± 48 AD	10558	3,9	Early Roman Period		Mandible
1075	L IA (Viking Age)	1175 ± 45	853 ± 67 AD	10559	0,4	?	(ER-VA in gravefield)	Mandible
1076	L IA (Viking Age)					Late Roman Period (V:1)		
1077	L IA (Vendel Period)					Circa AD 700		
1078	L IA (Viking Age)					Viking Age		
1079	R IA (Early Roman Period)					Early Roman Period (IV:2)		
1080	R IA (Early Roman Period)					Early Roman Period (IV:2)		
1081	R IA (Early Roman Period)					Early Roman Period (IV:1)		

1082	R IA (Early Roman Period)	1930 ± 45	67 ± 48 AD	10560	1,8	Early Iron Age		Mandible
1083	R IA (Roman Iron Age)					Roman Iron Age		
1084	L IA (Viking Age)	895 ± 45	1122 ± 63	10561	1,8	Viking Age?	See table 3	Mandible
1085	R IA (Early Roman Period)					Early Roman Period		
1086	L IA (Vendel Period)	1210 ± 45	799 ± 68 AD	10562	1,7	Viking Age?	date from burials close by	Mandible
1087	R IA (Early Roman Period)	1955 ± 45	36 ± 49 AD	10563	2,6	Iron Age	See table 3	Mandible
1088	L IA (Viking Age)	1170 ± 45	858 ± 68 AD	10564	2,1	Iron Age?	See table 3	Mandible
1089	R IA (Early Roman Period)	1890 ± 45	125 ± 57 AD	10565	1,9	Early Roman Period?	See table 3	Mandible
1090	R IA (Early Roman Period)					Early Roman Period (IV:2)		
1091	R IA (Early Roman Period)					Early Roman Period (IV:1)		
1092	R IA (Early Roman Period)					Early Roman Period (IV:2)		
1093	R IA (Early Roman Period)					Early Roman Period (IV:2)		
1094	R IA (Early Roman Period)	1890 ± 50	125 ± 62 AD	10268	5,2	Early Roman Period (B2/C1a)	See table 3	Rib
1095	R IA (Early Roman Period)	2255 ± 50	305 ± 69 BC	10272	4,2	Iron Age?	See table 3	Rib
1096	R IA (Early Roman Period)	1965 ± 45	25 ± 47 AD	10566	1,7	Early Roman Period (IV:1)	See table 3	Mandible
1097	L IA (Viking Age)	1000 ± 50	1053 ± 60 AD	10271	5,2	Viking Age?		Rib
1098	PR IA (Pre Roman Iron Age)	NA	160-140 BC*					-
1099	R IA (Late Roman Period)					Late Roman Period (V)		
1100	R IA (Early Roman Period)	1935 ± 50	61 ± 54 AD	10275	5,2	?		Mandible
1101	L IA (Viking Age)					Viking Age		
1102	R IA (Roman Iron Age)					Roman Iron Age		
1103	R IA (Early Roman Period)					Early Roman Period (B2)	B2	
1104	R IA (Early Roman Period)					Early Roman Period (B1-B2)	B1-B2	
1105	L IA (Viking Age)	1175 ± 50	853 ± 71 AD	10567	1,6	Early Roman Period	See Table 3	Mandible
1106	PR IA (Pre Roman Iron Age)	2065 ± 45	91 ± 61 BC	10568	1,8	Early Roman Period	See table 3	Mandible
1107	R IA (Late Roman Period)					Late Roman Period		Mandible
1108	L IA (Migration Period)	**	(400-550) **			Migration Period		-
1109	L IA (Migration Period)	**	(400-550) **			Migration Period		
1110	L IA (Vendel Period)	1405 ± 30	629 ± 18 AD***					-
1111	PR IA (Pre Roman Iron Age)	2085 ± 30	112 ± 45 BC***					-
1112	PR IA (Pre Roman Iron Age)	2110 ± 35	134 ± 49 BC***					-
1113	L IA (Vendel Period)	1265 ± 30	729 ± 36 AD***					-
1114	PR IA (Pre Roman Iron Age)	2250 ± 35	308 ± 65 BC***					-

Table 1. For chronological definitions see Table 2 below. Notes:
- ^{14}C date from from Hagberg, UE, Holgersson, K, Nilsson, Å. (1981). Nyupptäckt fornlämning äldre romersk järnålder, Brostorp 7:3. Glömminge socken. Öland. Riksantikvarieämbetet och Statens Historiska Museer, Rapport: 1980:49. Stockholm. Page 35.
*^{14}C date from Fallgren and Rash (2001: 91) (report unfinished but notes in ATA but no further specification of ^{14}C results)
**^{14}C and date as described in Viberg A, Victor H, Fischer S, Lidén K, Andrén A. (2012). A room with a view: archaeological geophysical prospection and excavations at Sandby ringfort, Öland, Sweden. In: Viberg A, editor. Remnant echoes of the past: archaeological geophysical prospectioning. Sweden. Stockholm: Stockholm University. p 1–20.
***^{14}C dates from : Olsson, T.G.S. (2009). Krigsbytesofferrelaterade studier med utgångspunkt från fynden i Finnestorp, Västergötland & Skedemosse, Öland. Västra Frölunda: Onsjö tingshus förlag.

	Period	Subperiod	Chronology
Early Iron Age (E IA)	Pre Roman Iron Age (PR IA)		500 BC-AD 0
	Roman Iron Age (R IA)	Early Roman Period	AD 0-200
		Late Roman Period	AD 200-400
Late Iron Age (L IA)	Migration Period		AD 400-550
	Vendel Period		AD 600-800
	Viking Age		AD 800- 1050

Table 2. Chronological definitions used in this study.

ÖJG= Beskow-Sjöberg and Arnell, 1987; Beskow-Sjöberg and Hagberg, 1991; Hagberg and Beskow-Sjöberg, 1996; Fallgren and Rasch, 2001
**** Id 1071: This grave has a date to Late Pre Roman-Early Roman set from one belt ornament (Beskow-Sjöberg and Arnell, 1987: 395ff) with a reference to Åhberg (1923). There is a second belt ornament also (both are photographed in situ on the bones in the grave), but this would correspond to a Vendel Period ornament using the same source (Åberg,1923:150, 153 Fig. 268). Considering both ornaments are in situ it would be less plausible that the youngest one would appear at least 400 years too early why I choose reinterpret the archaeological date to AD 550-800 which also matches the ^{14}C well. This individual does not have any indication of a diet especially likely to include fish in either form from the isotopic results why the reservoir effect is a less plausible explanation for the early date being likely

PAPER IV

Migration and integration on the Baltic island of Öland in the Iron Age

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Migration and integration on the Baltic island of Öland in the Iron Age

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ABSTRACT

This study explores a bi-isotopic approach to migration, adding δ^{18}O values to samples with ^{87}Sr/^{86}Sr values for 109 individuals from the Iron Age (500 BCE–1050 CE) on the island of Öland, Sweden. Determining a local baseline for ^{87}Sr/^{86}Sr was complicated due to the wide range of variation in faunal samples so we divided the human values into three groups: local, non-local and undetermined. The addition of δ^{18}O isotopes allowed identifying further non locals than the data from the ^{87}Sr/^{86}Sr alone provided. We found significant migration rates in both the Early period (500 BCE–400 CE) with 30% non-locals and in the Late (400–1050 CE), more than doubling to 68%. In both periods the non-locals appear to have diverse geographical origins.

In order to study integration and migration patterns we use a bioarchaeological approach to these non cremated individuals who come from all types of contexts, i.e. not just burials. This allows discussing the cultural and social integration of non-locals. Integration is apparent in both periods and in the Late period, with a higher proportion of non-locals, there is both integration and diversity. The proportion of female non-locals suggest a mobility in both periods, especially the Late, that is relatively large. Our results of diverse non-local origins, female mobility and integration on Öland throughout the Iron Age add a new perspective, a Scandinavian multi-isotopic bioarchaeological perspective, to current discussions of Viking movement and expansion.

1. Introduction

We already know there was significant first generation migration to the island of Öland throughout the Iron Age from strontium (^{87}Sr/^{86}Sr) isotopes investigated on a population level of 109 individuals (Wilhelmson and Ahlström, 2015). It appears the migration was mainly regional given ^{87}Sr/^{86}Sr values matching surrounding regions. Is this all we can use this data set for? Here we are investigating on the very same human population (the same samples) as before, but focusing on the individual level (not discussed in Wilhelmson and Ahlström, 2015) and new layers of information, such as (i) adding oxygen (δ^{18}O) isotopes to further define non-local individuals, (ii) by developing a specific approach to define locals and non-locals (in the geological and climate definition of childhood residence from provenience isotopes) on an individual level from ^{87}Sr/^{86}Sr and δ^{18}O baselines and (iii) by devising a methodology based in bioarchaeology for investigating migration patterns (i.e. age, sex etc.) and social integration (i.e., cultural responses to migration as seen in burial practice, body modification etc.). With this combined approach we aim to highlight the complexity of migration as a concept. Although migration patterns are at times studied with an isotopic approach the topic of integration is rarely addressed similarly in archaeological context. Unlike many isotopic studies we have not targeted the specific likely non-locals (individuals deviant in grave type and/or artefacts, c.f. review in Eckhardt et al. 2014), nor have we avoided them. Our dataset includes all types of uncremated human remains, inhumations as well as other types of contexts (for example wetland finds) which means we can investigate migration patterns and integration on a population basis for uncremated individuals

The island of Öland in the Baltic Sea, in size about 140 km from north to south and a maximum of 15 km east to west, is separated from the Scandinavian peninsula by the narrow, 10 km wide, Kalmar strait (Fig 1). In the Iron Age (500 BCE–1050 CE, often subdivided, see Table 1) the island was surrounded by the sea and completely reliant on maritime communication. The extensive archaeological remains of settlements, forts, hoards, graves and exotic objects are proof of an, at least at times, intensely settled island. The grave types are especially varied in the Late Iron Age period (400–1050 CE) and at the same time graves from the Early period (500 BCE–400 CE) are reused. In earlier studies, intense contacts and large scale trade involving Öland and the Roman Empire have been discussed in detail (Hagberg, 1967, Herschend, 1980). For the later Iron Age (primarily the Viking age) there are indications of interaction based on artefacts from the prominent trade centers in the Baltic (such as Birka and Haithabu) as well as the southeast Baltic areas (c.f. discussion in Thurborg, 1988, and more generally Hagberg, 1979 and Callmer, 1991 and Callmer, 1992). This could mean that the artefacts, and implicitly the people trading them,

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Fig. 1. The location of Öland and the location of the human samples on the island (right). Basemap: Esri, HERE, DeKorme, MapmyIndia, ©OpenStreetMap contributors and the GIS user community.

moved similarly, but that actual migration (settlement) was not necessarily governed by the same patterns of movements as trade. To trace migration in a more direct way $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ isotopes document an actual shift in the geographical location of an individual during his/her lifetime. Compared to DNA or skeletal epigenetic traits, the positive evidence of migration indicated by isotopes in human remains is today the optimal choice in an archaeological context for discussing first generation migration (i.e. local/non-local) and integration.

Depending on geological complexity of the area of study it can also be more or less straightforward to define a local baseline for $^{87}Sr/^{86}Sr$. The $^{87}Sr/^{86}Sr$ baseline as previously defined for Öland (Fornander et al., 2011 and Wilhelmson and Ahlström, 2015 adding more values from fauna to that dataset) is difficult to apply on an individual level to the large sample from Öland. There are many individuals with values close to the cutoff points which means the risk of an arbitrary division of locals and non-locals (if relying strictly on a mathematical approach) is apparent. Therefore our first objective is to address this problem, i.e., how can a $^{87}Sr/^{86}Sr$ baseline be defined in order to minimize the risk of misclassifying both locals and non-locals?

Oxygen isotope ratios can vary over time with climate change why we will add a baseline for $\delta^{18}O$ VPDB, taking this into account, in order to make a bi-isotopic definition of locals vs. non-locals. This will also allow investigation if migration truly is only regional as presumed and argued in Wilhelmson and Ahlström (2015). From the bulk of $^{87}Sr/^{86}Sr$ studies emerging just in the last ten years it is clear there are areas of similar Sr profiles to Öland in Scandinavia but also further away such as the continent and Great Britain. Moreover, much of Europe and Russia lack information on bioavailable $^{87}Sr/^{86}Sr$ which is also a bias. Here, a $\delta^{18}O$ baseline could aid in straightening out if a local $^{87}Sr/^{86}Sr$ value for Öland means the individual is local or if he/she just comes from an area of similar $^{87}Sr/^{86}Sr$ profiles (but differing climate).

Table 1
The chronological divisions (and further subdivisions) of the Iron Age in Scandinavia as used in this paper.

Early Iron Age	Pre Roman period	500 BCE–0 CE
	Early Roman	0–200 CE
	Late Roman	200–400 CE
Late Iron Age	Migration period	400–550 CE
	Vendel period	550–800 CE
	Viking Age	800–1050 CE

As an island, with many imported artefacts and a high proportion of non-local individuals, the extent and impact of this in terms of social integration is not well understood from previous studies based on other archaeological sources, a single isotope ($^{87}Sr/^{86}Sr$), and by only examining migration at the population (not individual) level (cf. Wilhelmson and Ahlström, 2015). We will therefore address the following specific research objectives using a bioarchaeological, bi-isotopic, approach:

(i) How does adding a $\delta^{18}O$ baseline affect the interpretation of individuals as local and non-locals based only on a $^{87}Sr/^{86}Sr$ baseline? Does the $\delta^{18}O$ baseline detect any non locals that have a “local” $^{87}Sr/^{86}Sr$ isotope value which would lead them to be misinterpreted as locals from a single isotopic approach (such as in Wilhelmson and Ahlström, 2015)? Is the migration only regional (as argued in Wilhelmson and Ahlström, 2015).

(ii) How do patterns of migration (age, sex, different origins) appear on Öland during the Early and the Late Iron Age, are they constant or changing? What indications of the kind of migration can the uncremated remains provide?

(iii) Were the non-locals (defined by $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ VPDB) integrated with the locals (defined by $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ VPDB) in society at large? Were they buried differently? Are there differences in social status, as potentially reflected in burial goods?

2. Material

The material for this study comes from the skeletal remains of 109 individuals and their Iron Age contexts, from excavations on Öland. All types of contexts were considered, i.e. not only inhumations, but all contexts with uncremated remains. The individuals were selected primarily on the basis of available permanent teeth for $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ isotopic analysis.

Both cremation and inhumation were practiced during the Iron Age, with cremations more predominant particularly in the middle of the period (i.e., 400 CE–800 CE) on Öland (Beskow-Sjöberg and Arnell, 1987; Beskow-Sjöberg and Hagberg, 1991; Hagberg and Beskow-Sjöberg, 1996; Rash, 2001). The most common burials are found in cists (made from local limestone available in quarries and the terrain) or pits. The orientation of the burial varies including NS (north-south) and EW (east-west) in both the Early and Late periods of the Iron Age.

Many graves are from the extended narrow grave fields oriented to fit the beach ridges. These are prominent gravel ridges that function as natural roads running in the north-south direction on both the east and west coasts of the island (Beskow-Sjöberg and Arnell, 1987; Beskow-Sjöberg and Hagberg, 1991; Hagberg and Beskow-Sjöberg, 1996; Rash, 2001). Many of the settlements also follow the ridges (Fallgren, 2006). Gravefields are at times difficult to distinguish as they sometimes overlap on the ridges, leading to a potentially arbitrary division of specific gravefields. This, along with a prominent reopening (c.f. Rasch, 1991:510, Rasch, 1994) and reuse not only of the burial grounds but even the specific graves throughout the entire period makes chronology a problem (c.f., discussion in Näsman, 1994). The individuals included in this study are therefore those that have been dated by radiocarbon ($n = 47$) or by detailed artifact typology and assigned to a subperiod within the Iron Age (details in Appendices A, B). Human remains have also been found in a wetland context on the island (Gejvall, 1968, Wilhelmson, 2015) and are included in this study.

Uncremated skeletal remains from all over the island are included (see Fig. 1 for distribution of sampled individuals). Excluding the cremated remains no doubt means that a potentially significant proportion of the population is not studied. These burials, however, provide little information on sex and age limiting their value for investigating migration patterns. Inhumation and cremation may have been reserved for individuals of different specific social identities. However, during the 1500 years (500 BCE–1050 CE) of the Iron Age on Öland the definition of social identity from either practice may have changed considerably. In the centuries from circa 400–800 CE cremation burial practice is the dominant form of burial and inhumations are very rare (Beskow-Sjöberg and Arnell, 1987; Beskow-Sjöberg and Hagberg, 1991; Hagberg and Beskow-Sjöberg, 1996; Rash, 2001). The social identity linked to cremation may well have been different in the bi-ritual society in the centuries following the almost 600 years of primarily cremation practice (800–1050 CE) than it was in the earlier part of the period (500 BCE–400 CE) when cremation also was practiced in parallel. We have here included the available uncremated human remains from the entire period, also the few available when cremation was the dominant burial form. Moreover, we do not study only inhumation burials but contexts not as easily defined as burials such as for example wetland finds. The uncremated remains from the contexts other than "normal" inhumations could be of individuals of a different social identity than the inhumations. Our sample is therefore not targeted to find a specific part of the population, or one social group, but instead as far as possible including all individuals from the entire period to study a population level development of migration.

2.1. Burial practice and specific archaeological context

All information on artefacts and burial types presented here derives from the extensive volumes detailing Iron Age graves on Öland (Beskow-Sjöberg and Arnell, 1987; Beskow-Sjöberg and Hagberg, 1991; Hagberg and Beskow-Sjöberg, 1996; Rash, 2001). The general outline of burial practice on Öland in the Iron Age is described above. Other contexts containing uncremated human remains such as wetland deposits, a boat burial and a house were included in this study as these are also human remains representative of the population on the island (cf. Table 2).

High status graves are here defined (similarly to earlier studies of these burials, cf. Beskow-Sjöberg, 1987:398f) as including gold, silver or bear claws (a bear skin). Weapons (whole or parts of sword, spear, arrowhead or shield) in graves could also indicate a specific social status and are included. Half moon knives are considered typical for Öland (e.g., Hagberg, 1979) and could in a sense possibly define a local identity. Imported artefacts are here defined as glass in the Early Iron Age, specific weapons and bear claws (defined as non-local in Beskow-Sjöberg and Arnell, 1987; Beskow-Sjöberg and Hagberg, 1991; Hagberg and Beskow-Sjöberg, 1996; Rash, 2001). Imported artefacts have often been suggested to indicate the origin of the person in the grave in archaeology at large.

3. Isotope background

3.1. Oxygen isotopes

Oxygen has three major isotopes, ^{16}O (99.762%), ^{17}O (0.038%), and ^{18}O (0.2%), all of which are stable and non-radiogenic. Oxygen isotopes are much lighter than strontium and highly sensitive to environmental and biological processes. Oxygen isotopes, which are commonly reported as the per mil difference (‰ or parts per thousand) in $^{18}O/^{16}O$ between a sample and a standard, can be measured in either the carbonate $(CO_3)^{-2}$ or phosphate $(PO_4)^{-3}$ portion of apatite in enamel and bone (Chenery et al., 2012). This ratio is designated as $\delta^{18}O$. In this study we have measured oxygen isotopes in carbonate ($\delta^{18}O_{carb}$ VPDB) as a component of tooth enamel. $\delta^{18}O_{en}$ (VPDB) values in human enamel generally range from 1.0‰ to −10.0‰.

Oxygen isotope ratios in the skeleton reflect those of body water (Luz et al., 1984; Luz and Kolodny, 1985), which in turn predominantly reflects local rainfall. Ratios in rainfall are greatly affected by enrichment or depletion of the heavy ^{18}O isotope relative to ^{16}O due to evaporation and precipitation. Major factors determining rainfall isotope ratios are latitude, elevation, and distance from the source (e.g., an ocean) — i.e., geographic factors. Like strontium, oxygen is incorporated into dental enamel during the early years of life where it remains unchanged through adulthood (White et al., 2004). Thus, oxygen isotopes also have the potential to be used to investigate human mobility and provenience (Longinelli, 1984).

At the same time, there is significant variation in oxygen isotopes that makes their interpretation more difficult. We have observed approximately ±2‰ variation within a population based on samples of archaeological humans. Oxygen isotope ratios can vary seasonally, annually, and long term with climatic change. There is no strong evidence that modern $\delta^{18}O$ values provide a reliable indicator of past levels. Sources of water introduce variation in $\delta^{18}O$ as well due to evaporation, storage, the use of well water, and more (c.f. Pestle et al., 2014; Brettell et al., 2012).

Another issue with $\delta^{18}O$ is the fact that similar values can be found over wide areas. A map of oxygen isotope ratios in modern precipitation for western Europe (Fig. 2) provides more detailed information. The range of values for the entire continent of Europe from north to south is only from −5.0‰ to −14.0‰ in $\delta^{18}O$ SMOW. For northwestern Europe $\delta^{18}O$ values generally increase from west to east and from south to north. Lower values are more common in Britain and along the Atlantic coast.

A map of oxygen isotope ratios (given in $\delta^{18}O$ SMOW) in modern rainfall in Sweden appears as Fig. 3 (Burgman et al., 1987). The Swedish values generally increase as well from west to east and north to south. The lowest values, −8‰ to −10‰, are found in the southwest of the

Table 2
Number of individuals determined to each bioarchaeological category. NS = north south oriented burial, SN = south north oriented, WE = west east oriented, NA = orientation not available. *described in Wilhelmson and Dell'Unto, 2015. ** described in Wilhelmson, 2015.

		Total	
		Early	Late
Age	Child (6–12 years)	4	1
	Juvenile (13–19 years)	11	6
	Juvenile-young (13–35 years)	2	3
	Young (20–35 years)	10	4
	Young-mature (20–59 years)	17	6
	Mature (36–59 years)	12	8
Imported artefacts (glass EIA, specific weapon, bear claws)	Mature-old (>36 years)	3	3
High status artefacts (gold, bearskins)	Old (>60 years)	9	6
Weapons	Young–old (>20 years)	3	1
Sex	Females	21	9
Cist	Males	38	20
Cultural modification	Filed teeth	0	2
Artefacts	Imported artefacts (glass EIA, specific weapon, bear claws)	7	1
Wetlands	High status artefacts (gold, silver, bear claws)	6	3
Boat burial	Weapons	11	8
Burial/context	Pit	12 NS, 1 WE (1 NA)	6 NS, 1 SN, 5 WE (1 NA)
	Cist	47 NS, 2 SN, 1 WE (2 NA)	13 NS, 1 SN, 1 WE
	Coffin	0	4 WE
	Wetland	5	2**
	Boat burial	0	2
	House*	0	2

country and the ratio increases to −14‰ in the north of Sweden and Norway. Values on Öland are shown between −11‰ and −10‰.

These values are not directly comparable to the δ^{18}O values measured in enamel carbonate, although a formula for conversion is available (Chenery et al., 2012). What is important is the direction of change observed in the enamel δ^{18}O values as more negative values in northern Europe should indicate more northerly and easterly origins.

Values for enamel carbonate (VPDB) are available for a number of locations in northern Europe and some of this information is summarized in Table 3. These human tooth enamel samples include some non-local individuals at almost every site. Nevertheless, the mean value for $\delta^{18}O_{en}$ VPDB can provide some indication of expected local ratios. The pattern is as expected from the rainfall values. Somewhat higher average values are found in more northerly Scandinavia. Values more negative than −5.0‰ are seen and at Hamar and Trondheim in Norway. Sites like Bryggen in modern Bergen, Birka outside Stockholm, and Kopparsvik on the island of Gotland have values more positive than −5.0‰. Uppåkra, outside of modern Lund, has an average value of −5.0‰. Values in southern Sweden, Denmark, and northern Germany generally average between −4.0‰ and −4.5‰ across a broad area. Values on other Baltic islands (Kopparsvik on Gotland and Ndr. Grødbygård on Bornholm) averaged −4.7‰ and −4.9‰ respectively.

In the case of Öland, like the other Baltic islands of Bornholm and Gotland, oxygen isotope values around −5.0‰, or slightly more negative, might be expected while slightly lower values around −4.0‰ could characterize southern Scandinavia — Scania or Denmark and perhaps northern Germany.

3.2. Strontium isotopes

The ratio of ^{87}Sr to ^{86}Sr varies geologically among different kinds of rocks. Because ^{87}Sr forms through a radiogenic process from rubidium over time, older rocks with more rubidium generally have a higher ratio, while younger rocks have lower ratios. Sediments reflect the ratio of their parent rock. Strontium moves into humans from rocks and sediment through the food chain. Strontium substitutes for calcium in the formation of the human skeleton and is deposited in bone and tooth enamel. Tooth enamel forms during childhood and remains unchanged through life and commonly after death. Values of ^{87}Sr/^{86}Sr in human tooth enamel that differ from the place of burial thus indicate that the individual moved from one geological terrain to another during his/her lifetime. Values for this ratio generally range from ca. 0.704 to 0.730 in humans. In actual fact, levels of strontium isotopes in human tissue may vary from local geology for various reasons (Price et al., 2002) and it is necessary to measure *bioavailable* levels of ^{87}Sr/^{86}Sr to determine local strontium isotope ratios (Sillen et al., 1998). Baseline information on bioavailable isotope values in an area needs to be obtained in order to make useful and reliable statements about the origin of the human remains under study.

Details on the geology and soil composition of Öland are available in Appendix C and in Wilhelmson and Ahlström (2015). Geology, however, is not always the best indicator of bioavailable ^{87}Sr/^{86}Sr (Price et al., 2002). Fortunately, in the case of Öland, there are prior studies of ^{87}Sr/^{86}Sr variation in humans and animals (Fornander et al., 2011; Wilhelmson and Ahlström, 2015) to aid in determining the local baseline values for the island. The specific methodology for determination of bioavailable baselines varies between studies in archaeological context. For example what animals are used as proxies and how the baseline is determined, mathematically or otherwise, can be very different (see discussion in for example Slovak and Paytan, 2012). Here we have chosen a different approach than the one used in the previous study of these samples (i.e. Wilhelmson and Ahlström, 2015).

All in all 32 faunal samples from archaeological and modern contexts are available for determining bioavailable ^{87}Sr/^{86}Sr in Öland. The Iron Age fauna sampled for a ^{87}Sr/^{86}Sr baseline (Wilhelmson and Ahlström, 2015) clearly matches that of an earlier study (Fornander et al., 2011), although some of those samples are more diagenetically sensitive - contemporary snails or bone - as opposed to the Iron Age samples that are enamel (details in Appendix D). The mean for all samples is 0.7143, std. (standard deviation) 0.0029, so if we should use the mean and 2 std. the baseline would be 0.7114–0.7172. It is however clear that the dogs are outliers among both low and high values and likely migrants. Further there is a subgroup with higher values than the bulk of the samples, those in the range between 0.7174 and 0.7189 (Fig. 4). These could be imported animals since they do not cluster on a specific part of the island corresponding to a specific soil or geology (as discussed in detail in Wilhelmson and Ahlström, 2015). The microfauna could however indicate small patches of for example till with comparably very high ^{87}Sr/^{86}Sr-levels. However, it is difficult to interpret whether these small habitats could be a suitable proxy for bioavailable ^{87}Sr/^{86}Sr for humans. This does highlight an ambiguity in formulating a bioavailable baseline as these values stand out from the majority (the most likely

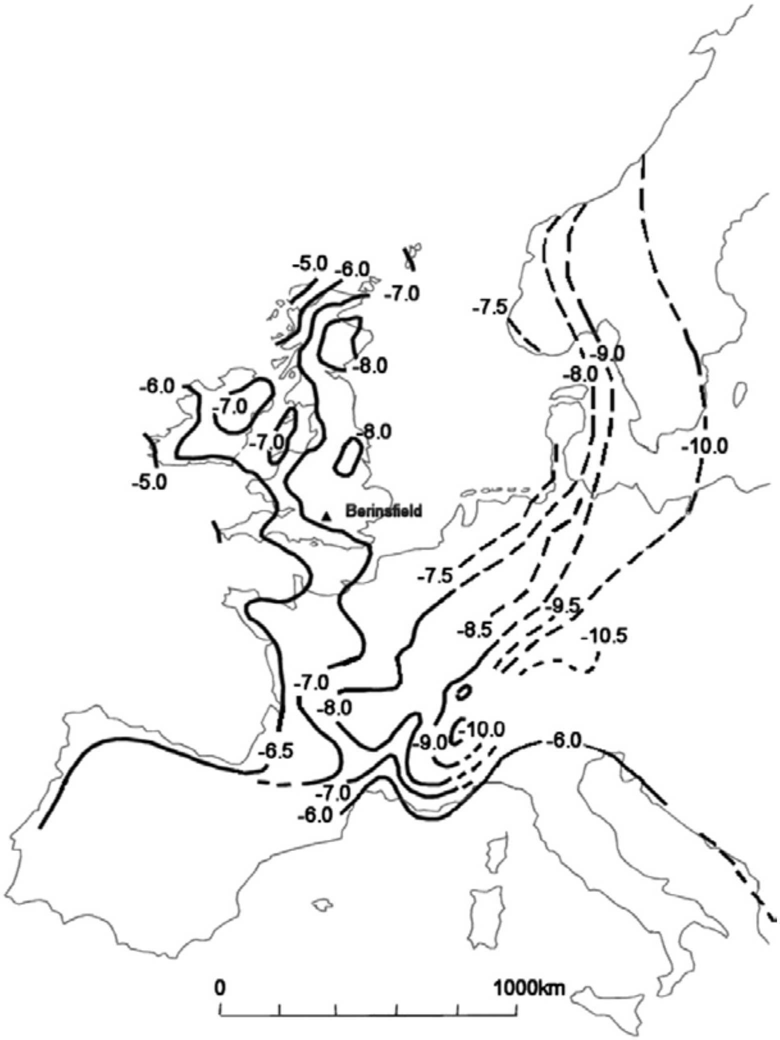

Fig. 2. Isoscape map of mean annual δ^{18}O values for precipitation in western Europe (Hughes et al., 2014).

local values) but not so much it is entirely clear these are non-local. These complexities in baselines are rarely addressed in detail in ^{87}Sr/^{86}Sr studies. This probably has to do with sample sizes of bioavailable data, rarely as comprehensive as 32 individual animals from such a small area as Öland. Usually when just one of two samples deviate from a baseline these are considered either as non-locals or locals, it is a matter of personal judgment in a sense.

We have, contrary to this approach, chosen to embrace the ambiguity instead of forcing strict boundaries for the definition of local and non-locals from ^{87}Sr/^{86}Sr that cannot be supported in the data at hand (resulting in a slightly different definition of baseline than in Wilhelmson and Ahlström, 2015). We will divide our human sample into three groups: those most likely local, those most likely non-local, and those in between, i.e., a gray zone/undetermined origin that will be excluded when we discuss differences between locals and non-locals. For Öland we argue this is the best option for avoiding overinterpretation or oversimplification, of our baseline on the individual level. This could be a local problem (limited to Öland) but it is also possible this is a more comprehensive problem for other areas of complex geology with glacial and postglacial soil deposits, such as other parts of northern Europe. We have here chosen a different approach to constructing a baseline than previously used for the ^{87}Sr/^{86}Sr data for Öland. Both Fornander et al. (2011) and Wilhelmson and Ahlström (2015) use the mean and 2 std. of selected faunal values to define locals. In the latter study a ^{87}Sr/^{86}Sr baseline was only statistically applied on a population level (the entire sample), to compare to baselines in selected areas in the region. The aim of that paper was to investigate the ^{87}Sr/^{86}Sr distribution on Öland in terms of a regional migration following the gravity model of migration, which was established as a possibility for both the Early and Late period. The methodology used in interpreting the ^{87}Sr/^{86}Sr distribution, Bayesian mixing, as well as the statistically formulated baseline definition are however not appropriate for the aims of this paper. Our focus is, in contrast to Wilhelmson and Ahlström (2015), on defining local and non-local *individuals*, not statistical proportions in the entire population. In this study, that statistical approach is inappropriate as it, when applied in the individual case, transfers an accuracy not supported by the variation in ^{87}Sr/^{86}Sr in the human samples. The gray zone/undetermined group of individuals

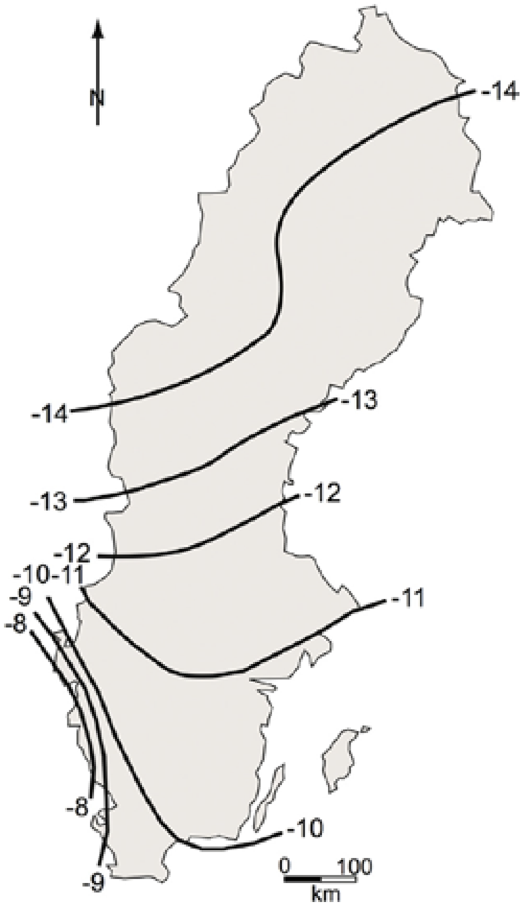

Fig. 3. Oxygen isotope ratios (δ^{18}O SMOW) for modern rainfall in Sweden (after Burgman et al., 1987).

that we have defined here take these uncertainties into account and prevent us from oversimplifying our specific results.

Based on the distributions of the bioavailable ^{87}Sr/^{86}Sr samples we have chosen to define locals as 0.7109–0.7164 (the bulk of the sample), non-locals as <0.7098 or >0.7189 (see ranked distribution of fauna in Fig. 4). This leaves two small zones that we choose to name undetermined or gray zones. The lower gray zone includes the values between two faunal values - the non-local dog (^{87}Sr/^{86}Sr 0.7098, Appendix A) and the first likely local value (a snail, ^{87}Sr/^{86}Sr 0.7109, Appendix A), i.e., 0.7098–0.7108. The upper gray zone includes the animals that are clustering in a group (noted non-local? in Fig.4) outside of the mean plus 2 std., i.e., 0.7164–0.7189.

Strontium isotope ratios measured for the 109 individuals (presented in Wilhelmson and Ahlström, 2015) have a mean of 0.7157 ± 0.0075 with a range from 0.7077 to 0.7391. The distribution of these values is shown in a bar graph of the rank ordered value for each individual (Fig. 5). The ^{87}Sr/^{86}Sr values have been compared to δ^{13}C results for the same enamel samples (of both humans and animals) elsewhere (Wilhelmson and Ahlström, 2015) and this showed that variations in ^{87}Sr/^{86}Sr were unlikely due to a marine diet or a seaspray effect. Further support for a primarily non marine diet was found in bone collagen isotopes (δ^{13}C and δ^{15}N) (Wilhelmson, in press). These samples are describing adult diet and not childhood diet but it is unlikely that the child diet should be mainly fish when the adult diet shows very little sign of fish consumption and is most likely mainly based on domesticate animals.

4. Methodology

4.1. Isotope methodology

Two isotopic ratios — oxygen and strontium — were measured in tooth enamel from the same samples of archaeological human and faunal remains from the island of Öland. Strontium and oxygen in enamel are used for isotopic proveniencing. The basic principle of isotopic proveniencing is straightforward. Human tooth enamel forms during birth up to adolescence. The chemical composition of that enamel originates in the food from the local environment consumed during the period of enamel formation. Strontium isotope ratios vary geographically with local geology and the isotopic ratios of the surface deposits that provide the nutrients for food resources. Oxygen isotope ratios vary with latitude, elevation, and distance from large bodies of water. Individuals who have an enamel isotopic ratio different from the place of death must have moved. The principles for the application and interpretation of these ratios are outlined in the following paragraphs along with the basic procedures for the analyses. In addition baseline values for Öland and neighboring areas are discussed for strontium and oxygen isotopes. The procedures and results from the ^{87}Sr/^{86}Sr isotope analysis are detailed in Wilhelmson and Ahlström (2015).

4.1.1. Oxygen isotope analysis

Teeth for δ^{13}C and δ^{18}O analysis were chemically cleaned using a standard procedure (Balasse et al., 2002). Enamel samples were placed in approximately 2 mL of 2–3% (v/v) solution of bleach for 8 h and rinsed three times with deionized water, centrifuging the tubes between each aliquot. Then, 0.1 mL/mg of 0.1 M acetic acid was added to each tube for exactly 4 h, and the samples were rinsed again with three aliquots of deionized water before being freeze-dried for analysis. Analysis of stable light isotopes was performed in the Environmental Isotope Laboratory (Department of Geosciences, University of Arizona)

Table 3
Oxygen isotope ratios ($\delta^{18}O_{carb}$ VPDB, in ‰) in human tooth enamel from archaeological sites in northern Europe. IA = Iron Age, LIA = Late Iron Age, EIA = Early Iron Age, MED = Medieval Period. Unpublished data from T.D Price.

Site	Country	n	Min	Max	Mean ± sd	Source	Period
Hamar	Norway	17	−7.7	−4.9	−6.3 ± 0.8	Unpublished	IA
Bryggen	Norway	15	−5.3	−3.2	−4.3 ± 0.7	Unpublished	IA
Trondheim	Norway	9	−7.6	−4.5	−6.0 ± 1.1	Unpublished	IA
Birka	Sweden	29	−7.4	−2.2	−4.9 ± 1.2	Price et al., 2016	LIA
Kopparsvik	Gotland, Sweden	44	−6.4	−2.5	−4.7 ± 1.1	Price et al., 2016	LIA
Uppåkra	Sweden	10	−6.8	−3.3	−5.0 ± 0.9	Price, 2013	IA
Sebbersund	Denmark	7	−4.7	−3.3	−4.0 ± 1.5	Price et al., 2016	MED
Trelleborg	Denmark	41	−5.8	−1.7	−4.4 ± 0.7	Price et al., 2016	LIA
Galgedil	Denmark	34	−6.0	−2.5	−4.2 ± 0.7	Unpublished	LIA
Ndr. Grodbygaard	Bornholm, Denmark	36	−6.4	−3.6	−4.9 ± 0.6	Price et al., 2013	LIA
Haithabu	Germany	53	−6.8	−2.7	−4.0 ± 0.8	Unpublished	LIA

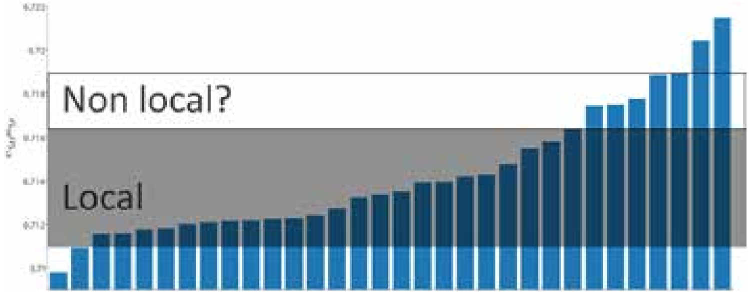

Fig. 4. The ranked distribution of all the faunal samples $^{87}Sr/^{86}Sr$ values with those interpreted as clearly local (indicated as local), those possibly non-local (indicated as non-local?) and the three samples (the lowest and the two highest values) that clearly fall outside of these ranges are considered clearly non-local.

using a Kiel device attached to a Finnigan MAT252 ratio mass spectrometer. Samples are converted to CO_2 with dehydrated 70 °C phosphoric acid. External precision, as calculated from repeated measurements of standard reference materials (NBS-18 & NBS-19) is $\pm 0.08‰$ for $\delta^{13}C$ and $\pm 0.1‰$ for $\delta^{18}O$ (1 s.d.).

4.1.2. Isotopic sampling

In this study permanent human teeth ($n = 109$, one/individual) were sampled. The sampled teeth are the exact same ones as used in the earlier presented $^{87}Sr/^{86}Sr$ results (Wilhelmson and Ahlström, 2015) and the corresponding $\delta^{18}O$ results will be presented here for the first time. The list of samples, various other information and isotope results are provided in Appendix A. We sampled primarily premolars for several reasons — functional, practical and representational. This is a common tooth; there are eight premolars in the dentition (compared to four first molars) which are developed basically simultaneously and therefore comparable with regard to enamel composition. If all premolars were available for one individual the tooth was chosen that was most accessible (if for example not *in situ* in the alveoli in the jawbone) and then the one with most preserved enamel (least worn) was chosen. In four cases of wetland deposits (id 1111–1114) molars were sampled as premolars where unavailable. Also two children age 7–8 years old were sampled (id 1102, 1025) from an incisor (FDI 32) and a molar (FDI 36) since their premolars were not fully matured.

4.2. A bioarchaeological approach to migration and integration

In order to examine migration patterns and societal integration with our isotope results we have employed a range of bioarchaeological traits for comparison with local or non-local status for each of the 109 human skeletal remains in this sample (details in Appendices A, B).

We have selected the following osteological traits to investigate migration and integration: age, sex and cultural modification such as for example filing of teeth. Current studies suggest that the most likely migrants are young-middle aged men, some specify the age to 20–30 years (f.x. Burmeister, 2000). Women and children are generally considered less likely migrants and mostly suggested to be chain migrators following the males when established in the community. An important exception to this is suggested to be in the case of slaves or captives being moved involuntarily as these are more likely to be females and children (Cameron, 2013) or those fleeing conflict. The exchange of marriage partners is also a possible cause for migration. The sex distribution of locals and non-locals would therefore be of interest when interpreting migration patterns. Age of death is more complex. An individual might migrate young and die very old. A non-local of young age at death would however be proof that migration could take place at a young age. The integration of (or lack of) non-local young individuals could be studied, as they would not have had the same possibility to be part of society on Öland for as long as an older individual potentially might have had. The cultural expression that is body modification is also relevant in this discussion and can be investigated to some extent on skeletal remains.

Integration is here studied as via the burial/depositional context. We will compare the occurrence of locals and non-locals in the different burial types and other contexts, as well as with artefacts. If the non-locals follow the locals in these respects we see this as integration as their identity in death was presented with local customs perhaps very different from that of their homeland. Such a comparison is relevant as we use a population approach to sampling i.e., including not only deviants but all the available (although only uncremated) population. This is different to the bulk of isotopic studies where a selection of sampled individuals is based on artefacts of interest (valuable or imported objects), presumed non-local burial types or unusual archaeological context (for example wetland deposits).

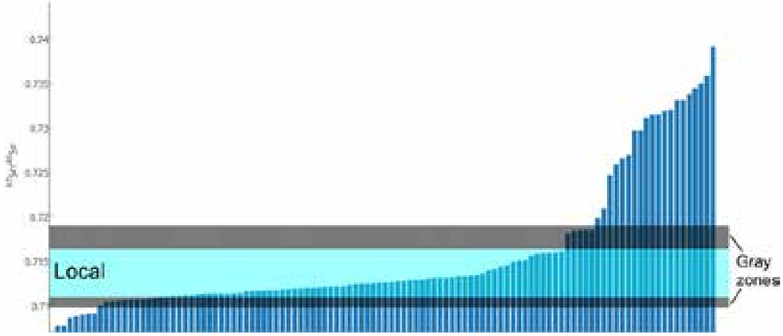

Fig. 5. The human samples in a ranked distribution with the ranges defined as local baseline (local), gray zone (i.e., $^{87}Sr/^{86}Sr$ neither clearly defined as local or non-local) and non-local (the values not included in the other ranges).

4.2.1. Osteology

Osteological analysis of age and sex of the 109 individuals was performed by HW. Age was determined for adults using the methods of Suchey-Brooks (Suchey, 1988) primarily and secondarily those of Buckberry and Chamberlain (2002) and thirdly of Kunos et al. (1999) depending on the preservation of the remains. Children were aged by methods for dental development (Gustafson and Koch, 1974) and epiphyseal development (Schaefer et al., 2009). Sex was determined primarily using pelvic characters and secondarily with skull features as recommended in Buikstra and Ubelaker (1994) and scored accordingly as 1–5. The sex estimates presented here include both certain (for example 1 = female) and less certain (for example 2 = possible female) as one group (female) if not otherwise stated.

The sample has a clear sex bias, most probably reflecting burial practice as our sample includes only uncremated human remains. The females are clearly underrepresented with 31% in the Early Iron Age and 35% in the Late (Table 2; details in Appendix B). This indicates a male dominated population on Öland, among the uncremated individuals. It is also possible that gender, social and/or cultural identity was more significant than the simple binary biological sex for a person's remains to enter the archaeological context as uncremated (c.f., discussion in for example Kupiec and Milek, 2014 on gender in the Viking age). During the long time period investigated (1500 years), and considering changes in burial practice, there is potential that whatever gender, social or cultural classifications determined burial (or depositional) mode as uncremated could have changed. However, with regards to biological sex the ratio is constant and unchanged. We therefore consider this a sign that our sampling of uncremated remains, regardless of context, means that the section of the population we are studying represents a comparable population in the Early vs Late Iron Age.

Two individuals presented filed teeth as described in detail by Arcini (2005), occurring primarily in Scandinavia and in male adults These are both males of mature age buried in NS-oriented cists. It has been suggested that individuals with filed teeth may have belonged to a specific social group (Arcini, 2005).

5. Results

5.1. The oxygen results

Measurement of $\delta^{18}O_{carb}$ VPDB for 106 enamel samples produced a mean value of −5.6‰ ± 0.9 with a range from −3.0‰ to −7.6‰. Three samples of the original 109 did not have enough enamel remaining to be analyzed for $\delta^{18}O$. The measurements of strontium and oxygen isotope ratios in combination provided a substantial data set for the Iron Age inhabitants of Öland (Appendix A).

5.2. The oxygen baseline and bi-isotopic definition of locals and non-locals

Establishing the local baseline for $\delta^{18}O$ VPDB on Öland is difficult. The mean value for human tooth enamel is −5.6‰ ± 0.9 with a range from −3.4‰ to −7.6‰. The distribution of values appears varied in relation to $^{87}Sr/^{86}Sr$ (Fig 6). A specific baseline for oxygen, due to changes in climate, is problematic in a long term study such as ours for Öland. Geographical estimations (as detailed above) can only go so far as climate shifts with time, not just location. When devising the $\delta^{18}O$ VPDB baseline it is therefore important to view our results on a time scale. For northern Europe changes in climate and temperature during the Iron Age have been documented (see data and discussion in Davis et al., 2003); however specific regional changes are less clear. Our entire sample is divided into two major time spans Early (500 BCE–400 CE) and Late (400–1050 CE) Iron Age as well as a subsample ($n = 47$) with individual ^{14}C–dates. There is a difference in distribution of oxygen isotope ratios when the human samples are divided by the Early (mean − 5.7‰, std. 0.7) and Late (−5.23‰, std. 1.1) periods. This could reflect a different proportion of non-locals (as suggested by the $^{87}Sr/^{86}Sr$ values) rather than a difference between the two periods in local $\delta^{18}O$ VPDB ratios.

When viewing the $\delta^{18}O$ VPDB distribution along with the $^{87}Sr/^{86}Sr$ determination for the individuals (local, non-local, or undetermined as described in Section 3.2) for each period (Fig. 7) and the subsample with ^{14}C-dates (Fig. 8) it appears that it is not justified to offer two different $\delta^{18}O$ VPDB baselines for Iron Age Öland. A slightly narrower baseline could be argued for the Early period, due to the lower overall variation, but this would require a precision we feel the $\delta^{18}O$ VPDB data do not warrant. The differences in distribution are most likely related to the different proportions of non-locals, not climate differences significant enough to change the $\delta^{18}O$ VPDB (cf. Fig 8). A baseline determined from the mean and two standard deviations (i.e., −4.7‰ to −6.5‰) seems as an appropriate approach and fits quite well with the geographically assessed baseline for Öland (around 4–6‰ see discussion in Section 3.2). However, as we have established a solid local $^{87}Sr/^{86}Sr$ range based on a large number of animal samples we find it necessary to take this into account and slightly adjust the $\delta^{18}O$ VPDB baseline accordingly. There are a few values just between −4.5‰ and −4.7‰ that have local $^{87}Sr/^{86}Sr$ values (Fig 9). We feel the statistical distribution of the $\delta^{18}O$ data (that we know holds some non-locals) does not give the precision enough to allow to determine these to be

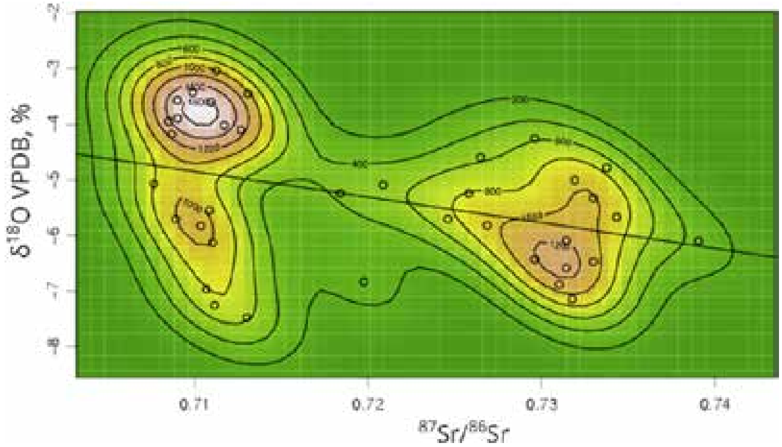

Fig. 6. Bivariate kernel density plot of the $\delta^{18}O_{carb}$ VPDB values and $^{87}Sr/^{86}Sr$ from human tooth enamel on Öland.

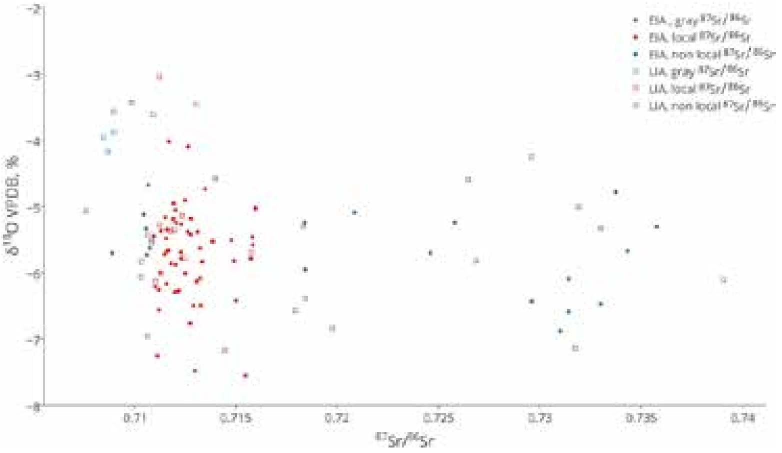

Fig. 7. The $\delta^{18}O_{carb}$ VPDB and $^{87}Sr/^{86}Sr$ distribution for the entire human sample ($n = 106$) divided by period and definition as local, non-local, gray (undetermined) by $^{87}Sr/^{86}Sr$ only as outlined in 3.2. EIA = Early Iron Age, LIA = Late Iron Age.

non-local when their $^{87}Sr/^{86}Sr$ is clearly local, based only on a 0.2‰ difference in $\delta^{18}O$. Our "informed baseline" (as opposed to purely statistical mean and two std.) is therefore set from −4.5‰ to −6.5‰. This is a conservative estimate as we do not want to risk stretching the $\delta^{18}O$ data beyond its precision.

In addition to $^{87}Sr/^{86}Sr$ definition of locals and non-locals (see Section 3.2), the $\delta^{18}O$ baseline indicates some likely non-locals (Fig 10). In fact, using the $\delta^{18}O$ baseline we can add 14 individuals as non locals that were undetected by the $^{87}Sr/^{86}Sr$. This distinction of the samples, using both $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ profiles, results in 13 individuals in the undetermined group (Table 4), i.e. 12% of the sample. These individuals will be excluded from the further discussion of migration and integration. Some of the individuals in the $^{87}Sr/^{86}Sr$ gray zone were designated as non-locals due to their deviant $\delta^{18}O$, as well as some designated $^{87}Sr/^{86}Sr$ locals. The proportion of non-locals is large, 43%, but it is very different for the two periods of the Iron Age (cf. Fig 10). From the early to the late period the proportion of non-locals more than doubled, from 30% to 68%. The $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ VPDB distribution indicate non-locals of clearly diverse origins in both periods.

5.3. Bioarchaeology and migration

When dividing the human sample into locals and non-locals, it is clear more complex differences between the Early and Late periods are present than a simple shift in the proportion of non-locals could explain (Table 5). For many bioarchaeological criteria (whether archaeological or osteological) some subgroups, already small before a division of the individuals as either locals, non-locals or of undetermined provenience, result in even smaller datasets. Evaluating correlation and significance with a statistical approach is thus less feasible why we will discuss all occurrences in detail below.

6. Discussion

6.1. Migration patterns

From our definition of baselines for $^{87}Sr/^{86}Sr$ and $\delta^{18}O_{carb}$ VPDB there is a substantial increase in migration to the island of Öland in the Late period, from 30% non-locals in the population in the Early period, to 68%. The migrants are from areas of diverse $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ origins in both periods. By adding the $\delta^{18}O$ isotopes to the $^{87}Sr/^{86}Sr$ data it can be confirmed that the immigration to Öland largely reflects mobility on a regional scale (as suggested in Wilhelmson and Ahlström, 2015). However, as a few of our $\delta^{18}O$ results suggest, the mobility also included more distant contacts. Moreover, the use of $\delta^{18}O$ further demonstrated the huge risk in using $^{87}Sr/^{86}Sr$ to discuss migration on a regional scale as the local values can be the same as those in very distant locations. In this case 11 individuals with a local $^{87}Sr/^{86}Sr$ and non-local $\delta^{18}O$ turned out to be mistaken as locals if just using the $^{87}Sr/^{86}Sr$ baseline.

It is likely that developments in maritime technology, introduction of sails, in Northern Europe (cf. Randsborg, 1991; Callmer, 1992) occurring at this time may have played a major part in this increase in numbers, as well as percentages, of non-locals. In particular, the larger proportion of deviant $\delta^{18}O$ in the Late period suggest longer travels

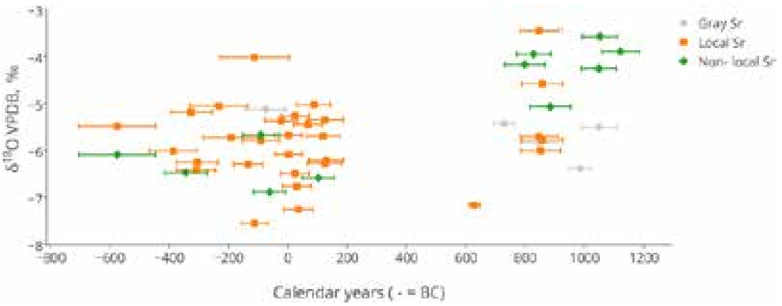

Fig. 8. The $\delta^{18}O_{carb}$ VPDB values distribution of the ^{14}C-dated subsample ($n = 47$). The error bars shows the standard deviation from the mean values. Details in Appendix A.

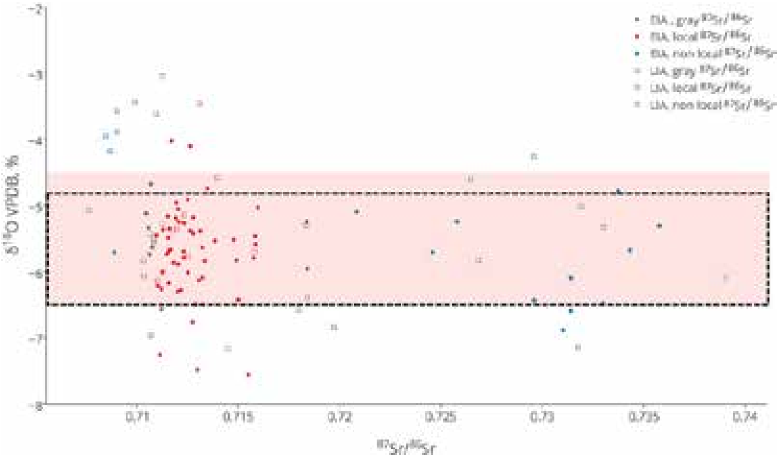

Fig. 9. The mean and two standard deviation range is indicated with a dashed rectangle and the "informed baseline" with the shaded rectangle. See Fig. 7 for legend and details.

became more frequent (cf. Fig. 7) and, due to less negative values, more likely from the west and south (cf. Figs 2, 3).

Establishing the age at which migration occurred is complex. The overall age distributions of locals and non-locals are very similar (Table 5), complicating the determination of whether migration took place at a specific age. It is clear some individuals migrated young (as they also died young), but they are in proportion compared to the other age groups or, more importantly, to the local age distribution.

The uneven sex distribution in the local and non-local groups in the two different periods is striking (Table 5). Although the overall proportion of females to males is the same for both periods, in the late period the women are almost all non-local. The non-local women have a heterogeneous $^{87}Sr/^{86}Sr$ distribution (in both periods), likely indicating varied origins, i.e., these individuals are coming from different places (Fig. 11). The higher proportion of non-local women in the Late Iron Age, suggests a specific increase in female migration. This could possibly be due to a lack of local females. Considering the heterogeneous $^{87}Sr/^{86}Sr$ as well as $\delta^{18}O$ provenience of the non-local females (Fig. 11) in both periods it seems more likely the greater female migration in the Late Iron Age is a reflection of general greater mobility rather than a specific type of migration (such as for example spousal migration for maintaining social ties). The importance of female migration in the Late Iron Age should not be overinterpreted considering the sample size. Cremation was practiced during this the Late Iron Age, and may explain why a substantial part of the population, perhaps local women in particular, could be missing in our sample. This is a surprising conclusion on its own as this has not been reported before to our knowledge for Late Iron Age Scandinavia. However, the proportion of females to males in the entire population is virtually identical in both periods, why the remarkably large number of non-local females compared to non-local males is interesting for a larger debate on migration, especially in the light of some recent interpretations of the Viking expansion.

Barrett (2008) recently summarized some reasons (which have been debated for example by Jesch, 2015) behind the Viking expansions, originating in Scandinavia including Öland. One of them is that a demographic surplus/lack of land would cause expansion. This would however not be a satisfactory explanation for Öland, the opposite, considering the extensive immigration to Öland. An interesting aspect of mobility and migration was recently highlighted by Ashby (2015:104) arguing a person "stood to gain particular status through the magic of having travelled", suggested with regards to the reasons behind Viking raiding and exploration. Also Dobat (2015) has emphasized that Viking age society was even more mobile than generally assumed and that travelling could be way of improving one's social status. This is not far from Neil Price's (2014) approach in viewing the Vikings as a pirate culture, where the travelling itself was a way of life rather than a means to a specific end. An approach to Vikings as a pirate society allows certain characteristics to be defined. The primary characteristic that is of relevance to Öland is that their bases are most likely islands. Another is that pirate societies are described as multiethnic, which if translated to being of multiple geographical origins and having differential burials customs practiced parallel, could clearly apply to Öland in the Late Iron Age (see discussion below on integration). Thirdly, as N. Price (2014) emphasizes, women had a part in these societies and in travelling that is likely understated today. Indeed, for Öland it appears women in the Late Iron Age were migrants of multiple origins the same as the men. In addition, they comprise a relatively large proportion, suggesting female mobility could be much more extensive than usually put forward for this period.

6.2. Integration

With respect to artefacts, high status objects and weapons, there are differences between the non-locals and locals in both the Early and Late Iron Age (Table 5). Imported artefacts are however not obviously associated with non-locals and occur frequently in graves of locals. This does suggest at least that in the Early Iron Age non-locals were not excluded from these contexts despite being a small component of the population in general. In the Late Iron Age more non-locals than locals have high status objects and weapons. The non-locals as a group thus do not appear inferior (not slaves for example) to the locals, particularly not in the Late period.

Considering burial type and orientation there are no apparent differences between the locals and non-locals groups in the Early period (Table 5). There appears to be complete integration. In the Late period this issue is more complex. A proportion of the non-locals are buried in the same tradition as the locals (NS cists), suggesting social integration. In addition, there is a larger group of almost exclusively non-locals that are buried in a WE direction (with just one local, 12–15 years old), clearly a different group. These two non-local groups, the NS and the WE, are heterogeneous with regard to $^{87}Sr/^{86}Sr$ and neither appears to be from one specific place of origin. The NS non-local group $^{87}Sr/^{86}Sr$ values ranges from 0.7077–0.7349 and the WE from 0.7090–0.7391. The youngest non-locals are included in both NS (one 11–12 year old) and WE (16 year old). We interpret this as a society in the Late period where some non-locals were integrated with the local individuals (and the very old tradition of NS oriented cist burials), but could also practice a distinctive tradition of WE oriented burials in pits or coffins.

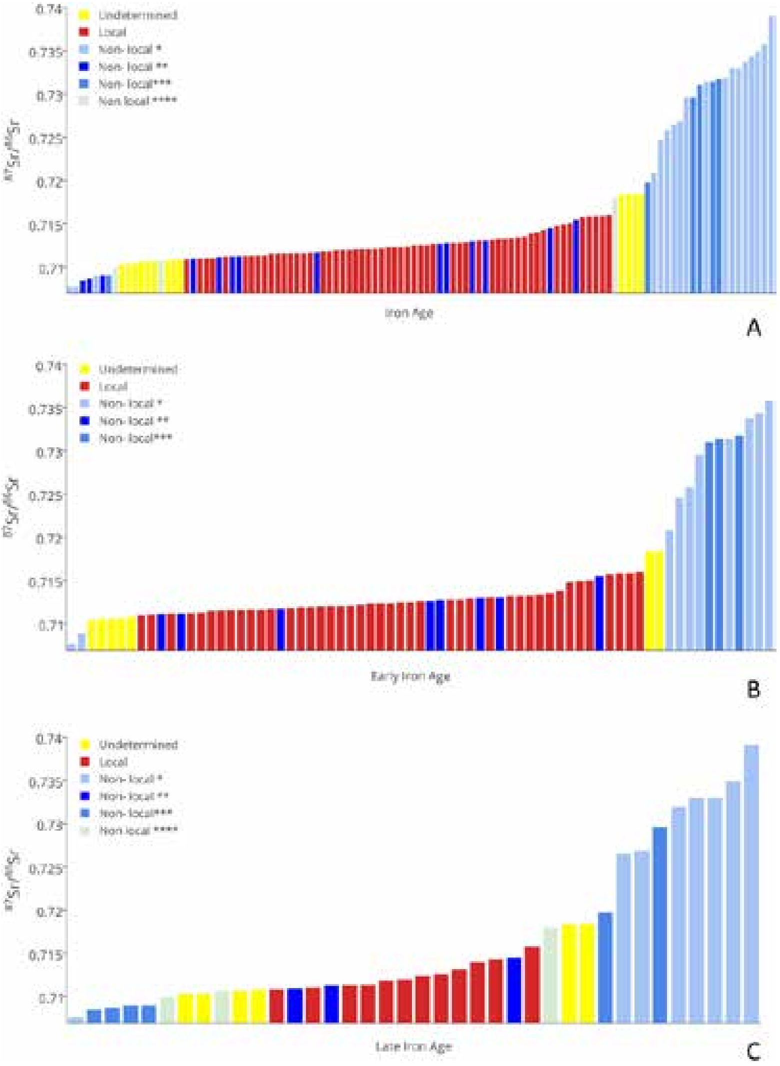

Fig. 10. The ranked $^{87}Sr/^{86}Sr$ distribution when the human sample is divided into our three groups: locals, non-locals and undetermined from both $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ (VPDB). The darkest bars and the lightest blue bars are individuals added as non locals due to the use of the $\delta^{18}O$ baseline ($n = 11$). The $^{87}Sr/^{86}Sr$ data alone therefore clearly underestimates the proportion of non-locals in Öland. A shows all the human samples ($n = 109$), B shows the Early Iron Age subsample ($n = 71$) and C the Late Iron Age subsample ($n = 38$).Legend: Undetermined (gray $^{87}Sr/^{86}Sr$, local O), Local ($^{87}Sr/^{86}Sr$ and $\delta^{18}O$), Non-local* (just $^{87}Sr/^{86}Sr$), Non-local** (non-local $\delta^{18}O$, local $^{87}Sr/^{86}Sr$), Non-local*** ($^{87}Sr/^{86}Sr$ and $\delta^{18}O$), Non local**** (gray $^{87}Sr/^{86}Sr$ and non-local $\delta^{18}O$). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In the more unusual contexts such as wetland depositions both locals and non-locals occur similarly, although in a limited sample, for Early and Late Iron Age. The possibly specific social factor as to why these individuals were not inhumated (or cremated) does therefore not appear to be related to being local or non-local. The two men found in a house within a fort and killed in an interpersonal conflict (Fig. 12), were both locals. This occurred during a period where cremation was the primary burial practice. The unusual burial treatment

Table 4
The division of the human samples in local, non-local or undetermined from both $^{87}Sr/^{86}Sr$ and $\delta^{18}O_{carb}$ (VPDB) values. Note: 3 of the samples do not have $\delta^{18}O$ values (two non-local from $^{87}Sr/^{86}Sr$ (Id 1022, 1037) and one $^{87}Sr/^{86}Sr$ local (Id 1071). The definitions of non-locals (*–****) given in the table in brackets is the same as used in Fig. 10 to facilitate comparison.

	Total	Part	Description	EIA	LIA
Local	55		Both $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ local	44	11
Non-local	41	18	Just $^{87}Sr/^{86}Sr$ non-local (*)	20 (30%)	21 (68%)
		9	Non-local $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ (***)		
		11	Non-local $\delta^{18}O$ ($^{87}Sr/^{86}Sr$ local) (**)		
		3	Non-local $\delta^{18}O$ gray $^{87}Sr/^{86}Sr$ (****)		
Undetermined	13	13	Gray $^{87}Sr/^{86}Sr$, $\delta^{18}O$ local or not available	7	6

Table 5
Overview of the results of the division of the sample in the Early (EIA) and Late Iron Age (LIA). NS = north south oriented burial, SN = south north oriented, WE = west east oriented, NA = orientation not available. Note: Both individuals with bear claws are in the undetermined group i.e. local/non-local.

		Early Iron Age		Late Iron Age	
		Local	Non-locals	Locals	Non-locals
	Child	4	0	0	1
Age	Juvenile	7	3	2	1
	Juvenile-young	1	1	1	1
	Young	8	1	1	3
	Young-mature	9	4	1	5
	Mature	7	5	3	4
	Mature-old	2	1	1	2
	Old	5	3	1	4
	Young-old	2	1	1	0
Sex	Females	12	7	1	7
	Males	25	10	7	7
Cultural modification	Filed teeth	0	0	1	1
Artefacts	Imported artefacts (glass EIA, specific weapon, bear claws)	4	1	0	1
	High status artefacts (gold, silver, bear claws)	3	2	0	4
	Weapons	9	3	1	5
	Half moon knives	1	0	0	0
Burial/context	Pit	9 NS (1 NA)	3 NS, 1 WE	2 NS	9 WE, 1SN
	Cist	28 NS, 2 SN, 1 WE (1 NA)	15 NS	6 NS	6 NS
	Coffin	0	0	1 WE	3 WE
	Wetland	2	1	0	1
	Boat burial				1
	House			2	

during this period (the Migration period, see Table 1), likely a consisting only of a destruction of the house to cover the bodies after some time of decomposition (c.f. Wilhelmson and Dell'Unto, 2015), could be seen as pointing towards them not being accepted by the local society. As they both appear to be locals to Öland this raises an interesting issue on why they were not buried according to the local norm for that time.

The two men with filed teeth turned out to be one local and one non-local, both buried in NS cists. Since it is not possible to estimate when the non-local moved, or when in the life course either of them had the incisors filed, any further discussion is difficult.

The boat burial is the only one on Öland, and a high status type of burial (although in this case the social status of the individuals is unclear as the human remains were commingled), contained one non-local and one of undetermined provenience (gray zone ^{87}Sr/^{86}Sr) and a non-local dog (details in Table 5, Appendices A, B).

In conclusion, all high status burials are non-locals in the Late period and also the majority of the weapon burials are non-locals in the Late period. Also, the only boat burial had a non-local individual in it, along with a non-local dog. The concept of "stranger kings" (c.f. Sahlins, 2008, discussion in Ashby, 2015, Dobat, 2009, 2015), i.e., high individual status could be associated with being non-locals, in the Viking period in particular is interesting in this context. The results from Öland support this suggestion of social status linked to being non-locals, but should

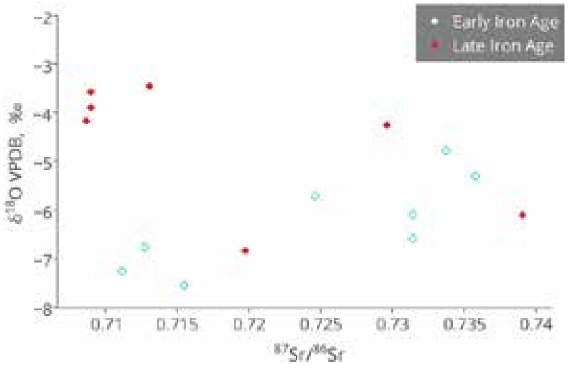

Fig. 11. The ^{87}Sr/^{86}Sr and $\delta^{18}O_{carb}$ (VPDB) distribution of non-local females in Early and Late Iron Age. Note that the definition of non-locals include the combined baselines from ^{87}Sr/^{86}Sr and δ^{18}O.

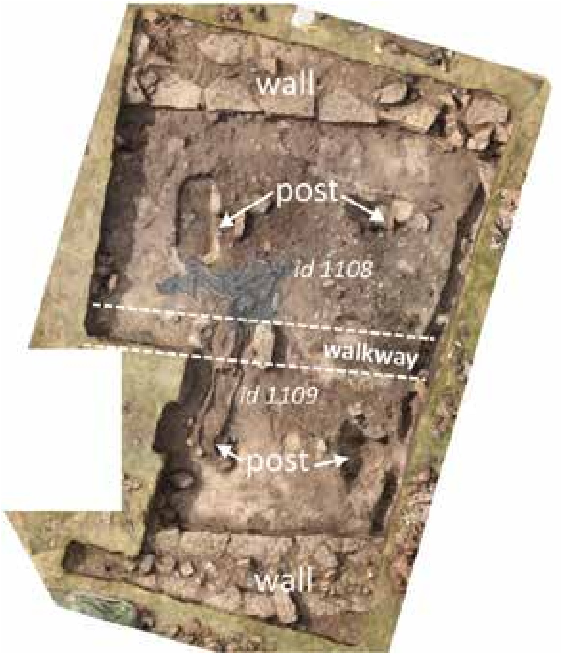

Fig. 12. The two individuals left unburied (and unburned) in a house on Öland during the Migration period. The house walls as well as roof bearing posts are indicated in the image. Id 1108 has the text immediately next to his head and 1109 next to his right femur (he is prone). The paved center walkway (lime slabs placed in a straight line) is indicated by dashed lines as only three stones were still remaining *in situ* at this stage of the excavation. Id 1109's torso is covering the middle stone of the walkway. The image shows two integrated image based 3D models (of two different excavation seasons) imported into 3DGIS by Nicoló Dell'Unto, Department of Archaeology and Ancient History, Lund University (for details see Wilhelmson and Dell'Unto, 2015).

be tentatively interpreted as this period has such a great proportion of non-locals on the island in general (and as the parallel cremation practice limits the sample). Today, it would be possible to investigate the cremations, our missing data, since $^{87}Sr/^{86}Sr$ analysis has proven successful with cremated human remains (Harvig et al., 2014; Snoeck et al., 2015). However the problems with osteologically determining sex in cremations would still leave questions concerning migration patterns unanswered.

7. Conclusions

Our results demonstrate the great potential of a more population-oriented bioarchaeological approach to bi-isotopic proveniencing for furthering our understanding of the patterns of mobility, and its effect on society. We have here applied methodological developments (in the definition $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ baseline for individual level studies) and more theoretical ones (in discussing migration patterns and integration). This approach led to several new conclusions regarding mobility on Öland. Firstly, more non-local individuals could be identified from adding the $\delta^{18}O$ VPDB data than from $^{87}Sr/^{86}Sr$ alone (as in Wilhelmson and Ahlström, 2015) which demonstrated the greater potential in a bi-isotopic approach. Moreover, we could also establish that the migration was not only regional but also more long distance than previously assumed (also in Wilhelmson and Ahlström, 2015). These results show the potential with a bi-isotopic approach as well as point out the pitfalls if using a single isotope approach as in Wilhelmson and Ahlström (2015). When setting out to define migration as regional it was clearly misleading in that study to be using an isotope that in that case apparently was not sufficient to be able to find the interregional differences, which we could find here. The varied burial practice in the Late Iron Age on Öland could be explained by an increasing immigration and likely a more multi-ethnic community compared to earlier. The results indicate both diversity and integration of the different non-local origins implying geographical origin being, at times, more likely secondary to other identities (which could for example be religious or ethnic). Female mobility was substantial in the Late Iron Age, which offers an intriguing contribution to the many current discussions on Viking mobility connecting mobility in specific with higher social status. The great immigration to Öland, as well as the apparent integration, could imply a new hypothesis for the Viking expansions - that the desire to travel and settle in new places, integrating with locals, was a practice (at least in Öland) with which they were familiar. We have also demonstrated that the complexity of the $^{87}Sr/^{86}Sr$ proveniencing method, on a case by case basis, needs to be acknowledged and embraced in interpretations. Moreover, in spite of unknowns with oxygen isotope ratios, they can still be useful information as seen in our study where several non-locals were identified by variation in oxygen isotope ratios.

Discussions on integration in particular and first generation migration patterns targeting a population scale and covering longer time periods, are still rare. We hope, as isotopic sampling of greater numbers of individuals is becoming more economically feasible, sampling not just likely immigrants and a selection of likely locals, but instead the entire population (as we have done here) could become a more frequently applied strategy (c.f. Price et al., 2012). We have strived to highlight some of the possibilities for archaeology in general with such an approach in this paper. In the future, coupled with a similar approach to aDNA, this could be taken even further by comparing first-generation and more long term trends in migration, mobility and integration. The discussions on social integration and culture that are often held within the domain of material culture in archaeology could thereby be expanded and deepened by adding these new dimensions.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.jasrep.2017.01.031.

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Appendix A

Human tooth enamel samples from Öland. chronology. and isotopic data.

ID	*Tooth (FDI)*	*$^{87}Sr/^{86}Sr$*	*$\delta^{18}O_{carb}$ VPDB. ‰*	*$\delta^{18}O_{carb}$ VSMOW. ‰ (Coplen 1988)*	*$\delta^{18}O_{phos}$ VSMOW.‰ (Chenery et al. 2012)*	*Period**	*C14-Calibrated*	*SHM (grave field)*	*Grave number*
1002	34	0.7107	-4.7	26.1	-7.2	ER		9754	25
1003	34	0.7127	-4.1	26.7	-6.2	R		31890	8
1004	34	0.7117	-4.0	26.8	-6.1	ER	112 +-116 AD	31890	11
1005	35	0.7184	-5.2	25.5	-8.1	ER		31890	18
1006	25	0.7089	-5.7	25.0	-8.8	PR		25570	2
1007	34	0.7123	-5.8	24.9	-9.0	PR	91 +/-61 BC	23981	35c
1008	24	0.7131	-3.5	27.4	-5.2	Vi	847 +-65 AD	24542	I undre
1009	34	0.7149	-5.8	24.9	-9.0	R		23494	21
1010	14	0.7120	-5.1	25.7	-7.8	PR	232 +/-98 BC	25570	2
1011	14	0.7130	-7.5	23.2	-11.8	LR		23280	
1012	44	0.7318	-7.1	23.5	-11.2	Vi		28549	
1013	44	0.7113	-3.0	27.8	-4.5	Vi		27365	35
1014	44	0.7135	-4.7	26.0	-7.3	ER		28364	108 F231 III
1015	44	0.7110	-6.2	24.5	-9.7	ER	130+/-57 AD	25153	
1016	34	0.7198	-6.8	23.9	-10.7	Vi		25096	
1019	24	0.7119	-5.2	25.6	-8.0	R		31890	25
1020	34	0.7159	-5.6	25.2	-8.6	ER		1785/67 Bårby	6
1021	34	0.7118	-5.4	24.9	-9.1	Vi		26454	3
1022	35	0.7349				Vi		26454	2?
1023	34	0.7113	-5.3	24.7	-9.3	Vi		26454	1?
1024	25	0.7296	-4.3	24.3	-10.0	Vi	1049+/-58 AD	25129	
1025	32	0.7133	-5.6	24.6	-9.5	PR/ER		23981	35b
1026	34	0.7184	-6.4	24.8	-9.3	Vi	986 +/-38 AD	19726	1
1027	44	0.7314	-6.1	24.1	-10.3	PR	575+-129 BC	19726	13
1028	34	0.7077	-5.1	25.7	-7.8	Vi	885 +/- 69 AD	22486	
1029	34	0.7128	-5.2	25.3	-8.4	PR	326+/-70 BC	18521	
1030	25	0.7330	-5.3	24.2	-10.1	Vi		25657	
1031	34	0.7118	-5.9	25.4	-8.3	LR		27768	
1032	45	0.7113	-6.0	25.5	-8.1	ER		27702	39
1033	44	0.7296	-6.4	26.5	-6.5	ER		27702	2
1034	44	0.7133	-6.1	25.1	-8.7	ER	3 AD +/-46	25130	-
1035	44	0.7184	-6.0	24.3	-10.0	ER		22348	-
1036	44	0.7314	-6.6	24.6	-9.5	ER	103 +/-54 AD	23267	1
1037	44	0.7077				ER		27702	1
1038	45	0.7358	-5.3	25.4	-8.2	ER		28364	6
1039	34	0.7128	-5.4	25.6	-8..0	ER		27702	36
1040	34	0.7330	-6.5	25.4	-8.2	PR	344 +/-71 BC	28514	
1041	24	0.7116	-6.2	24.6	-9.6	PR		24544	5
1042	44	0.7115	-5.7	25.0	-8.9	PR	191+/-95 BC	24544	2
1043	44	0.7121	-5.9	24.8	-9.1	PR		24847	3
1044	44	0.7258	-5.2	25.5	-8.1	ER		27764	
1045	44	0.7110	-3.6	27.2	-5.4	Vi		29352	24
1046	14	0.7158	-5.7	25.0	-8.8	Vi	847 +/-65 AD	22291	-
1047	44	0.7116	-5.7	25.1	-8.8	ER	3 +-46 AD	23981	47
1048	14	0.7123	-5.3	25.5	-8.1	ER	25 +/-47 AD	23981	35a
1051	34	0.7246	-5.7	25.0	-8.8	PR		24846	1
1052	24	0.7125	-6.0	24.7	-9.3	PR	386+/-80 BC	24846	2 (?)
1053	44	0.7148	-5.5	25.2	-8.5	ER		27702	90
1054	24	0.7120	-5.0	25.8	-7.6	ER		27702	140
1055	44	0.7104	-6.1	24.7	-9.4	Ve		22231	4
1056	44	0.7113	-5.4	25.4	-8.3	PR	22 +/- 55 BC	27125	
1057	45	0.7124	-5.1	25.6	-7.9	Vi		29352	13
1058	34	0.7108	-5.5	25.2	-8.5	Vi	1049 +/-58 AD	28364	134
1059	44	0.7103	-5.8	24.9	-9.0	Vi	847 +/-65 AD	23494	20
1060	45	0.7107	-7.0	23.7	-10.9	Vi		23494	19
1061	24	0.7127	-5.4	25.4	-8.3	LR		24543	3
1062	24	0.7160	-5.0	25.7	-7.7	ER	88 +/-57 AD	19197	2?
1063	44	0.7116	-5.5	25.3	-8.5	PR	576 +/-130 BC	22126	
1064	44	0.7125	-5.8	25.0	-9.0	Vi	858 +/- 68 AD	22394	
1065	45	0.7391	-6.1	24.6	-9.5	Vi		6393/75	3
1066	14	0.7120	-5.4	25.4	-8.3	Vi		6393/75	10

1067	45	0.7180	-6.6	24.1	-10.3	Vi		6393/75	20
1068	34	0.7265	-4.6	26.8	-7.0	Vi		29352	18
1069	34	0.7105	-5.1	25.6	-7.9	PR	75 +/-69 BC	29764	-
1070	44	0.7125	-4.9	25.9	-7.5	PR		29764	Ind II
1071	14	0.7143				Ve	716 +/-44 AD	27513	3
1072	44	0.7123	-5.7	25.0	-8.8	ER	119 +/-56 AD	12097	-
1073	44	0.7085	-3.9	26.8	-6.0	Vi	829 +/-57 AD	27771	1
1074	44	0.7128	-6.8	23.9	-10.6	ER	30+/-48 AD	25098	
1075	14	0.7113	-6.0	24.7	-9.3	Vi	853 +/- 67 AD	28364	164
1076	44	0.7337	-4.8	26.0	-7.3	LR		28364	136
1077	35	0.7269	-5.8	24.9	-9.0	Ve		22231	8
1078	44	0.7184	-5.3	25.4	-8.2	Vi		21367	A5
1079	44	0.7115	-5.2	25.6	-8.0	ER		31890	12
1080	14	0.7134	-5.8	24.9	-9.1	ER		31890	5
1081	44	0.7106	-5.3	25.4	-8.2	ER		31890	6
1082	34	0.7110	-5.4	25.3	-8.4	ER	67 +/-48 AD	24543	2
1083	34	0.7209	-5.1	25.7	-7.8	R		24543	1
1084	34	0.7090	-3.9	26.9	-5.9	Vi	1122 +/-63	24542	25
1085	24	0.7108	-5.6	25.1	-8.7	ER		24866	G
1086	44	0.7087	-4.2	26.6	-6.3	Ve	799 +/-68 AD	29352	25
1087	24	0.7112	-7.3	23.4	-11.4	ER	36 +/-49 AD	23267	2
1088	34	0.7140	-4.6	26.2	-7.0	Vi	858 +/-68 AD	23267	3
1089	34	0.7122	-6.3	24.4	-9.8	ER	125 +/-57 AD	23267	4?
1090	34	0.7112	-6.6	24.1	-10.3	ER		27702	37
1091	24	0.7106	-5.7	25.0	-8.9	ER		29352	113
1092	44	0.7158	-5.8	24.9	-9.0	ER		12142	9 över?
1093	44	0.7158	-5.5	25.3	-8.4	ER		12142	9 under
1094	24	0.7116	-5.4	25.4	-8.3	ER	125 +/-62 AD	25132	
1095	34	0.7112	-6.3	24.5	-9.8	PR	305 +/-69 BC	25605	
1096	34	0.7133	-6.5	24.2	-10.1	ER	25 +/-47 AD	24813	II
1097	34	0.7090	-3.6	27.2	-5.4	Vi	1053 +/-60 AD	22763	-
1098	34	0.7117	-5.7	25.1	-8.8	PR		4186/73	3
1099	34	0.7131	-6.1	24.6	-9.5	LR		1785/67	5
1100	24	0.7310	-6.9	23.8	-10.8	ER	61 +/-54 AD	25021	
1101	44	0.7319	-5.0	25.8	-7.7	Vi		21367	24
1102	36	0.7121	-5.2	25.5	-8.1	R		23349	3 (?)
1103	14	0.7139	-5.5	25.2	-8.6	ER		21368	37 undre
1104	44	0.7129	-6.5	24.2	-10.1	ER		21368	37 övre
1105	34	0.7099	-3.4	27.4	-5.1	Vi	853 +/-71 AD	28364	108:I:169
1106	44	0.7343	-5.7	25.1	-8.8	PR	91 +/-61 BC	28364	108:IV:282
1107	14	0.7131	-5.4	25.4	-8.3	LR		19765	13
1108	44	0.7110	-6.1	24.6	-9.5	M		Sb	Individ I
1109	34	0.7109	-5.5	25.2	-8.6	M		Sb	Individ 2
1110	44	0.7145	-7.2	23.5	-11.2	Ve	629 +-18 AD	2 623 927 121	29
1111	37	0.7155	-7.6	23.1	-11.9	PR	112 +- 45 BC	26733/26732	26
1112	47	0.7120	-6.3	24.4	-9.8	PR	134 +/-49 BC	27121	2
1113	47	0.7107	-5.4	25.3	-8.4	Ve	729 +/-36 AD	26239	8
1114	48	0.7150	-6.4	24.3	-10.0	PR	308 +-65 BC	26732	15

For $\delta^{18}O_{carb}$ VSMOW: the values are converted from the equation SMOW = 1.03091 x δ^{18}O PDB + 30.91 in Coplen (1988)

$\delta^{18}O_{DW}$ VSMOW: the values are recalculated using the equation δ18ODW=1.590x δ18OC (SMOW)-48.634 in Chenery et al. (2012)

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* Period. legend:

	Period	**Subperiod**	**Chronology**
Early Iron Age (E IA)	Pre Roman Iron Age (PR IA)		500 BC-AD 0
	Roman Iron Age (R IA)	Early Roman Period (ER)	AD 0-200
		Late Roman Period (LR)	AD 200-400
Late Iron Age (L IA)	Migration Period (M)		AD 400-550
	Vendel Period (Ve)		AD 600-800
	Viking Age (Va)		AD 800- 1050

Appendix B

Bioarchaeological characters

ID	Period	Local ?	Sex	Age	Grave/Context		Artefacts			Other
					Type	Orientation	Import	High status	Weapons	
1002	Early	gray	male	5	cist	NS				
1003	Early	non local	male	5	cist	NS				
1004	Early	non local	undetermined	3	cist	NS				
1005	Early	gray	male	8	cist	NS	yes	yes	yes	
1006	Early	non local	NA	9	cist	NS				
1007	Early	local	male	8	pit	NS				
1008	Late	non local	female	5	cist	NS		yes		
1009	Early	local	male	8	cist	SN				
1010	Early	local	NA	1	cist	NS				
1011	Early	non local	male	6	cist	NS		yes	yes	
1012	Late	non local	male	5	pit	WE				
1013	Late	non local	male?	6	cist	NS				
1014	Early	local	male	6	cist	NS	yes			
1015	Early	local	female	4	cist	NS				
1016	Late	non local	female?	8	pit	WE				
1019	Early	local	NA	4	cist	NS				
1020	Early	local	female?	6	cist	NS				
1021	Late	local	female?	5	cist	NS				
1022	Late	non local	undetermined	5	pit	SN				
1023	Late	local	undetermined	9	cist	NS				
1024	Late	non local	female	2	pit	WE				
1025	Early	local	NA	1	pit	NS				
1026	Late	gray	male	8	pit	NA				
1027	Early	non local	female	6	cist	NS				
1028	Late	non local	male	6	cist	NS				filed incisor
1029	Early	local	male	4	pit	NS				
1030	Late	non local	male?	7	cist	NS				
1031	Early	local	male	2	cist	NS	yes	yes	yes	yes
1032	Early	local	female?	6	cist	NS		yes		
1033	Early	non local	male?	5	cist	NS	yes	yes	yes	yes
1034	Early	local	male	5	cist	NS				
1035	Early	gray	female	4	cist	NS				
1036	Early	non local	female?	4	cist	NS				
1037	Early	non local	male?	2	cist	NS		yes		
1038	Early	non local	female	6	cist	NS		yes	yes	yes
1039	Early	local	female?	4	cist	NS				half moon knife
1040	Early	non local	male	6	pit	NS				
1041	Early	local	male	5	pit	NA				
1042	Early	local	male	5	cist	NA				
1043	Early	local	female?	2	cist	NS				
1044	Early	non local	male?	8	cist	NS				
1045	Late	non local	male	8	pit	NS	yes	yes		
1046	Late	local	male	3	cist	NS				
1047	Early	local	male	9	cist	NS				
1048	Early	local	male?	5	pit	NS				
1051	Early	non local	female	8	cist	NS				
1052	Early	local	male	2	pit	NS				
1053	Early	local	undetermined	6	cist	NS				

1054	Early	local	NA	1	pit	NS				
1055	Late	gray	NA	3	boat	NA		yes	yes	yes
1056	Early	local	NA	2	cist	SN				
1057	Late	local	male?	8	pit	NS				
1058	Late	gray	female	6	cist	WE				
1059	Late	gray	male	2	cist	SN				
1060	Late	non local	NA	1	cist	NS				
1061	Early	local	male	6	pit	NS				
1062	Early	local	female?	5	cist	NS				
1063	Early	local	male	8	cist	NS				
1064	Late	local	male	6	cist	NS				filed incisor
1065	Late	non local	female?	7	coffin	WE				
1066	Late	local	NA	2	coffin	WE		yes	yes	yes
1067	Late	non local	male	8	coffin	WE				
1068	Late	non local	male	5	pit	NS		yes		
1069	Early	gray	NA	2	wetland	NA				
1070	Early	local	male?	2	wetland	NA				
1071	Late	local	undetermined	7	cist	NS				
1072	Early	local	male	6	cist	NS		yes	yes	yes
1073	Late	non local	male	6	pit	NS				
1074	Early	local	female	4	cist	NS				
1075	Late	local	male	6	cist	NS				
1076	Early	non local	female	6	pit	WE				
1077	Late	non local	NA	3	boat	NA		yes	yes	yes
1078	Late	gray	NA	2	cist	NS		yes	yes	yes
1079	Early	local	male?	5	cist	NS		yes	yes	yes
1080	Early	local	female	5	cist	NS				
1081	Early	gray	NA	5	cist	NS	yes	yes		
1082	Early	local	male	6	pit	NS				
1083	Early	non local	male	8	pit	NS				
1084	Late	non local	female	8	pit	NS				
1085	Early	gray	female?	5	cist	NS				half moon knife
1086	Late	non local	female	4	pit	WE				
1087	Early	non local	female?	2	cist	NS				
1088	Late	local	male	6	pit	NS				
1089	Early	local	male	2	cist	NS		yes	yes	
1090	Early	non local	male	5	cist	NS				
1091	Early	gray	male	5	cist	NS		yes	yes	
1092	Early	local	male	7	cist	NS		yes	yes	
1093	Early	local	male	4	cist	NS		yes	yes	
1094	Early	local	female	8	pit	NS				
1095	Early	local	male	4	cist	NS				
1096	Early	local	male?	5	cist	NS				
1097	Late	non local	female?	6	pit	WE		yes	yes	
1098	Early	local	male?	7	cist	WE				
1099	Early	local	female	2	cist	NA				
1100	Early	non local	male	2	pit	NS				
1101	Late	non local	male	4	coffin	WE				
1102	Early	local	NA	1	cist	NS				
1103	Early	local	female	8	cist	NS	yes	yes	yes	
1104	Early	local	male?	5	cist	NS	yes	yes	yes	
1105	Late	non local	male?	4	cist	NS				
1106	Early	non local	male	7	cist	NS				
1107	Early	local	male	4	cist	NS		yes	yes	
1108	Late	local	male	2	house	NA				

1109	Late	local	male	4	house	NA
1110	Late	non local	male	5	wetland	NA
1111	Early	non local	female?	5	wetland	NA
1112	Early	local	undetermined	3	wetland	NA
1113	Late	gray	NA	2	wetland	NA
1114	Early	local	female?	9	wetland	NA

Early = Early Iron Age (500 BC- AD 400), Late= Late Iron Age (AD 400- 1050). 1: child 2: Juvenile 3: Juvenile-young 4: Young 5: Young-mature 6: Mature 7: Mature-old 8: Old 9: Young-old . NS=north south oriented burial, SN=south north, WE=West-East, NA= not abvailable.

Appendix C

Sr and geological background for Öland

Öland has a very distinctive geology. Nearby mainland Sweden is composed primarily of ancient granites and other metamorphic rocks formed around 1800 million years ago. Öland is dominated by Ordovician limestone, along with some Cambrian and Ordovician shales with an age of approximately 450 to 540 mya (Freden 1994, Königsson 1968, Loberg 1999). These deposits lie on top of a Precambrian basement that is nowhere exposed on the island. Holocene changes are largely due to the building of beach ridges and aeolian activity.

Öland is long from north to south and narrow east to west. The narrow half of the island to the north is characterized by a craggy and irregular, heavily eroded landscape, while the south is dominated by the Alvar Plain, one of the largest limestone barrens in Europe. This largely flat region lacks substantial topsoil and is often characterized by exposed limestone bedrock. Most of the human settlement and activity on Öland took place on low, wide ridges on either side (east and west) of the island where soils are more developed and farming more feasible. These beach ridges built up as a result of successive changes in the level of the Baltic Sea during the late Pleistocene and early Holocene. In various places on Öland, there are local deposits of glacial till and outwash left by the melting ice at the end of the Pleistocene. These glacial materials largely originated in the crystalline mainland area of older rock and likely have higher ^{87}Sr/^{86}Sr values that the limestone and shale on the island (Fig A3:1).

Local strontium isotope ratios on Öland can initially be estimated from the age of the geological deposits. Ordivician limestones and shales exhibit the strontium isotope ratio of seawater during that geological period, reported between 0.7078 and 0.7090 (Hess et al. 1986, Vezier 1989). SGU measured seven samples of kalksteen from two sites on Öland with a mean value of 0.7090 ± 0.0001 (Ebneth et al 2001:2290).

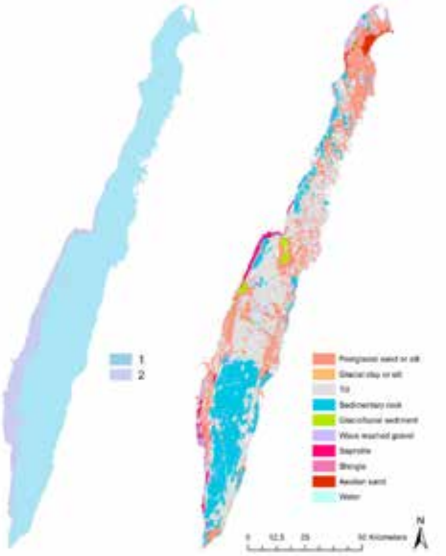

Figure A3:1. Geology in Öland and the adjacent mainland. Legend: 1= Carbonate-rich sedimentary rock (limestone, dolomite, marble etc.). 2= Mica-rich sedimentary rock (shale, siltstone etc.). Both 1 and 2 are mainly bedded rocks in the youngest bedrock unit (850-34 million years). Right: The soil distribution in Öland. Both maps: Data © SGU. Basemap: Esri, HERE, DeKorme, MapmyIndia, ©OpenStreetMap contributors and the GIS user community.

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Appendix D

Animal	**$^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$**	**Interpretation**	**Site (SHM)**	**Feature/burial**	**Source**
dog	0.7098	non- local	10302	A1:1	Wilhelmson and Ahlström 2015
snail	0.7109	local			Fornander et al. 2011
dog	0.7115	local	27702	A2	Wilhelmson and Ahlström 2015
sheep/goat	0.7116	local	27702	A2	Wilhelmson and Ahlström 2015
microfauna	0.7118	local	28364	108 F169. I	Wilhelmson and Ahlström 2015
snail	0.7118	local			Fornander et al. 2011
pig	0.7120	local	27362	F112	Wilhelmson and Ahlström 2015
dog	0.7121	local	31890	A17	Wilhelmson and Ahlström 2015
sheep/goat	0.7121	local	Sandby borg	house 40	Wilhelmson and Ahlström 2015
hare	0.7121	local			Fornander et al. 2011
snail	0.7122	local			Fornander et al. 2011
microfauna	0.7123	local	27362	F13	Wilhelmson and Ahlström 2015
microfauna	0.7124	local	27362	F112	Wilhelmson and Ahlström 2015
sheep/goat	0.7127	local	10302	A1:1	Wilhelmson and Ahlström 2015
roe deer	0.7132	local			Fornander et al. 2011
snail	0.7134	local			Fornander et al. 2011
microfauna	0.7135	local	31890	A17	Wilhelmson and Ahlström 2015
pig	0.7139	local			Fornander et al. 2011
sheep/goat	0.7139	local	Sandby borg	house 40	Wilhelmson and Ahlström 2015
microfauna	0.7142	local	31890	A5	Wilhelmson and Ahlström 2015
hare	0.7143	local			Fornander et al. 2011
dog	0.7147	local	12142		Wilhelmson and Ahlström 2015
hare	0.7155	local			Fornander et al. 2011
microfauna	0.7158	local	27362	F99	Wilhelmson and Ahlström 2015
dog	0.7164	local	31890	A5	Wilhelmson and Ahlström 2015
pig	0.7174	non- local?			*Fornander et al. 2011*
microfauna	0.7175	non- local?	27702	A2	Wilhelmson and Ahlström 2015
microfauna	0.717735	non- local?	28364	108. F231	Wilhelmson and Ahlström 2015
sheep/goat	0.718818	non- local?			*Fornander et al. 2011*
pig	0.718909	non- local?	28364	A85	Wilhelmson and Ahlström 2015
dog	0.720421	non- local	27513	3	Wilhelmson and Ahlström 2015
dog	0.721472	non- local	22231	A4	Wilhelmson and Ahlström 2015

A summary of all the faunal samples from Öland. The animals sampled are each separate individual animals found in different contexts and locations. Data compiled from Fornander et al. 2011 and Wilhelmson and Ahlström 2015. The interpretation is however made solely by the authors of this study.

PAPER V

Island hierarchy, violence and society: a bioarchaeological approach to Iron Age Öland

Helene Wilhelmson

The paper was submitted to a peer-reviewed BAR conference volume with contributions from the session "Islands and Archipelagos" in EAA (European Association of Archaeology) in Glasgow 2015.

Island hierarchy, violence and society: a bioarchaeological approach to Iron Age Öland

Helene Wilhelmson

INTRODUCTION

The intense human activities on the long and narrow Baltic island, only 1,3 km2 in size, of Öland (Figure 1) in the Iron Age (500 BC- AD 1050) have no precedence either before or after this period. Some 230 small villages appear to be established in this period and the landscape is heavily partitioned by stone walls intimately (Fallgren 2006:186ff). The settlement remains along with burial variation indicates a socially divided and hierarchical society. Artefacts indicate extensive regional, and more distant contacts, resulting in both artefacts and humans (cf. Wilhelmson and Ahlström 2015; Wilhelmson and Price in prep.) settling on the island throughout the period. The degree of human immigration increases in the later part of the period (AD 400-1050) which most likely is the result of improvements in maritime technology specific to Öland being an island (c.f discussion in Wilhelmson and Ahlström 2015). The significant increase in immigration over time could mean social changes were taking place during the Iron Age. Social hierarchy has so far been investigated by settlement (primarily Fallgren 2006) and artefacts (Hagberg 1967; Näsman 1984) and/or burial practice (Beskow-Sjöberg 1987; Rash 1991; Räf 2001) and concluded to be clearly expressed in these materials. Population size has been suggested to be fluctuating throughout the period (primarily discussed Stenberger 1933, Hagberg 1978 and Fallgren 2006). In the first and second centuries AD also the more marginal areas of the island were being exploited for farming and grazing (the great lime barren Alvaret) but soon abandoned, likely due to ecological collapse (Enckell et al. 1979). The degree of population pressure on the island could have implications for social organization in both hierarchy and violence as well as immigration.

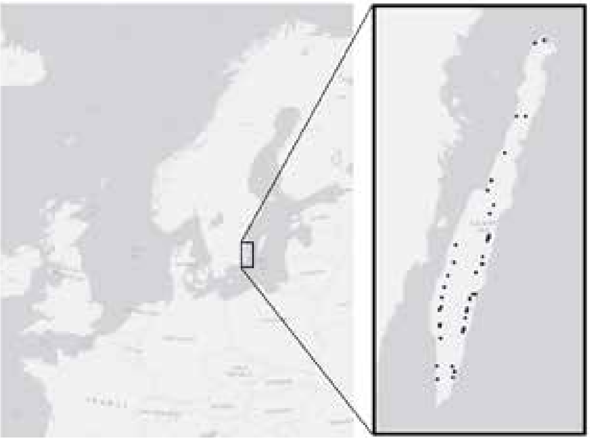

Figure 1. The location of Öland in the Baltic Sea and the distribution of the human remains studied. Esri, HERE, DeKorme, MapmyIndia, ©OpenStreetMap contributors and the GIS user community.

Violence in Iron Age Öland is currently poorly understood and mainly wetland finds have been used in these discussion or singular cases of *sensu lato* dates (Gejvall 1968; Sjøvold, 1994; Monikander 2009) and sacrifice has been discussed also in burial contexts due to multiple reburials (Rasch 1991:510). During the Iron Age some significant changes in societal organization have been suggested based on burial customs in particular, but also wetland depositions, hoards (primarily Stenberger, 1933; Hagberg 1978, Herschend 1980; Räf 2001) in the transitions between the different periods (Figure 2), primarily in the transition from Early to Late Iron Age around AD 400, in the wake of the fall of the Roman Empire. Others however argue for continuity when looking at settlements and landscape organization from AD 200-1300 (Fallgren 2006). Räf (2001) has suggested a change on Öland in society, religion and gender (based primarily on primarily archaeological sex estimations) roles occurred in the transition between the Late and Early Roman subperiods (circa AD 200) of the Scandinavian Iron Age based on graves and wetland depositions. The many ringforts, along with much of the extensive settlement remains are suggested to be developed from circa AD 200 (Fallgren, 2006), however the apparent shift in settlement tradition taking place AD 200 is poorly understood as earlier settlements are lacking clear dates (Fallgren 2006: 27). There has long been argued for a shift in burial practice occurring AD 400 with a virtual cease in inhumations that has been considered a significant change. However, the decline appears to occur already from AD 200 (Hagberg 1979: 14; Beskow-Sjöberg 1987; Rasch 1991; Räf 2001) on Öland which was recently established by extensive radiocarbon dating as a much more extensive decline than previously assumed (Wilhelmson in prep.). Especially for the Early Iron Age (up to AD 400) an "upper "social class, including "princely" or "chieftain" graves, has been suggested from the artefacts (Hagberg 1967:107f; Beskow-Sjöberg 1987:388f; Rash 1991:474, 477) as well as "middle" and "lower" (Beskow-Sjöberg 1987:388ff). Uncremated human remains occur in a range of more or less normative (normative as in frequently occurring context and non-normative as unusual) contexts on Öland. The variation, as well as temporal shifts in burial traditions or "disposal" of bodies, likely indicates a deviant social status, either high or low. In order to determine if the status of the individual in the non normative context was high or low the bioarchaeological profile (age, sex, native/non native, violence etc) could be compared to the population at large.

When studying violence in an approach based in material culture warfare and warriors unavoidably become focus due to the reliance of specialized weapons. Usually other sources such as war spoil depositions, fortifications, iconography, written sources and human skeletal remains (for example Vandkilde 2006) are added for context. If basing the discussion primarily on human remains there is a possibility to have a broader perspective on violence by focusing on the victims and the context surrounding the cases. In today's social theory it is recognized that violence in war is intimately tied to violence in society in general and that "aggression" is a social construct giving social legitimacy for men (especially young) to use violence in both contexts although more explicitly in combat (Nordstrom 1998; Scheper-Hughes and Bouorgois 2004). As the aggressors usually choose victims physically inferior in strength (but instead possessing social power) the "blind aggression" reserved primarily for young males does not hold true. This is expressed clearly today in warfare where the great majority of victims are civilians and primarily women and children (cf. discussion in Nordstrom 1998). Should we apply this to archaeological contexts then violence (different types of attacks) could be used to study societal organization (not only warfare) as those possessing social power would be more likely to be subjected to excessive interpersonal violence. Not only specifics of the trauma from interpersonal violence but the age, sex and social identity (type of burial and if native or non native to the island) of the victims/agressors could also be investigated in detail by a bioarchaeological approach to the human remains. Here societal organization is discussed using a bioarchaeological approach to violence, both interpersonal and structural, based on uncremated human skeletal remains and their contexts from the island of Öland representative of the entire population, during the Iron Age (500 BC- AD 1050) for a long time perspective.

Migration is recognized as a social factor that could potentially explain either low or high social status. It is generally agreed that slavery or similar type of social organization, existed in Scandinavia in the Viking age. However, it has been suggested to be older and initiated at least in the Roman Iron Age through contacts with the Roman Empire (c.f discussion in Brink, 2012). If slaves were captives this would mean they would have a different childhood origin (non natives to Öland) which could be traced by provenance isotopes such as $Sr^{86/87}$ and $\delta^{18}O$. One way of addressing potential slavery during the Iron Age on Öland could be to investigate if natives and non natives were differently exposed to violence and/or social oppression. However, recently it was suggested in specific for Viking Age Scandinavia (Ashby 2015; Dobat 2015) that non natives could have a very high social status, recruited as foreign leaders and kings. The social organization and violence in specific, during the Iron Age in Öland has so far not been investigated using a bioarchaeological approach.

Early Iron Age	Pre Roman period	500 BC – AD 0
	Early Roman	AD 0-200
	Late Roman	AD 200-400
Late Iron Age	Migration period	AD 200-550
	Vendel period	AD 550-800
	Viking Age	AD 800-1050

Figure 2. Table listing the chronological divisions of the Iron Age in Scandinavia

The aim of this study is to investigate changes in social organization, using AD 200 as a watershed, due to the abrupt change in burial practice and possibly concurring shift in population density on the island, from a bioarchaeological approach focused on violence and hierarchy. In specific I will investigate:

(i) How do low and/or high status individuals compare when using multiple bioarchaeological characters? Are violence and hierarchy connected to one another?

(ii) Do the Öland/ island specific parameters: such as limited space leading up to AD 200, the skewed sex ratio with more males than females throughout the period and the increasing migration during the later period, correlate with violence and hierarchy?

(iii) Are there any tangible changes in social organization, detected in violence and/or hierarchy, between the period leading up to AD 200 and that after?

MATERIAL AND METHODS

Material

The material for this study is selected Iron Age human remains from Öland from various contexts all of which were subjected to $Sr^{86/87}$ and $\delta^{18}O$ isotope analysis in a previous study (cf. Wilhelmson and Ahlström 2015; Wilhelmson and Price in prep). The sample was selected on the account of being dated to a specific period in the Iron Age (by artefacts or ^{14}C) and having teeth and bone preserved for isotopic analysis and includes all securely dated human remains available for bioarchaeological study by the criteria outlined below.

Age was determined for adults using the methods of Suchey-Brooks (Suchey 1988), (Buckberry and Chamberlain 2002), (Kunos et al. 1999) in descending order of preference. Children were aged by methods for dental development (Gustafson and Koch 1974) and epiphyseal development (Schaefer et al. 2009). There are a significant propor-

	Child	**Juvenile**	**Young**	**Mature**	**Old**	Juvenile/adult	Adult/mature	Mature/old	Adult/mature/old
years	*6-12*	*13-19*	*20-35*	*36-59*	*60+*	*13-35*	*20-59*	*36+*	*20+*
n	5	17	14	20	15	5	23	6	4

Figure 3. Table showing the distribution of age estimations to different age groups. Some more specific age estimations transcend the age groups why they are in the combined groups and some were more general (due to poorer preservation) such as those in the group 20+ years.

Period	**Chronological definition**	**Female/male/ambiguous/unsexed**
Early Iron Age	500 BC-400 AD	21/38/3/9
Late Iron Age	400-1050 AD	9/20/3/6

Figure 4. Table showing the distribution of sex determinations. The unsexed category refers to the subadult individuals and individuals of poorer preservation (without assessable characters in pelvis or skull).

tion of juveniles in the sample as well as older individuals (Figure 3).

Sex was determined primarily using pelvic characters and secondarily with skull features as recommended in Bukistra and Ubelaker (1994) and scored accordingly as 1-5. The sex estimates presented here include both certain (such as 1= female) and less certain (such as 2=possible female) as one group (female) if not otherwise stated. The entire sample of uncremated human remains from Öland has a sex bias with circa 70% males throughout the Iron Age (Figure 4).

A bioarchaeological approach to violence and social identity: social groups

In bioarcheology it could be argued violence is the explicitly most popular singular theme in the recent years (Martin et al., 2012; Schulting and Fibinger 2012; Martin et al., 2013; Harrod and Martin, 2013; Knüsel and Smith, 2014; Martin and Anderson, 2014; c.f. review in Martin and Harrod, 2015). As in archaeology in general, some aspects of social theory can lend ideas on both defining and approaching violence in specific (such as Arendt, 1969; Nordstrom 1998; Scheper-Hughes and Bourgois 2004). A dynamic definition of violence is that of Scheper-Hughes and Bourgois: *"Violence can never be understood solely in terms of its physicality-force, assault, or the infliction of pain-alone. Violence also includes assaults on the personhood, dignity, sense of worth or value of the victim. The social and cultural dimensions of violence are what give violence its power and meaning."* (Sheper-Hughes and Bourgois, 2004:1). The violence studied here is purely its physicality (skeletal traces). The aspects of violence in relation to social status are however possible to investigate when considering archaeological context (non normative burial/disposalor high status burial) as well as with the individuals sex and age. The mode of disposal of the dead body (body position, type of context) could also be considered to indicate social status (however this is most complex, cf. discussion in Weiss- Krejci 2013). Persons of very low social status, slaves, could potentially be captives, which would mean they could have a different geological origin. The same could be true for high status individuals (the concept of stranger kings as discussed above).

The samples are screened for fit into four groups which are designed as a tool to probe different aspects of social status expressed in an individual at the time of death and the time leading up to it. An individual can belong to multiple groups. The definitions of the groups are presented in Figure 5 with further explanation below. In addition to assigning individuals to these groups their age, sex and if they are from a context before or after AD 200 is also taken into consideration.

Group: 1 Interpersonal violence

In this group all individuals presenting skeletal traces of interpersonal violence, ante- (i.e. healed injuries, survived trauma) or peri-mortem (unhealed, i.e. inflicted at the time of death) are included. The social processes resulting in trauma in situations with a lethal outcome (whether the trauma itself is possible to determine as lethal or not) may be different from those resulting in healed trauma (c.f. discussions in Walker 2001; Schulting and Fibinger 2012) why they will be discussed as two separate groups. Also trauma inflicted by sharp force or blunt force are investigated separately as these may be caused by different types of weapons or occur in different types of attacks.

Interpersonal violence is defined here as skeletal marks from blunt or sharp force trauma to the skull or perimortem sharp force trauma to postcranial bones. Other types of trauma could be inflicted by interpersonal violence as well but since the etiology ambiguous, accidents would leave similar injuries, for example the so called parry fracture of the ulna that may result from bracing falls rather than defending attacks (c.f. Judd, 2008; Martin and Harrod, 2014: Larsen 2015:122f and discussions therein). Many injuries resulting from interpersonal violence do not leave any traces on the bones, only on the soft tissue, which means the levels of violence detected in skeletal remains is a considerable underestimation (Walker, 2001:584) at any rate. The skull is often pointed out as the main target for interpersonal violent attacks when studying skeletal remains (c.f. Walker, 2001).

		Criteria	Subdivision
Group 1	Interpersonal violence	Blunt or sharp force trauma to the skull or perimortem sharp force trauma to postcranial bones	Peri-mortem Ante-mortem SFT, BFT or both Multiple or single
Group 2	Non normative contexts	Early Iron Age: any other context than a NS-oriented inhumation Late Iron Age: any other inhumation than a NS or WE oriented A body position indicating tied extremities and an arm under the body and/ or a prone position	Wetland Prone or other pose Orientation Boat House
Group 3	High status burials	include weapons (i.e. sword, spear, arrowhead or shield, fragments or whole) *and/or* precious metal (silver or gold) *and/or* bear claws	High status
Group 4	Native or non native	Definition of native (local) or non native (non local) from Sr and O isotope analysis (Wilhelmson and Price, in prep)	-

Figure 5. The criteria of the groups used as a tool to discuss social identity.

This can be attributed to the fact that comparably little soft tissue surrounds the bones which allow wounds to be identified more easily in skeletal remains. Injuries to the skull also leave the victim clearly visually marked by the assailant and additionally are effective to cause major damage as well due to brain involvement why they are frequently found in association with interpersonal violence. Details on the individual trauma are available in Appendix 2, Figure 1.

Group 2: Non normative contexts

In archaeology it is often argued that the burial details (orientation, placement of the body, grave goods) are related to aspects of the burial community (their philosophical-religious beliefs) and the social identity of the deceased (cf discussion in Rebay-Salisbury 2012 and Carr 1995). Non normative contexts could be indicating either high or low social status of an individual why they are addressed as deviant and the connections of these individuals with the other social groups will be guiding in determining if either low or high status is more likely.

In this study a non normative context can be any type of burial/treatment of a body that does not correspond to those most frequently recorded from the specific period and region. For Öland the contexts in which human bones occur uncremated show chronological differences and most notably inhumations are virtually completely lacking in the period AD400-700 (cf. Appendix 1, Wilhelmson in prep). There is a clear reduction in inhumations starting already in the end of the second century AD and cremation is practiced, more or less in tandem with inhumations, for the entire Iron Age on Öland (Beskow-Sjöberg and Arnell, 1987; Beskow-Sjöberg and Hagberg, 1991; Hagberg and Beskow-Sjöberg, 1996; Fallgren and Rasch, 2001). The details in the definition of burials as normative or non normative for the different periods of the Iron Age can be found in Appendix 2 Figure 2 and 3.

A non-normative position of the body in a context can, regardless of if the context is otherwise normative, (for example a pit burial), constitute a non normative context in this study. Contexts where the skeletal remains were lying in a prone position and/or with the arm positioned under the body, clearly sprawled limbs and/or feet very close (possibly tied) stood out as clearly non normative. In the cases included in this study, taphonomic events (including post mortem manipulation) were possible to positively rule out as a cause of the specific non normative position of the skeletal remains.

Group 3: High status burials

Burials with high numbers of artefacts or specific types (such as weapons) are often treated with special attention in archaeology in relation to social status. While other objects than those today recognizable (for example perishable fabrics) could have been important social status markers as well as specific aspects of the burial construction this type of selection gives inherent bias.

Beskow Sjöberg divides the Early Iron Age society on Öland into to three social classes (upper, middle and lower class) based on grave goods and grave type. However concluding the grave goods and grave type do not necessarily co-vary (Beskow-Sjöberg 1987:398f). Some graves she also point out as “princely” or ”fürstengraber” (f.x. Beskow-Sjöberg 1987:389), including exclusive objects such as roman imports. I have chosen a definition of high status for the Iron Age that includes weapons (i.e. sword, spear, arrowhead or shield, fragments or whole) *and/or* precious metal (silver or gold) *and/or* bear claws to fit Beskow-Sjöbergs definitions. The occurrence of these artefacts in the high status burials is indicated in detail Appendix 1.

Definition of the low status burials as those lacking of artefacts is very misleading when it comes to Iron Age Öland in specific since a great deal of the burials are reused and many are clearly secondarily manipulated and possibly looted (c.f. Rasch 1994). Low status burials can therefore not be defined from lack of artefacts in this study. A non normative context could however, considering specific circumstances indicate low status as discussed above.

Group 4: Non natives

This group singles out those individuals most unlikely to have spent their early childhood on Öland to investigate if this has any connection with the other aspects of social status investigated here. The definition of non native and native for this sample is outlined in (Wilhelmson and Price, in

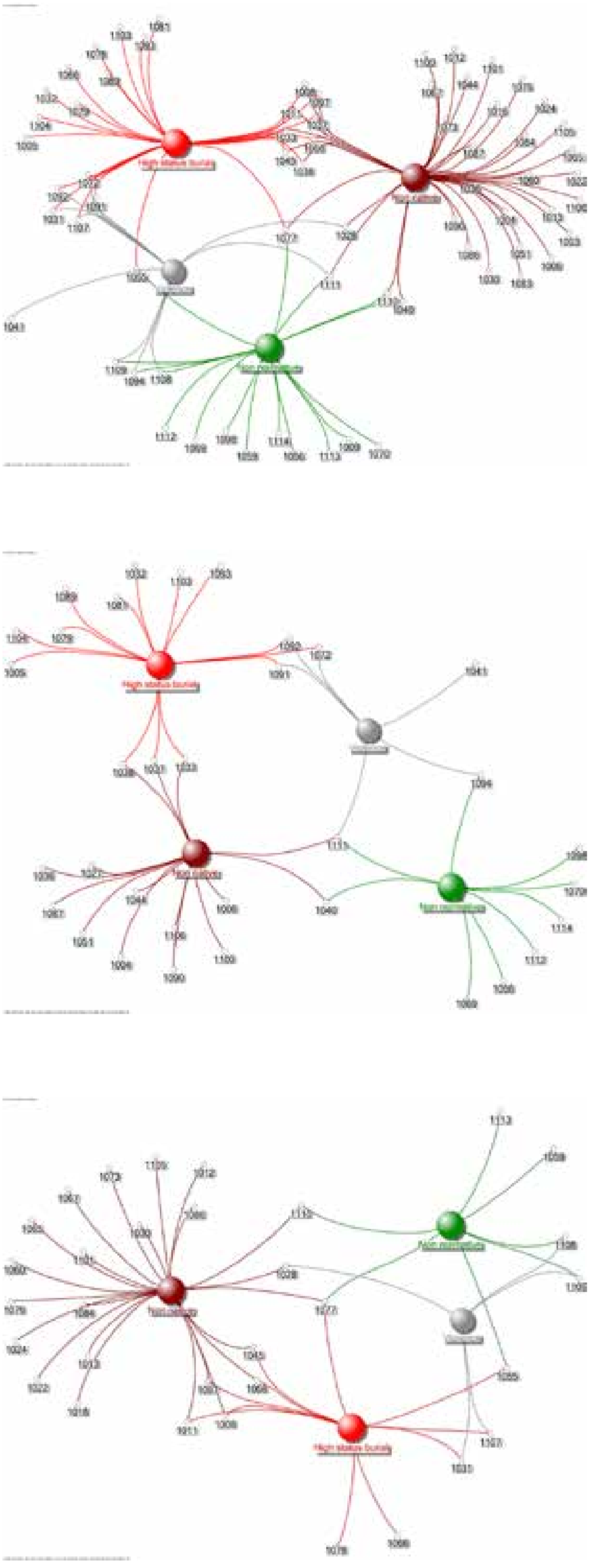

Figure 6. Graph showing the connections between individuals(id numbers) and the six groups. Created with the software NodeXL and data processed by the Harel-Koren Fast Multiscale (Harel and Koren, 2001) algorithm. Violence= group 1, Non normative contexts= group 2, High status burials = group 3, Non native = group 4. For definitions of the groups see Figure 5. A= The entire sample. B= the part of the sample dated before AD 200. C=the part of the sample after AD 200.

prep) and based on Sr and O isotope analysis of tooth enamel in comparison to local fauna and geology.

Each individual of the 109 in the original sample got an estimation as either local, non local or undetermined after an interpretation of baseline for Sr and O (details available in Wilhelmson and Price in prep.). The distribution of the sample is summarized in Appendix 2, Figure 4.

Among the individuals that could be assigned as local/ non local (native and non native) from the Sr$^{86/87}$ and δ^{18}O analysis, and divided by AD 200 as a watershed, sex differences are apparent. The increase in the proportion of non natives after AD 200 shifts from 33% to 55% for males and from 35% to 80% for females; indicating a biased increase in female immigration.

SOCIAL NETWORK ANALYSIS (SNA)

The division of the sample into multiple social groups, in which an individual can belong to any number of groups, is not sufficient to discuss social status as this could co-vary with age, sex and period of the Iron Age. In order to be able to penetrate the possible relationships within the groups these three characters (age, sex and period) also need to be included in the analysis. A sociogram, in this case a *graph*, is a tool to study social structure and relation between individuals in sociology (c.f. Bandyopadhyay et al 2011); a form of network analysis. Network analysis in general has recently increased in popularity in archaeology as a methodological approach to investigate connections between places, materials or objects (c.f. Knappet, 2013) and recently extended to include connections of these with humans (Hodder and Mol, 2015). The nodes in this study are always individuals (presented as id numbers in the graphs, corresponding to the tables in Appendix 1) but can also be qualities (age, sex, time, period) and/or the six groups. Here the connections between the nodes, the edges (ties without direction) are given as simple presence-absence relationships only (lines in the graph). The results are visualized in graphs using the NodeXL software (http://nodexl.codeplex.com/).

RESULTS

The results of scoring each individual of the 109 in the entire sample led to 69 individuals appearing in at least one of the four groups investigated. Less than half of these (23) appear in more than one group. This does not mean these 23 individuals have the same social status, the opposite, as the selection according to groups was targeted specifically to involve those of potentially both very high and low social statuses. The occurrence of individuals in the groups is detailed in Appendix 1. Group 4, non natives, is the biggest group as they include 40 individuals and 26 belong to just this group.

The second largest group is the high status burials where 10 of the 25 individuals only belong to this one group. The individuals in non normative contexts are also well interconnected with the other groups and only 9 of 17 belong solely to this group. Also the individuals with interpersonal violence appear mostly in other groups; 1 of 12 appears only in this one group.

The result of the network analysis of the connections of each individual to each group is presented graphs (Fig 6A-C). Interpersonal violence is the only group connected to all other groups giving it a central placement in the graph and only one individual in this group is not connected to any of the other groups. This is therefore be considered to be the most principal group, indicating violence has some correlation to social status. Over all there is significant overlap with the groups why investigating not only inter- but also intra-group variation is essential. The factors age, sex, subgroups (such as lethal or non leathal violence) as well as the division in chronology (before or after AD 200) will be explored below for each individual group using graphs.

The intra- and intergroup variation

Group 1: Interpersonal violence

Most violence was lethal and this was primarily sharp force trauma (SFT) (Figure 7). Three of the individuals that suffered lethal attacks have both BFT and SFT (1041, 1092, 1094). These attacks included multiple weapons or that a sharp force weapon was used also for blunt force blows (for example the shaft or handle). All these individuals are from before AD 200 but one of them stands out in three respects: she (1094) is a woman buried in a non normative context and has multiple injuries that are sharp force *and* multiple blunt force. Her murder appears to be a different social situation than that involving the two men leading to a different burial, more of a disposal than a burial as is detailed below regarding the non normative context.

Only two individuals clearly suffered multiple interpersonal attacks and both had a single lethal SFT. The male (1072) was still healing his first wound at the time of death. The woman (1111) was too part of a non normative context, a wetland deposition. The man was buried in an identical manner to the two men with multiple perimortem traumas. There is clearly a differential treatment of men and women with perimortem trauma suggesting these non normative contexts (wetland and a prone burial) are indicating a differential social status at least in death.

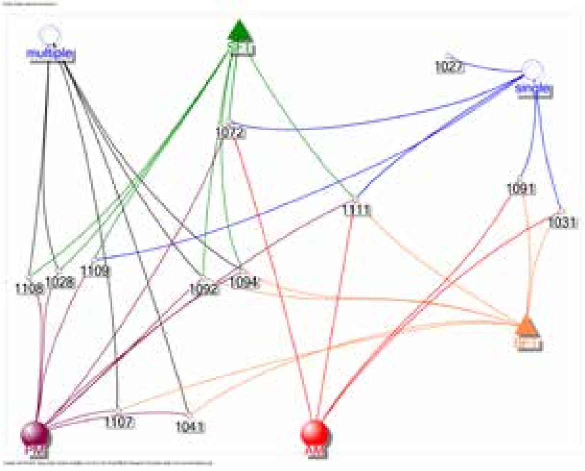

Figure 7. Graph describing the intragroup connections of interpersonal violence. PM=perimortem violence, lethal; AM= antemortem violence, survived. SFT= sharp force trauma, BFT=blunt force trauma. Single=single trauma, multiple=multiple trauma

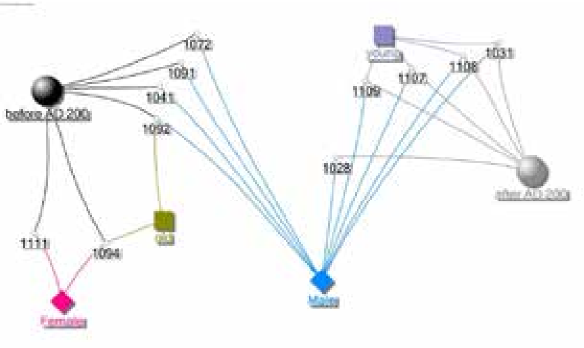

Figure 8. Graph with a chronological overview of the individuals with interpersonal violence. The age groups are defined in Figure 3. Details on age estimation and chronology are available in Appendix 1.

There is a specific chronology considering the interpersonal violence and a shift can be established after AD 200 (Figure 8). Before this time all victims were older adults (mature or older age) and include both men and women. In the subsequent periods, the Late Roman and migration period it is all young (around 20 years old) men. In the Viking Age it is again an older adult (male) victim.

Group 2: Non normative contexts – non normative individuals?

This is a most diverse group of contexts (Figure 9). The biggest subgroup is the wetland contexts which are mainly from one large site/complex of sites, Skedemosse, mentioned earlier. Two individuals are from another site, Emmetorp, not known for other wetland depositions in contrast to Skedemosse. It was recently argued this find was not comparable to Skedemosse (Wilhelmson 2015). As an assemblage, it clearly stands out, being two teenagers and in that the older one had a partially healed complete femoral fracture re-

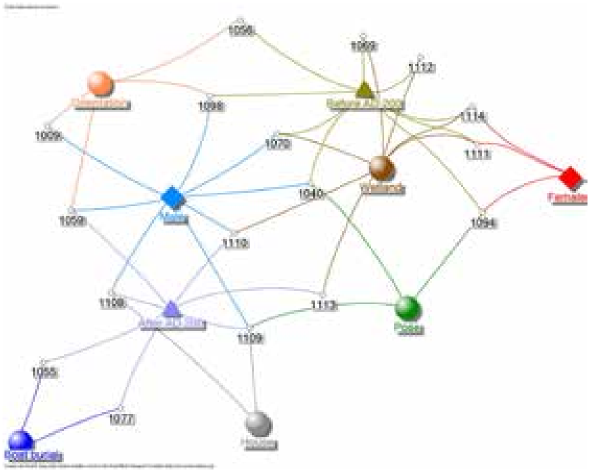

Figure 9. Graph with a chronological overview of the types of non normative contexts with sex and chronology. Created with the software NodeXL and data processed by the Harel-Koren Fast Multiscale (Harel and Koren, 2001) algorithm.

sulting in shortening of the leg. The bones are not weathered the same way as for the individuals in Skedemosse and the skeletons are much more complete and appear articulated. considering their poor health it is likely they were of low social status. They are interpreted to be potentially accidental deaths due to the injury and as they are so differently preserved as an assemblage to Skedemosse (Wilhelmson 2015). The wetland contexts are overall difficult to interpret as they involve both men and women, few with traces of violence and all ages. The often poor preservation of these individuals are limiting the potential for their interpretation. However, it is interesting that the amount of violence detected in other contexts surpasses the wetland contexts by far which is contrary to this frequently described as a wetland phenomenon.

The burials in deviant burial direction do not appear linked to social status in any discernible way by sex, age or chronology. However, one of them (1098) was partially burned (primarily his left side and torso) but otherwise buried in a normative burial style, so potentially cause of death could have some bearing for the non normative orientation of the body.

Two young men (1108, 1109) were found in a most unusual context, a house. The corpses had been left in a standing house that later, after some decomposition, collapsed over them (Wilhelmson and Dell'Unto, 2015). Both were murdered and one was in a prone position. One woman (1094) was placed in a pit, also in a prone position, with her feet likely tied and one arm under the body. The excessive amount of violence she suffered stands out from the other cases, as mention earlier. She was found in the outer perimeter of a grave field but due to the *sensu lato* date of these burials it is not possible to determine whether it was a functional grave field at the time. This is likely concealment/disposal rather than a burial, inferring the killing was not socially sanctioned. The woman showed no signs of poor health considering her age. One other individual (1040) whose feet appear tied and where one arm is behind the body was in an otherwise normative burial and a non native.

The two individuals (1055, 1077) from a boat burial, Nabberör, are not possible to determine whether they would have been high or low status individuals as the exact location of some extraordinary finds of weapons, are unclear in relation to the human remains collected despite later interpretations (c.f. original account in Anderbjörk 1939). These individuals could therefore be of high or low (if sacrificed) social status and due to their poor preservation no further inferences on potential social status could be made from skeletal criteria. One of them (1077) is non native, as is the dog sampled from that boat (Details in Wilhelmson and Price in prep).

Non normative context are clearly complicated to correlate with social status, as they are a most diverse group in types of contexts (Figure 9). Violence occurs to the greatest extent in seemingly normative contexts and are more frequent in the high status burials (5 individuals, compared to 4 in the non normative group) (Figure 6A). The connection between violence and non normative contexts is less significant, high status burials are more significant. In my interpretation those of the non normatives with lowest social status *at the time of death* could be the two women with perimortem traumas (1094, 1111), the two teenagers where one had a trauma (1069, 1070) and the two murdered men left unburied in a house (1108, 1109). The man with tied feet and an arm behind the back (1040) could also be a candidate.

Group 3: High status in burial and life?

The high status burial group includes men and women of all ages similarly in both periods (Figure 10). Men are in majority, which is expected since they are in majority in the entire sample. Of the 19 graves with weapons five were those of men also belonging to the violence group (Figure 6A). Three females (1038, 1103, 1097) were found in graves with weapons where one (1103) was one of multiple burials but the others are unambiguously associated with the weapons. The archaeological method of sexing graves as male due to the occurrence of weapons thus in result seems inappropriate for Iron Age Öland. Two individuals, both 12-15 years old, (1066, 1078), both Viking Age, both have arrowheads and one also a spearhead in the fill of the grave. The burials are significantly different as one (1078) is in NS orientation while the other is an EW oriented wood coffin (1066). Five burials could be considered to stand out from the other high status burials in that they include a diversity of objects of high quality (1005, 1031, 1033, 1079, 1107). These are all males and all but one before AD 200 (1107). The high status burial group in conclusion appears to have no specific bearing on any of the other groups. Violence is associated with some of these burials (all including weapons) but since violence occurs in other types of burials, and non normative contexts, there is no clear connection.

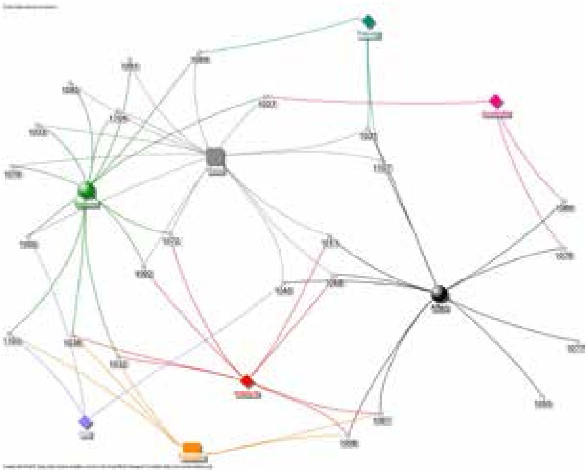

Figure 10. Graph with a chronological overview the high status burials with regards to sex, age and chronology. Created with the software NodeXL and data processed by the Harel-Koren Fast Multiscale (Harel and Koren, 2001) algorithm.

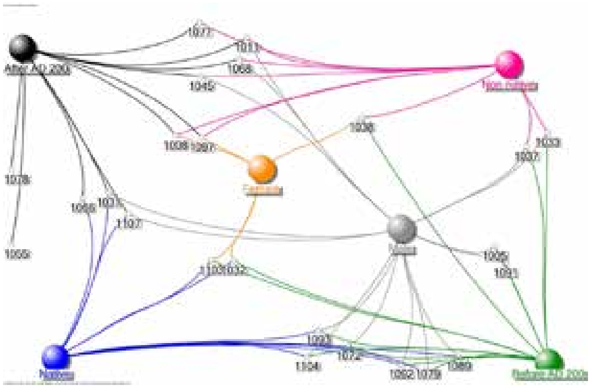

Figure 11: The occurrence of non natives and natives with sex and chronology of those individuals belonging to any of the other groups. Created with the software NodeXL and data processed by the Harel-Koren Fast Multiscale (Harel and Koren, 2001) algorithm.

Group 4: Non natives-slaves or masters?

For the non natives as a group most notable is that the majority (26 of 40) of have no connections to either of the other groups), which this is similar to the local group (where 35 of 56 are not in a group). The non natives have a comparably large proportion of females but if viewing only those individuals that occur in the other groups (Figure 11) this is less apparent. The skeweness towards more non native males than natives after AD 200, and the opposite before AD 200 is prominent. There are few cases of violence in the non natives (2; 8 for natives) and few non normative contexts (4 ; 9 for natives). The high status burials are on the other hand are many (9; 11 natives, Figure 6A), suggesting high status was not less common in this group. When viewing the high status burials divided as natives and non natives the majority are non natives after AD 200 and the pattern is opposite for the Early period (Figures 6B and 6C). The population is dominated natives in the early period and by non natives in the late period which would mean the high status burials are equally distributed among both parts of the population, i.e. nativity was not a significant factor for gaining a high status burial. In conclusion the non natives were not likely to have a differential social status on the island (low or high) in either period, before or after AD 200. The skewness instead only mirrors the entire population composition in the respective periods.

DISCUSSION

The results of the SNA analysis of the bioarchaeological characters as presented in groups in the results are discussed below. The first research question (i) is discussed under the subheading *The bioarchaeology och social status, violence, and hierarchy* and the two last (ii, iii) under *Social changes and the island parameters.*

The bioarchaeology of social status, violence and hierarchy

The use of SNA, and graphs, provided a dynamic overview of both the individual groups related to social status and the interconnection of these groups. Defining individual of low status proved difficult for Öland as the individuals in non normative burials and high status burials both overlapped with the violence group and the non native group. It is possible the social status and gender (age and sex) at the time of death, or even the mode of death itself, could be a more significant factor to the type of burial. The, for Öland, often discussed extensive social differences and hierarchy are thus not detected unambiguously by a bioarchaeological approach. The changes in representation of natives and non natives in the groups appear to match the change in immigration rather than setting the non natives apart in any sense.

The interpersonal violence directed at men appears socially sanctioned in that they are all buried in normative contexts. Walker (2001) has argued violence is gendered and men are more likely as both victims and perpetrators. In the case of Öland this seems to fit less well with the comparably violent period leading up to AD 200. Three females suffered interpersonal violence, two lethal attacks of which one was the second interpersonal attack and the other used excessive force. It could be indicative of a social structure in which at least some women, similarly to men, could have a social status that would put them at risk for violence, ie. in order for someone else to try take that status away from them. For two women who met a violent end their murders resulted in non normative disposals of the bodies. The differential disposal of their corpses indicates it was not accepted to murder women with the same methods as used for men. Violence and hierarchy seem correlated but not in a unanimous hierarchical way as violence occurs in individuals of potentially very low and very high social status at the time of death and differently for the sexes.

Social changes and the island parameters

The higher occurrence of violence in the period leading up to AD 200 could be related to the island being so densely populated at this time. It is also possible that the decline in violence could be related to a social shift as the pattern in violence changes from involving men and women of older age to virtually only involving young men. The results from Öland show that this violence does not fit with the standard warfare/warriors approach as the victims are more diverse and especially so for the cases of leathal violence and extensive attack. This pattern is more in line with modern social theory regarding violence as a form of social renegotiation (c.f. Nordstrom, 1998; Sheper-Hughes and Bourgois, 2004). One potential interpretation for this scenario is that some older individuals, up to circa AD 200, in older age (as most are perimortem injuries) were at higher risk to suffer a renegotiation of their social status resulting in death (due to decline in physical strength with age possibly). Comparably after AD 200 the warrior/warfare ideal could be the form of violence emerging as young males appear the primary targets of violence. This could be the effect of contacts with the continent and the Roman Empire "warrior ideal" (c.f. Vandkilde 2006) and the concept of aggression (devaluated by Nordstrom 1998 to be a political tool to allow and encourage young men to use violence in war) being applied in Öland.

Räf (2001) suggested that a change in women's status occurred in the transition from the Early Roman to Late Roman period (around AD 200). By a regional context her interpretation was that a patriarchal hierarchy, where men had more power and a gendered division was stricter replaced a structure where both men and women could have significant social power. The results of this study seem to lend support to this theory of both a change in social power around AD 200 but also to this change having gender connotations. The increasing migration after AD 200 could also potentially have a bearing on the decline in violence as the population becomes more mixed and the right to land and/or socioeconomic power by genealogy might lose some of its significance when the majority of the population (at least the uncremated part) is not born on the island. Judging from the proportion of high status burials social organization in the sense expressed by artefacts in graves does not change significantly between the two periods and non natives occur proportionally in these contexts in both periods.

The skewed sex ratio accounts sufficiently for the underrepresentation of females in two of the social status groups discussed here, the non normative contexts and the high status burials. Females are however proportionally overrepresented in the period before AD 200 in the violence group and the same also after AD 200 in the non native group. The significant increase in proportion of non native females after AD 200 corrects the otherwise apparent lack of females in the population compared to in the earlier period and could be an island specific development.

In the transition between the Early and Late Roman periods, around AD 200, a different pattern in the victims of interpersonal violence emerges where older adults (both males and females) are replaced by younger men. After AD 200 it seems older individuals were not similarly involved in this type of status negotiation, instead younger men appear to have taken over this arena. This change could be coupled with a change in society and social structures at large that has been suggested to occur around AD 200. As previously mentioned changes related to some aspects of violence, such as depositions of weapons in wetlands (considered war booty, c.f. Hagberg 1967) occur at this time as well as the establishment of the ring forts. The function of the ring forts are debated, however, their thick walls and location in a landscape largely lacking natural defensive features (such as hills, dense forests etc) is interpreted as indicative of some sort of military function but a general communal function is often emphasized (Fallgren 2008, 2009; Andrén 2014). It is possible the ringforts, sacrificed weapons and the young men with traces of violence all make up parts in a new era in Öland with a different social structure with a more military focus. From the pattern of violence it seems social status was renegotiated in a context where having a physical advantage, as young males, was the significant factor. Before this, before AD 200, the societal structure gave social power also to old individuals, regardless of their actual physical ability to inflict violence themselves and both sexes, as these are the individuals suffering from violence. This structure could be kinbased where the older members of society could get social power by lineage which was only challenged once they were significantly physically weekend but still possessed extensive social power. Another potentially significant factor could be overcrowding as the island up to and around AD 200 was densely populated (judging from burials and settlements including partitioning walls), and most intensively exploited as also marginal areas were settled and farmed. The island factor of overpopulation could be related to increases in violence as is often suggested to be a factor for conflict whether or not also tied to climate and/or competition for resources (c.f. Martin and Harrod 2013).

Conclusions

Hierarchy is expressed with some ambiguities in the bioarchaeological record, possibly due to shifts in social identity related to gender and specific mode of death. The analysis of the four social groups (violence, non normative contexts, high status burials and non natives) all overlap showing the dynamic results from such an approach. Some patterns however emerged taking chronology and gender into account.

Changes in social organization are evident in the bioarchaeological record from Öland as investigated using SNA. The occurrence and patterns of violence on Öland in specific are shifting around AD 200 and are at that point more similar to what would be expected in warfare type contexts. The extensive occurrence of violence before AD 200 does not seem connected to a great social hierarchy at that time and not to non natives. It is more likely this is related to the island being densely populated and divided at that time which caused social tensions to be released in violence as a renegotiation of social roles. Another possibility is that the majority of non natives in the population after AD 200 made the violence decline as the claims of for example land by birthright were less extensive in a small native population. The varying roles of females are potentially island influenced. After AD 200 the females are mainly non natives but occur in high status burials similarly as in the earlier period. The occurrence of violence in females, restricted to the period before AD 200, could potentially be an island related phenomenon (due to over population) and is interpreted here as primarily signaling high social status.

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APPENDIX 1

ID	CHRONOLOGY	AGE	SEX	GROUPS				TYPE OF GROUP 2	DETAILS GROUP 3
				1	2	3	4		
1003	0-400	M	35-45				non local		
1004	112 +-116 AD	amb.	juvenile-adult				non local		
1005	40-150/160 AD	M	60+			x	gray		spearheads, sword, spurs, shield boss, ceramics, ornament
1006	BC500-O AD	undet	adult-senile				non local		
1007	91 +/-61 BC	M	73+				local		
1008	847 +-65 AD	F	38+-10			x	non local		knife, silver wire
1009	0-400	M	senile		x		local	SN	
1010	232 +/-98 BC	undet	8				local		
1011	200-400	M	40-45			x	non local		shield boss fragments, ceramics, knife, animal bones
1012	800-1050	M	35-45				non local		
1013	800-1050	M	44-50				non local		
1014	0-200	M	45-50				local		
1015	130+/-57 AD	F	20-30				local		
1016	800-1050	F	70+				non local		
1019	40-310/320 AD; IV:2/V:1	undet	adult				local		
1020	40-150/160 AD;IV:2	F	mature				local		
1021	800-1050	F	adult-mature				local		
1022	800-1050	amb.	adult-mature				non local		
1023	800-1050	amb.	adult-senile				local		
1024	1049+/-58 AD	F	16				non local		
1025	BC 100-AD 100	undet					local		
1027	575+-129 BC	F	45-55				non local		
1028	885 +/- 69 AD	M	mature	x			non local		
1029	326+/-70 BC	M	30-35				local		
1030	800-1050	M	mature-senile				non local		
1031	250/260-310/320; C2	M	19-21	x		x	local		gold ring, bronze and iron clasps, sword, shield boss, spearhead, lance head, knife, ceramics
1032	40-150/160 AD;IV:2	F	mature			x	local		ornament, ceramics, knife, gold foil pearls, bronze with silver inlay, animal bones
1033	40-150/160 AD;IV:2	M	adult-mature			x	non local		jewelry, tools, spurs silver decoration, fittings, sword fittings, looted (2 glass bowls/cups, spurs with silver filigree, bronze tool, small bronzes with silver filigree, sword details, shield rim ornament, drinking horn)
1034	3 +/-46 AD	M	30-40				local		
1036	103 +/-54 AD	F	20-30				non local		
1037	0-200	M	15-17			x	non local		Gold foild glass bead, blue glass bead, clay bead; looted; multiple burials
1038	0-200	F	ca 40			x	non local		tools, weapon (fittings for sword, shield etc) ornament
1039	0-40 AD; IV:1	F	adult				local		
1040	344 +/-71 BC	M	50-60		x		non local	pose	
1041	BC 500-0AD	M	adult-mature	x			local		
1042	191+/-95 BC	M	adult-mature				local		
1043	BC 500-BC 200	F	16-17				local		
1044	0-200	M	senile				non local		
1045	800-1050	M	60+			x	non local		tool, knife, glass beads, fabric, Samanid 942-943 AD (Lund and Rasch 1991:313
1046	847 +/-65 AD	M	ca 20				local		
1047	3 +-46 AD	M	adult-senile				local		
1048	25 +/-47 AD	M	adult-mature				local		
1051	see 1052	F	60-70				non local		
1052	386+/-80 BC	M	19				local		
1053	0-200	amb.	mature				local		
1054	0-200	undet	9-10				local		
1055	700-800	undet	juvenile-adult		x	x	gray	Boat burial	Weapons (swords, shields etc) with silver inlay, soapstone spindle whorl, glass beads, dogs in chains, horse, sheep, pig
1056	22 +/- 55 BC	undet	13-15		x		local	SN	
1057	800-1050	M	senile				local		
1059	847 +/-65 AD	M	19		x		gray	SN	

1060		undet	11-12				non local		
1061		M	mature				local		
1062	88 +/-57 AD	F	adult-mature				local		
1063	576 +/-130 BC	M	65-70				local		
1064	858 +/- 68 AD	M	mature				local		
1065	800-1050	F	mature-senile				non local		
1066	800-1050	undet	12-15			x	local		knife comb, arrowhead?, spearhead just outside of coffin
1067	800-1050	M	72+				non local		
1068	800-1050	M	30-40			x	non local		knife, flints, gamepiece, silver, bronze, stones, iron tool, slate whetstone, fittings
1069	75 +/-69 BC	undet	13-15		x		gray	wetland	
1070	see 1069	M	17-18		x		local	wetland	
1071	716 +/-44 AD	amb.	mature-senile				local		
1072	119 +/-56 AD	M	51+-14	x		x	local		knife, spearhead, shield boss, resin; looted?
1073	829 +/-57 AD	M	55-65				non local		Weapons (swords, shields etc) with silver inlay, soapstone spindle whorl, glass beads, dogs in chains, horse, sheep, pig
1074	30+/-48 AD	F	ca 30				local		7 arrowheads in fill
1075	853 +/- 67 AD	M	mature				local		
1076	150/160-260/270; V:1	F	50-60				non local		
1077	700-800	undet	juvenile-adult		x	x	non local	Boat burial	see 1055
1078	800-1050	undet	12-15			x	gray		
1079	40-150/160 AD;IV:2	M	adult-mature			x	local		lancehead, shield boss, spur, animals (dog, cattle, sheep/goat, swine)
1080	40-150/160 AD;IV:2	F	adult-mature				local		
1081	0-40 AD; IV:1	undet	adult-mature			x	gray		bear claws, tools, ceramics
1082	67 +/-48 AD	M	45-55				local		
1083	0-400	M	60+				non local		
1084	1122 +/-63	F	60+				non local		
1086	799 +/-68 AD	F	38				non local		
1087	36 +/-49 AD	F	17-21				non local		
1088	858 +/-68 AD	M	45-60				local		
1089	125 +/-57 AD	M	18-21			x	local		shield boss, sword, spearhead
1090	40-150/160 AD;IV:2	M	adult-mature				non local		
1091	0-40 AD; IV:1	M	adult-mature	x		x	gray		knife, lance head, ceramics
1092	40-150/160 AD;IV:2	M	mature-senile	x		x	local		sword, clasp, ceramic, resin; multiple burials
1093	40-150/160 AD;IV:2	M	adult			x	local		sword, ceramics, fittings/ornament
1094	125 +/-62 AD	F	60+	x	x		local	prone	
1095	305 +/-69 BC	M	adult				local		
1096	25 +/-47 AD	M	adult-mature				local		
1097	1053 +/-60 AD	F	mature			x	non local		ornament, lance and spear heads
1098	160-140 BC*	M	mature-senile		x		local	WE Early IA	
1099	200-400	F	18-19				local		
1100	61 +/-54 AD	M	16-18				non local		
1101	800-1050	M	ca 23				non local		
1102	0-400	undet	7-8				local		
1103	70-150/160	F	senile			x	local		knife, spearhead, glass pearl; multiple burials
1104	0-150/160	M	adult-mature			x	local		knife, spearhead, glass bead
1105	853 +/-71 AD	M	adult				non local		
1106	91 +/-61 BC	M	mature-senile				non local		
1107	200-400	M	25-30	x		x	local		lance head, spearhead, shield boss and handle, silver fittings, knife, pig and bird bones; multiple burials
1108	460-490	M	17-19	x	x		local	house	
1109	460-490	M	19-22	x	x		local	House, prone	
1110	629 +-18 AD	M	adult-mature		x		non local	Wetland	
1111	112 +- 45 BC	F	adult-mature	x	x		non local	Wetland	
1112	134 +/-49 BC	amb.	juvenile-adult		x		local	Wetland	
1113	729 +/-36 AD	undet	14-16		x		gray	Wetland	
1114	308 +-65 BC	F	adult-senile		x		local	Wetland	

Appendix 2

Id	**Trauma description**
1028	multiple SFT perimortem, R parietal
1031	single AM BFT, Frontal R
1041	R parietal perimortem BFT, rektangular top of the head
1072	single SFT L parietal perimortem, single BFT R parietal/frontal
1091	loss of all anterior teeth in maxilla
1092	multiple SFT BFT most of skull
1094	multiple SFT BTF most of skull perimortem
1107	Multiple BFT. Also SFT? Most of skull
1108	multiple SFT L Parietal perimortem, R scapula multiple SFT perimortem
1109	SFT perimortem R rib
1111	single PM SFT R parietal, single BFT AM parietal

Figure 1: Details, group 1

Type	Total	Early Iron Age	Late Iron Age
pit	27	14	13
cist	67	52	15
coffin	4		4
ship	2		2
wetland	7	5	2
other	2		2
total	*109*	*71*	*38*

Figure 2: Overview of variation in burial types

Orientation	**Total**	**Early Iron Age**	**Late Iron Age**
NS	79	60	19
SN	3	1	2
WE	12	1	10
NO/other	15	8	7

Figure 3: Overview of variation in burial orientation (i.e. which direction the head the was in the grave, SN =head in south and feet in the north)

	total	**part**	description	Before AD 200	After AD 200
Local (native)	55		both Sr and O local	38	16
Non local (non native)	41	18	just Sr non local	15 (28%)	23(58%)
		9	non local Sr and O		
		11	non local O (Sr local)		
		3	non local O gray Sr		
Undetermined provenance	13	13	Grey Sr, O local or not available	7	6
Females	32	29	Non native	6	10
			Native	11	2
Males	45	40	Non native	7	12
			Native	11	10

Figure 4: The division of the human samples in local, non local or undermined from both Sr and O values. Note: 3 of the samples do not have O values (2 non local just Sr and 1 Sr local). For the sexed individuals a few could not be assigned to provenance (Undetermined), in total 3 for the period before AD 200 and 5 for the period after AD 200.

THE APPENDIX

Legend

L=left side
R=right side
NS= north south
WE= west east
SN=south north
Burial orientation: NS= head to the north

Local/-non-local: the definition used in Paper IV, including both $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ (VPDB)

Chronology

	Period	Subperiod	Chronology
Early Iron Age (E IA)	Pre Roman Iron Age (PR IA)		500 BC-AD 0
	Roman Iron Age (R IA)	Early Roman Period	AD 0-200
		Late Roman Period	AD 200-400
Late Iron Age			
(L IA)	Migration Period		AD 400-550
	Vendel Period		AD 600-800
	Viking Age		AD 800- 1050

Specific pathologies

For all: 0= not present, 1= present, 9= unobservable. OP = ostephyte. PO =porosity. EB = eburnation.

Cribra orbitalia: score 1 indicates porosity in at least one orbital roof, both healed or unhealed.

Porotic hyperstosis: score 1 indicates porosity present to any extent in skull vault (most likely parietal). Score 0 only if 1 parietal is present and unaffected.

Non-specific periostitis: score 1 indicates periostits is classified as non-specific, ie not secondary to trauma or for ex TBC or syphilis.

Trauma (any type of trauma): scored 0 or 1 if more than one bone is present from skull, upper and lower extremity respectively.

Enthesopathy: score 1 indicates enthesopathy present. Scored 9 if less than two sites available for evaluation.

OD, ostechondritis dissecans: scored 9 if less than 50% of large joints present.

OA, osteoarthritis: scored 1 if eburnation is present in at least one joint surface. OA is only scored if primary, not if secondary to trauma or other pathology. Scored 9 if less than 50% of large joints present.

Schmorls nodes: scored 0 if more than 12 vertebrae are present (and unaffected). Score 1 if more than 1 vertebrae affected.

LEH, linear enamel hypoplasia: Scored 0 if more than 1 tooth present and without LEH. Scored 1 if at least 1 tooth is affected.

Pathology: numbering ("1: ", "2: "etc) indicates the different pathologies, if more than one, for an individual.

Stature and measurements: Stature estimations are based on Sjøvold (1990). Segment measurements and calculations were made using Steele & McKern (1969).

Measurements were only performed on bones without disfiguring pathology (likely to impact length) and with satisfactory preservation of the measurement points.

Sjøvold, T. (1990). Estimation of stature from long bones utilizing the line of organic correlation. Human evolution, 5(5), 431-447.

Steele, D. G., & McKern, T. W. (1969). A method for assessment of maximum long bone length and living stature from fragmentary long bones. American Journal of Physical Anthropology, 31(2), 215-227.

ID	*1002*
Parish	Gårdby
SHM (grave field)	9754
Grave number	25
Year of excavation	1894?
Excavator/-s	Baerehndz
MNI	2
Body position	Unavailable
Gravetype	cist
Orientation	NS
Sex	male
Age group	young-mature
Age	35-50?
Measurement details	Femur 1; L;1; 134.7 mm; est. Total 469.1 mm; stature estimation from calculated total measurement 172.99 ±4.52 cm
Stature (Sjovold 1990)	
local/non-local?	gray
Sampled tooth (FDI)	34
$^{87}Sr/^{86}Sr$	0.7107
$\delta^{18}O_{carb}$ VPDB. ‰	-4.7
$\delta^{13}C$ (VPDB) ‰ apatite	-14.4
$\delta^{13}C$ (VPDB) ‰ collagen	-20.2
$\delta^{15}N$ (AIR) ‰ collagen	12.7
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Early Roman Period
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	0
Trauma	0
Enthesopathy	0
OD	1
OA	0
Schmorls nodes	1
LEH	0
Pathology	

ID	*1003*
Parish	Glömminge
SHM (grave field)	31890
Grave number	8
Year of excavation	1969-70
Excavator/-s	Hagberg
MNI	2
Body position	mixed
Gravetype	cist
Orientation	NS
Sex	male
Age group	young-mature
Age	35-45
Measurement details	Tibia 1; L ; Segment 1; 31.3 mm: est. total 374. 1 mm; stature estimation from calculated total measurement 170.42 ± 4.11 cm
Stature (Sjovold 1990)	
local/non-local?	non-local
Sampled tooth (FDI)	34
^{87}Sr/^{86} Sr	0.7127
δ^{18}O$_{carb}$ VPDB. ‰	-4.1
δ^{13}C (VPDB) ‰ apatite	-13.1
δ^{13}C (VPDB) ‰ collagen	-19.6
δ^{15}N (AIR) ‰ collagen	12.4
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Roman Iron Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Roman Iron Age
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	1
Trauma	0
Enthesopathy	0
OD	0
OA	0
Schmorls nodes	9
LEH	1
Pathology	

ID	*1004*
Parish	Glömminge
SHM (grave field)	31890
Grave number	11
Year of excavation	
Excavator/-s	
MNI	2
Body position	mixed
Gravetype	cist
Orientation	NS
Sex	undetermined
Age group	juvenile-young
Age	
Measurement details	Femur 1; L;1; 107.8 mm; est. Total 452.9 mm; stature estimation from calculated total measurement 168. 62 ± 4.52 cm
Stature (Sjovold 1990)	
local/non-local?	non-local
Sampled tooth (FDI)	34
^{87}Sr/^{86} Sr	0.7117
$\delta^{18}O_{carb}$ VPDB. ‰	-4.0
δ^{13}C (VPDB) ‰ apatite	-15.0
δ^{13}C (VPDB) ‰ collagen	-19.7
δ^{15}N (AIR) ‰ collagen	13.4
Sampled bone (δ^{13}C δ^{15}N)	tibia
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	1895 +-100
^{14}C calibrated	112 +-116 AD
Date, typology as given in ÖJG	Early Roman Period IV:1
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	9
Trauma	0
Enthesopathy	0
OD	9
OA	9
Schmorls nodes	9
LEH	1
Pathology	

ID	*1005*
Parish	Glömminge
SHM (grave field)	31890
Grave number	18
Year of excavation	
Excavator/-s	
MNI	3
Body position	supine
Gravetype	cist
Orientation	NS
Sex	male
Age group	old
Age	60+
Measurement details	Femur 1; R; 490 mm (Femur 1; L; 491 mm)
Stature (Sjovold 1990)	178.65 ±4.52 cm
local/non-local?	gray
Sampled tooth (FDI)	35
^{87}Sr/^{86} Sr	0.7184
δ^{18}O$_{carb}$ VPDB. ‰	-5.2
δ^{13}C (VPDB) ‰ apatite	-13.9
δ^{13}C (VPDB) ‰ collagen	-20.3
δ^{15}N (AIR) ‰ collagen	8.0
Sampled bone (δ^{13}C δ^{15}N)	humerus
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Early Roman Period IV:2
Cribra orbitalia	0
Porotic hyperstosis	9
Non-specific Periostitis	0
Trauma	0
Enthesopathy	0
OD	0
OA	1
Schmorls nodes	9
LEH	0
Pathology	

ID	*1006*
Parish	Gräsgård
SHM (grave field)	25570
Grave number	2
Year of excavation	1956
Excavator/-s	Rosell
MNI	2
Body position	unobservable
Gravetype	cist
Orientation	NS
Sex	NA
Age group	young-old
Age	
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	non-local
Sampled tooth (FDI)	25
$^{87}Sr/^{86}Sr$	0.7089
$\delta^{18}O_{carb}$ VPDB. ‰	-5.7
$\delta^{13}C$ (VPDB) ‰ apatite	-15.1
$\delta^{13}C$ (VPDB) ‰ collagen	-19.7
$\delta^{15}N$ (AIR) ‰ collagen	12.8
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	cranium
Date, typology and 14C	Pre Roman Iron Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Pre Roman Iron Age
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	9
Trauma	9
Enthesopathy	9
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	

ID	*1007*
Parish	Smedby
SHM (grave field)	23981
Grave number	35c
Year of excavation	1948
Excavator/-s	Stenström
MNI	2
Body position	side
Gravetype	pit
Orientation	NS
Sex	male
Age group	old
Age	73+
Measurement details	Femur 1; L ; Segment 1; 79.4 mm; est. Total 461.6 mm; stature estimation from calculated total measurement 170. 96 ±4.52 cm
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	34
^{87}Sr/^{86} Sr	0.7123
$\delta^{18}O_{carb}$ VPDB. ‰	-5.8
δ^{13}C (VPDB) ‰ apatite	-15.2
δ^{13}C (VPDB) ‰ collagen	-19.8
δ^{15}N (AIR) ‰ collagen	14.0
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Pre Roman Iron Age
^{14}C conventional age, BP	2065 +/-45
^{14}C calibrated	91 +/-61 BC
Date, typology as given in ÖJG	Iron Age?
Cribra orbitalia	1
Porotic hyperstosis	1
Non-specific Periostitis	0
Trauma	0
Enthesopathy	1
OD	0
OA	0
Schmorls nodes	1
LEH	0
Pathology	Epiphysiolysis (SCFE) with slipped capital epiphysis. Eburnation likely secondarly.

ID	*1008*
Parish	Smedby
SHM (grave field)	24542
Grave number	I undre
Year of excavation	1951
Excavator/-s	Rosell, Hvarfner
MNI	2
Body position	Unavailable
Gravetype	cist
Orientation	NS
Sex	female
Age group	young-mature
Age	38 +-10
Measurement details	Femur 1; L; 371 mm
Stature (Sjovold 1990)	146.4 ± 4.52 cm
local/non-local?	non-local
Sampled tooth (FDI)	24
^{87}Sr/^{86}Sr	0.7131
δ^{18}O$_{carb}$ VPDB. ‰	-3.5
δ^{13}C (VPDB) ‰ apatite	-12.8
δ^{13}C (VPDB) ‰ collagen	-19.1
δ^{15}N (AIR) ‰ collagen	11.4
Sampled bone (δ^{13}C δ^{15}N)	femur
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	1180 +/-45
^{14}C calibrated	847 +-65 AD
Date, typology as given in ÖJG	Viking Age?
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	1
Trauma	0
Enthesopathy	1
OD	0
OA	0
Schmorls nodes	0
LEH	0
Pathology	Costae 3-12; diaphysis; Callus formation potruding superiorly or inferiorly from rib body. Very slight depression on anterior surface-possibly well healed fracture

ID	*1009*
Parish	Smedby
SHM (grave field)	23494
Grave number	21
Year of excavation	1945
Excavator/-s	Lagerholm
MNI	1
Body position	Unavailable
Gravetype	cist
Orientation	SN
Sex	male
Age group	old
Age	
Measurement details	Femur;Segment 1; R; 95,7 mm; est. Total 461.62 mm; stature estimation from calculated total measurement 170.96 ± 4.52 cm
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	34
^{87}Sr/^{86} Sr	0.7149
$\delta^{18}O_{carb}$ VPDB. ‰	-5.8
δ^{13}C (VPDB) ‰ apatite	-13.0
δ^{13}C (VPDB) ‰ collagen	-19.5
δ^{15}N (AIR) ‰ collagen	12.1
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Roman Iron Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Late Roman Period
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	1
Trauma	0
Enthesopathy	9
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	

ID	*1010*
Parish	Gräsgård
SHM (grave field)	25570
Grave number	2
Year of excavation	1956
Excavator/-s	CO Rosell
MNI	2
Body position	unobservable
Gravetype	cist
Orientation	NS
Sex	NA
Age group	child
Age	8
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	14
^{87}Sr/^{86}Sr	0.7120
δ^{18}O$_{carb}$ VPDB. ‰	-5.1
δ^{13}C (VPDB) ‰ apatite	-13.6
δ^{13}C (VPDB) ‰ collagen	-19.6
δ^{15}N (AIR) ‰ collagen	12.3
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Pre Roman Iron Age
^{14}C conventional age, BP	2155 +/-45
^{14}C calibrated	232 +/-98 BC
Date, typology as given in ÖJG	Iron Age?
Cribra orbitalia	1
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	0
Enthesopathy	9
OD	9
OA	9
Schmorls nodes	9
LEH	1
Pathology	

ID	*1011*
Parish	Runsten
SHM (grave field)	23280
Grave number	
Year of excavation	1944
Excavator/-s	N Lagerholm
MNI	2
Body position	supine
Gravetype	cist
Orientation	NS
Sex	male
Age group	mature
Age	40-45
Measurement details	Femur 1; L; 455 mm
Stature (Sjovold 1990)	169.1 ± 4.52 cm
local/non-local?	non-local
Sampled tooth (FDI)	14
$^{87}Sr/^{86}Sr$	0.7130
$\delta^{18}O_{carb}$ VPDB. ‰	-7.5
$\delta^{13}C$ (VPDB) ‰ apatite	-13.2
$\delta^{13}C$ (VPDB) ‰ collagen	-18.9
$\delta^{15}N$ (AIR) ‰ collagen	10.4
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Late Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Late Roman Period
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	1
Enthesopathy	0
OD	0
OA	0
Schmorls nodes	1
LEH	0
Pathology	1:Coccyx. Fusion of segment 3 and 4 at a 90 degree angle. Segment 4 torsion to the R. Probable fracture resulting in misaligned fusion. 2:Fibula, R; diaphysis; distal. No signs of crushing or fractures. No apparent callus formation. Depression with bone formation, possibly penetrating into the medullar cavity.

ID	*1012*
Parish	Runsten
SHM (grave field)	28549
Grave number	
Year of excavation	1966
Excavator/-s	I Sjögren
MNI	1
Body position	supine
Gravetype	pit
Orientation	WE
Sex	male
Age group	young-mature
Age	35-45
Measurement details	Femur 1; L; 480 mm
Stature (Sjovold 1990)	175.94 ± 4.52 cm
local/non-local?	non-local
Sampled tooth (FDI)	44
^{87}Sr/^{86}Sr	0.7318
$\delta^{18}O_{carb}$ VPDB. ‰	-7.1
δ^{13}C (VPDB) ‰ apatite	-16.1
δ^{13}C (VPDB) ‰ collagen	-19.9
δ^{15}N (AIR) ‰ collagen	12.6
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Viking Age
Cribra orbitalia	0
Porotic hyperstosis	9
Non-specific Periostitis	0
Trauma	1
Enthesopathy	0
OD	9
OA	0
Schmorls nodes	9
LEH	0
Pathology	Clavicle; possible fracture, partial, with intact alignment . Minor inferior extension. Minimal porosity in smooth sclerotic surface.

ID	*1013*
Parish	Smedby
SHM (grave field)	27365
Grave number	35
Year of excavation	1963
Excavator/-s	C Menschke
MNI	2
Body position	supine
Gravetype	cist
Orientation	NS
Sex	male?
Age group	mature
Age	44-50
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	non-local
Sampled tooth (FDI)	44
^{87}Sr/^{86} Sr	0.7113
$\delta^{18}O_{carb}$ VPDB. ‰	-3.0
δ^{13}C (VPDB) ‰ apatite	-15.5
δ^{13}C (VPDB) ‰ collagen	-19.4
δ^{15}N (AIR) ‰ collagen	12.2
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Viking Age
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	9
Trauma	0
Enthesopathy	9
OD	9
OA	0
Schmorls nodes	0
LEH	0
Pathology	

ID	*1014*
Parish	Gärdslösa
SHM (grave field)	28364
Grave number	108 F231 III
Year of excavation	
Excavator/-s	
MNI	4
Body position	Unavailable
Gravetype	cist
Orientation	NS
Sex	male
Age group	mature
Age	45-50
Measurement details	Femur 1; L ; 499 mm
Stature (Sjovold 1990)	181.1 ± 4.52 cm
local/non-local?	local
Sampled tooth (FDI)	44
$^{87}Sr/^{86}Sr$	0.7135
$\delta^{18}O_{carb}$ VPDB. ‰	-4.7
$\delta^{13}C$ (VPDB) ‰ apatite	-13.9
$\delta^{13}C$ (VPDB) ‰ collagen	-19.8
$\delta^{15}N$ (AIR) ‰ collagen	12.7
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Early Roman Period
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	0
Enthesopathy	0
OD	0
OA	0
Schmorls nodes	1
LEH	0
Pathology	

ID	*1014*
Parish	Gärdslösa
SHM (grave field)	28364
Grave number	108 F231 III
Year of excavation	
Excavator/-s	
MNI	4
Body position	Unavailable
Gravetype	cist
Orientation	NS
Sex	male
Age group	mature
Age	45-50
Measurement details	Femur 1; L; 499 mm
Stature (Sjovold 1990)	181.1 ± 4.52 cm
local/non-local?	local
Sampled tooth (FDI)	44
^{87}Sr/^{86} Sr	0.7135
$\delta^{18}O_{carb}$ VPDB. ‰	-4.7
δ^{13}C (VPDB) ‰ apatite	-13.9
δ^{13}C (VPDB) ‰ collagen	-19.8
δ^{15}N (AIR) ‰ collagen	12.7
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Early Roman Period
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	0
Enthesopathy	0
OD	0
OA	0
Schmorls nodes	1
LEH	0
Pathology	

ID	*1015*
Parish	Hulterstad
SHM (grave field)	25153
Grave number	
Year of excavation	1954
Excavator/-s	Pettersson
MNI	3
Body position	mixed
Gravetype	cist
Orientation	NS
Sex	female
Age group	young
Age	20-30
Measurement details	Femur 1; L ; 427 mm
Stature (Sjovold 1990)	161.58 ±4.52 cm
local/non-local?	local
Sampled tooth (FDI)	44
$^{87}Sr/^{86}Sr$	0.7110
$\delta^{18}O_{carb}$ VPDB. ‰	-6.2
$\delta^{13}C$ (VPDB) ‰ apatite	-13.4
$\delta^{13}C$ (VPDB) ‰ collagen	-19.6
$\delta^{15}N$ (AIR) ‰ collagen	15.2
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	1885 +/-45
^{14}C calibrated	130+/-57 AD
Date, typology as given in ÖJG	Early Roman Period
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	1
Trauma	0
Enthesopathy	1
OD	0
OA	0
Schmorls nodes	0
LEH	0
Pathology	fusion failure of a segment of sternum

ID	*1016*
Parish	Hulterstad
SHM (grave field)	25096
Grave number	
Year of excavation	1954
Excavator/-s	CO Rosell
MNI	1
Body position	mixed
Gravetype	pit
Orientation	WE
Sex	female?
Age group	old
Age	70
Measurement details	Femur 1; L ; 441 mm
Stature (Sjovold 1990)	165.37 ± 4.52 cm
local/non-local?	non-local
Sampled tooth (FDI)	34
^{87}Sr/^{86}Sr	0.7198
$\delta^{18}O_{carb}$ VPDB. ‰	-6.8
δ^{13}C (VPDB) ‰ apatite	-15.1
δ^{13}C (VPDB) ‰ collagen	-19.8
δ^{15}N (AIR) ‰ collagen	13.0
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Viking Age
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	0
Enthesopathy	1
OD	0
OA	0
Schmorls nodes	1
LEH	0
Pathology	

ID	*1019*
Parish	Glömminge
SHM (grave field)	31890
Grave number	25
Year of excavation	1987
Excavator/-s	
MNI	1
Body position	mixed
Gravetype	cist
Orientation	NS
Sex	NA
Age group	young
Age	
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	24
^{87}Sr/^{86} Sr	0.7119
δ^{18}O$_{carb}$ VPDB. ‰	-5.2
δ^{13}C (VPDB) ‰ apatite	-14.4
δ^{13}C (VPDB) ‰ collagen	-19.9
δ^{15}N (AIR) ‰ collagen	13.6
Sampled bone (δ^{13}C δ^{15}N)	humerus
Date, typology and 14C	Roman Iron Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Roman Iron Age (IV:2/V:I)
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	9
Trauma	0
Enthesopathy	0
OD	9
OA	9
Schmorls nodes	1
LEH	0
Pathology	

ID	*1020*
Parish	Mörbylånga
SHM (grave field)	1785/67 Bårby
Grave number	6
Year of excavation	1966-67
Excavator/-s	ES Königsson, B Falk-Gehlin
MNI	1
Body position	mixed
Gravetype	cist
Orientation	NS
Sex	female?
Age group	mature
Age	
Measurement details	Femur 1; L ; 478 mm
Stature (Sjovold 1990)	175.4 ± 4.52 cm
local/non-local?	local
Sampled tooth (FDI)	34
^{87}Sr/^{86} Sr	0.7159
δ^{18}O$_{carb}$ VPDB. ‰	-5.6
δ^{13}C (VPDB) ‰ apatite	-13.0
δ^{13}C (VPDB) ‰ collagen	-19.7
δ^{15}N (AIR) ‰ collagen	15.9
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Roman Iron Age per IV:2
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	9
Trauma	0
Enthesopathy	0
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	

ID	*1021*
Parish	Sandby
SHM (grave field)	26454
Grave number	3
Year of excavation	1959
Excavator/-s	Petersson
MNI	2
Body position	supine
Gravetype	cist
Orientation	NS
Sex	female?
Age group	young/mature
Age	
Measurement details	Femur 1; L ; Segment 1; 74.14 mm; est. Total 449.43 mm; stature estimation from calculated total measurement 167.65 ± 4.52 cm cm
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	34
^{87}Sr/^{86} Sr	0.7118
δ^{18}O$_{carb}$ VPDB. ‰	-5.4
δ^{13}C (VPDB) ‰ apatite	-14.1
δ^{13}C (VPDB) ‰ collagen	-20.3
δ^{15}N (AIR) ‰ collagen	13.7
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Viking Age
Cribra orbitalia	1
Porotic hyperstosis	9
Non-specific Periostitis	9
Trauma	0
Enthesopathy	1
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	

ID	*1022*
Parish	Sandby
SHM (grave field)	26454
Grave number	2?
Year of excavation	1959
Excavator/-s	KG Petersson
MNI	1
Body position	supine
Gravetype	pit
Orientation	SN
Sex	undetermined
Age group	young/mature
Age	
Measurement details	Femur 1; R ; Segment 1; 82.5 mm; est. Total 468.75 mm; stature estimation from calculated total measurement 172.89 ±4.52 cm
Stature (Sjovold 1990)	
local/non-local?	non-local
Sampled tooth (FDI)	35
^{87}Sr/^{86} Sr	0.7349
δ^{18}O$_{carb}$ VPDB. ‰	
δ^{13}C (VPDB) ‰ apatite	NA
δ^{13}C (VPDB) ‰ collagen	-20.0
δ^{15}N (AIR) ‰ collagen	12.1
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Viking Age
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	9
Trauma	9
Enthesopathy	9
OD	9
OA	9
Schmorls nodes	1
LEH	0
Pathology	

ID	*1023*
Parish	Sandby
SHM (grave field)	26454
Grave number	1?
Year of excavation	1959
Excavator/-s	KG Petersson
MNI	1
Body position	Unavailable
Gravetype	cist
Orientation	NS
Sex	undetermined
Age group	young-old
Age	
Measurement details	Humerus 1; L ; Segment 1; 39.6 mm; est. Total 332. 92 mm; stature estimation from calculated total measurement 172.81 ± 4.94 cm
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	34
^{87}Sr/^{86}Sr	0.7113
δ^{18}O$_{carb}$ VPDB. ‰	-5.3
δ^{13}C (VPDB) ‰ apatite	-14.5
δ^{13}C (VPDB) ‰ collagen	-20.0
δ^{15}N (AIR) ‰ collagen	12.3
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Viking Age
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	1
Trauma	0
Enthesopathy	1
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	

ID	*1024*
Parish	Smedby
SHM (grave field)	25129
Grave number	
Year of excavation	1954
Excavator/-s	KG Petterson
MNI	2
Body position	unobservable
Gravetype	pit
Orientation	WE
Sex	female
Age group	juvenile
Age	16
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	non-local
Sampled tooth (FDI)	25
^{87}Sr/^{86} Sr	0.7296
δ^{18}O$_{carb}$ VPDB. ‰	-4.3
δ^{13}C (VPDB) ‰ apatite	-14.6
δ^{13}C (VPDB) ‰ collagen	-19.3
δ^{15}N (AIR) ‰ collagen	11.1
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	1005 +/-45
^{14}C calibrated	1049+/-58 AD
Date, typology as given in ÖJG	Iron Age?
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	1
Trauma	1
Enthesopathy	0
OD	0
OA	0
Schmorls nodes	1
LEH	1
Pathology	Ulna; diaphysis. Greenstick/incomplete fracture with good alignment. Medial part of diaphysis just below middiaphysis. 40 mm. Distal radius missing.

ID	*1025*
Parish	Smedby
SHM (grave field)	23981
Grave number	35b
Year of excavation	1948
Excavator/-s	Stenström
MNI	2
Body position	unobservable
Gravetype	pit
Orientation	NS
Sex	NA
Age group	child
Age	8?
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	32
$^{87}Sr/^{86}Sr$	0.7133
$\delta^{18}O_{carb}$ VPDB. ‰	-5.6
$\delta^{13}C$ (VPDB) ‰ apatite	-13.3
$\delta^{13}C$ (VPDB) ‰ collagen	-19.6
$\delta^{15}N$ (AIR) ‰ collagen	12.1
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	cranium
Date, typology and 14C	Pre Roman/ Early Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Iron Age?
Cribra orbitalia	0
Porotic hyperstosis	1
Non-specific Periostitis	9
Trauma	0
Enthesopathy	9
OD	9
OA	9
Schmorls nodes	9
LEH	9
Pathology	

ID	*1026*
Parish	Hulterstad
SHM (grave field)	19726
Grave number	1
Year of excavation	1931
Excavator/-s	E Floderius
MNI	1
Body position	unobservable
Gravetype	pit
Orientation	NA
Sex	male
Age group	old
Age	60
Measurement details	Femur 1; L; 419 mm
Stature (Sjovold 1990)	159.4 ± 4.52 cm
local/non-local?	gray
Sampled tooth (FDI)	34
^{87}Sr/^{86}Sr	0.7184
δ^{18}O$_{carb}$ VPDB. ‰	-6.4
δ^{13}C (VPDB) ‰ apatite	-14.8
δ^{13}C (VPDB) ‰ collagen	-19.7
δ^{15}N (AIR) ‰ collagen	13.4
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	1035 +/-45
^{14}C calibrated	986 +/-38 AD
Date, typology as given in ÖJG	Iron Age?
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	0
Enthesopathy	1
OD	1
OA	0
Schmorls nodes	1
LEH	0
Pathology	

ID	*1027*
Parish	Hulterstad
SHM (grave field)	19726
Grave number	13
Year of excavation	1931
Excavator/-s	Floderius
MNI	1
Body position	supine
Gravetype	cist
Orientation	NS
Sex	female
Age group	mature
Age	45-55
Measurement details	Femur 1; L ; 457 mm
Stature (Sjovold 1990)	169.7 ± 4.52 cm
local/non-local?	non-local
Sampled tooth (FDI)	44
^{87}*Sr/*^{86}*Sr*	0.7314
δ^{18}*O*$_{carb}$ *VPDB. ‰*	-6.1
δ^{13}*C (VPDB) ‰ apatite*	-14.5
δ^{13}*C (VPDB) ‰ collagen*	-19.5
δ^{15}*N (AIR) ‰ collagen*	11.1
Sampled bone (δ^{13}*C δ*^{15}*N)*	mandible
Date, typology and 14C	Pre Roman Iron Age
^{14}*C conventional age, BP*	2425+-45
^{14}*C calibrated*	575+-129 BC
Date, typology as given in ÖJG	Roman Iron Age
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	1
Enthesopathy	1
OD	0
OA	0
Schmorls nodes	0
LEH	0
Pathology	Acessory cervical ribs on cervical vertebrae (C7). R smaller than L. The R 1st rib is also smaller than L.

ID	*1028*
Parish	Vickleby
SHM (grave field)	22486
Grave number	
Year of excavation	1939
Excavator/-s	CO Rosell
MNI	1
Body position	supine
Gravetype	cist
Orientation	NS
Sex	male
Age group	mature
Age	
Measurement details	Femur 1; L; 467 mm
Stature (Sjovold 1990)	172.4 ± 4.52 cm
local/non-local?	non-local
Sampled tooth (FDI)	34
^{87}Sr/^{86}Sr	0.7077
δ^{18}O$_{carb}$ VPDB. ‰	-5.1
δ^{13}C (VPDB) ‰ apatite	-13.3
δ^{13}C (VPDB) ‰ collagen	-19.3
δ^{15}N (AIR) ‰ collagen	11.6
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	1140 +/-50 BP
^{14}C calibrated	885 +/- 69 AD
Date, typology as given in ÖJG	Viking Age
Cribra orbitalia	1
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	1
Enthesopathy	1
OD	0
OA	0
Schmorls nodes	9
LEH	0
Pathology	1: Skull (parietal). Perimortem SFT. Extension: from bregma to lateral. A second SFT parallell to coronal suture. Rim very sharp and tilted (anteriorly). Ovate in shape. Possibly more traumas to the skull, fragments missing. 2: Sacrum has an extra (sixth) segment.

ID	*1029*
Parish	Långlöt
SHM (grave field)	18521
Grave number	
Year of excavation	1927
Excavator/-s	M Hofrén
MNI	2
Body position	Unavailable
Gravetype	pit
Orientation	NS
Sex	male
Age group	young
Age	30-35
Measurement details	Femur 1; R ; 519 mm
Stature (Sjovold 1990)	186.5 ±4.52 cm
local/non-local?	local
Sampled tooth (FDI)	34
$^{87}Sr/^{86}Sr$	0.7128
$\delta^{18}O_{carb}$ VPDB. ‰	-5.2
$\delta^{13}C$ (VPDB) ‰ apatite	-15.4
$\delta^{13}C$ (VPDB) ‰ collagen	-20.1
$\delta^{15}N$ (AIR) ‰ collagen	12.1
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Pre Roman Iron Age
^{14}C conventional age, BP	2295 +/-45
^{14}C calibrated	326+/-70 BC
Date, typology as given in ÖJG	Iron Age?
Cribra orbitalia	1
Porotic hyperstosis	0
Non-specific Periostitis	1
Trauma	1
Enthesopathy	1
OD	0
OA	0
Schmorls nodes	1
LEH	0
Pathology	Maxilla. Ante mortem fractured tooth (FDI 27). Circa 1/3 of the crown is chipped off almost all the way down through the CEJ. Calculus in fracture surface and slightly rounded (worn) margins

ID	*1030*
Parish	Södra Möckleby
SHM (grave field)	25657
Grave number	
Year of excavation	1956
Excavator/-s	KG Petterson
MNI	2
Body position	unobservable
Gravetype	cist
Orientation	NS
Sex	male?
Age group	mature/old
Age	
Measurement details	Humerus 1; R ; 373 mm
Stature (Sjovold 1990)	191.33 ± 4.94 cm
local/non-local?	non-local
Sampled tooth (FDI)	25
^{87}Sr/^{86}Sr	0.7330
δ^{18}O$_{carb}$ VPDB. ‰	-5.3
δ^{13}C (VPDB) ‰ apatite	-14.5
δ^{13}C (VPDB) ‰ collagen	-20.5
δ^{15}N (AIR) ‰ collagen	13.1
Sampled bone (δ^{13}C δ^{15}N)	cranium
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Viking Age
Cribra orbitalia	1
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	1
Enthesopathy	1
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	Ulna; diaphysis; distal. Healed but misaligned fracture and displacement of bone to medial/superior in the posterior (longitudinal displacement). Resulting shortening of the bone. Lateral surface looks almost normal.

ID	*1031*
Parish	Gräsgård
SHM (grave field)	27768
Grave number	
Year of excavation	1960
Excavator/-s	KG Pettersson
MNI	2
Body position	supine
Gravetype	cist
Orientation	NS
Sex	male
Age group	juvenile
Age	19-21
Measurement details	Femur 1; L; Segment 1; 98.9 mm; est. Total 504.63 mm; stature estimation from calculated total measurement 182.61 ± 4.52 cm
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	34
^{87}Sr/^{86} Sr	0.7118
$\delta^{18}O_{carb}$ VPDB. ‰	-5.9
δ^{13}C (VPDB) ‰ apatite	-13.8
δ^{13}C (VPDB) ‰ collagen	-20.1
δ^{15}N (AIR) ‰ collagen	14.2
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Late Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Late Roman period (C2)
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	1
Enthesopathy	1
OD	0
OA	0
Schmorls nodes	1
LEH	1
Pathology	Frontal; external; lateral. Deep depression in the outer table, not penetrating into the inner table. Lense shape. Smooth but slightly organic/irregular shape (possibly from picking the wound clean from bone splinters?). Very even floor of lesion. BFT or possibly grazing SFT.

ID	*1032*
Parish	Gärdslösa
SHM (grave field)	27702
Grave number	39
Year of excavation	1964
Excavator/-s	Ulf Erik Hagberg
MNI	2
Body position	Unavailable
Gravetype	cist
Orientation	NS
Sex	female?
Age group	mature
Age	
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	45
^{87}Sr/^{86}Sr	0.7113
$\delta^{18}O_{carb}$ VPDB. ‰	-6.0
δ^{13}C (VPDB) ‰ apatite	-14.4
δ^{13}C (VPDB) ‰ collagen	-20.1
δ^{15}N (AIR) ‰ collagen	13.1
Sampled bone (δ^{13}C δ^{15}N)	humerus
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Early Roman period (IV:2)
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	9
Trauma	0
Enthesopathy	0
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	

ID	*1033*
Parish	Gärdslösa
SHM (grave field)	27702
Grave number	2
Year of excavation	1964
Excavator/-s	Ulf Erik Hagberg
MNI	5
Body position	Unavailable
Gravetype	cist
Orientation	NS
Sex	male?
Age group	young/mature
Age	
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	non-local
Sampled tooth (FDI)	44
^{87}Sr/^{86}Sr	0.7296
δ^{18}O$_{carb}$ VPDB. ‰	-6.4
δ^{13}C (VPDB) ‰ apatite	-14.3
δ^{13}C (VPDB) ‰ collagen	-20.0
δ^{15}N (AIR) ‰ collagen	11.0
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Early Roman period (IV:2)
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	9
Trauma	9
Enthesopathy	9
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	

ID	*1034*
Parish	Stenåsa
SHM (grave field)	25130
Grave number	-
Year of excavation	1954
Excavator/-s	KG Peterson
MNI	1
Body position	Unavailable
Gravetype	cist
Orientation	NS
Sex	male
Age group	young-mature
Age	30-40
Measurement details	Femur 1; L ; 454 mm (Femur 1; R ; 455 mm)
Stature (Sjovold 1990)	168.9 ± 4.52 cm
local/non-local?	local
Sampled tooth (FDI)	44
^{87}Sr/^{86} Sr	0.7133
$\delta^{18}O_{carb}$ VPDB. ‰	-6.1
δ^{13}C (VPDB) ‰ apatite	-13.9
δ^{13}C (VPDB) ‰ collagen	-19.7
δ^{15}N (AIR) ‰ collagen	13.2
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	1990 +/-45
^{14}C calibrated	3 AD +/-46
Date, typology as given in ÖJG	Early Iron Age
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	1
Trauma	1
Enthesopathy	0
OD	1
OA	0
Schmorls nodes	0
LEH	0
Pathology	Clavicle, R. Remodeling/angulation of diaphysis fractured inferiorly and overlapping. Modest callus formation. Relatively well aligned. Minor pores in fracture site. Diaphysis thicker than in L.

ID	*1035*
Parish	Kastlösa
SHM (grave field)	22348
Grave number	-
Year of excavation	1939
Excavator/-s	JE Anderbjörk
MNI	1
Body position	supine
Gravetype	cist
Orientation	NS
Sex	female
Age group	young
Age	19-27
Measurement details	Femur 1; L ; 410 mm (Femur 1; R ; 405 mm)
Stature (Sjovold 1990)	157. 0 ± 4.52 cm
local/non-local?	gray
Sampled tooth (FDI)	44
^{87}Sr/^{86} Sr	0.7184
$\delta^{18}O_{carb}$ VPDB. ‰	-6.0
δ^{13}C (VPDB) ‰ apatite	-13.9
δ^{13}C (VPDB) ‰ collagen	-19.6
δ^{15}N (AIR) ‰ collagen	13.2
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Early Roman Period
Cribra orbitalia	1
Porotic hyperstosis	0
Non-specific Periostitis	1
Trauma	0
Enthesopathy	0
OD	0
OA	1
Schmorls nodes	9
LEH	1
Pathology	1: OA (EB PO OP) in joints between Mt II and III and tarsals in L. Other available joints unaltered/healthy. Secondary to localized trauma? 2:Sacrum, spina bifida occulta).

ID	*1036*
Parish	Smedby
SHM (grave field)	23267
Grave number	1
Year of excavation	1944
Excavator/-s	EB Lundberg
MNI	2
Body position	supine
Gravetype	cist
Orientation	NS
Sex	female?
Age group	young
Age	20-30
Measurement details	Femur 1; R ; 449 mm
Stature (Sjovold 1990)	167.5 ± 4.52 cm
local/non-local?	non-local
Sampled tooth (FDI)	44
^{87}*Sr/*^{86} *Sr*	0.7314
$\delta^{18}O_{carb}$ *VPDB. ‰*	-6.6
δ^{13}*C (VPDB) ‰ apatite*	-12.5
δ^{13}*C (VPDB) ‰ collagen*	-19.2
δ^{15}*N (AIR) ‰ collagen*	13.9
Sampled bone (δ^{13}*C* δ^{15}*N)*	mandible
Date, typology and 14C	Early Roman Period
^{14}*C conventional age, BP*	1905 +/-45
^{14}*C calibrated*	103 +/-54 AD
Date, typology as given in ÖJG	Roman Iron Age
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	0
Enthesopathy	1
OD	1
OA	0
Schmorls nodes	1
LEH	0
Pathology	

ID	*1037*
Parish	Gärdslösa
SHM (grave field)	27702
Grave number	1
Year of excavation	1964
Excavator/-s	Ulf Erik Hagberg
MNI	5
Body position	Unavailable
Gravetype	cist
Orientation	NS
Sex	male?
Age group	juvenile
Age	15-17
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	non-local
Sampled tooth (FDI)	44
^{87}Sr/^{86}Sr	0.7077
$\delta^{18}O_{carb}$ VPDB. ‰	
δ^{13}C (VPDB) ‰ apatite	NA
δ^{13}C (VPDB) ‰ collagen	-19.8
δ^{15}N (AIR) ‰ collagen	14.6
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Early Roman Period
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	0
Trauma	0
Enthesopathy	0
OD	0
OA	0
Schmorls nodes	9
LEH	0
Pathology	Spondylolysis L5; L5, bilateral.

ID	*1038*
Parish	Gärdslösa
SHM (grave field)	28364
Grave number	6
Year of excavation	1964-66
Excavator/-s	Ulf Erik Hagberg
MNI	1
Body position	Unavailable
Gravetype	cist
Orientation	NS
Sex	female
Age group	mature
Age	ca 40?
Measurement details	Femur 1; L;1; 236 mm; est. Total 426.2 mm; stature estimation from calculated total measurement 161. 36 ± 4.52 cm
Stature (Sjovold 1990)	
local/non-local?	non-local
Sampled tooth (FDI)	45
^{87}Sr/^{86} Sr	0.7358
δ^{18}O$_{carb}$ VPDB. ‰	-5.3
δ^{13}C (VPDB) ‰ apatite	-13.9
δ^{13}C (VPDB) ‰ collagen	-19.9
δ^{15}N (AIR) ‰ collagen	13.2
Sampled bone (δ^{13}C δ^{15}N)	humerus
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Early Roman Period
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	9
Trauma	0
Enthesopathy	1
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	

ID	*1039*
Parish	Gärdslösa
SHM (grave field)	27702
Grave number	36
Year of excavation	1964
Excavator/-s	Ulf Erik Hagberg
MNI	2
Body position	Unavailable
Gravetype	cist
Orientation	NS
Sex	female?
Age group	young
Age	
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	34
^{87}Sr/^{86}Sr	0.7128
δ^{18}O$_{carb}$ VPDB. ‰	-5.4
δ^{13}C (VPDB) ‰ apatite	-14.9
δ^{13}C (VPDB) ‰ collagen	-19.9
δ^{15}N (AIR) ‰ collagen	15.2
Sampled bone (δ^{13}C δ^{15}N)	cranium
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Early Roman Period (IV:1)
Cribra orbitalia	1
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	0
Enthesopathy	9
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	

ID	*1040*
Parish	Resmo
SHM (grave field)	28514
Grave number	
Year of excavation	1966
Excavator/-s	I Sjögren
MNI	1
Body position	supine
Gravetype	pit
Orientation	NS
Sex	male
Age group	mature
Age	50-60
Measurement details	Femur 1; R ; 448 mm
Stature (Sjovold 1990)	167.2 ± 4.52 cm
local/non-local?	non-local
Sampled tooth (FDI)	34
^{87}Sr/^{86} Sr	0.7330
δ^{18}O$_{carb}$ VPDB. ‰	-6.5
δ^{13}C (VPDB) ‰ apatite	-13.0
δ^{13}C (VPDB) ‰ collagen	-20.2
δ^{15}N (AIR) ‰ collagen	12.2
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Pre Roman Iron Age
^{14}C conventional age, BP	2315 +/-45
^{14}C calibrated	344 +/-71 BC
Date, typology as given in ÖJG	Iron Age
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	0
Enthesopathy	1
OD	9
OA	9
Schmorls nodes	9
LEH	9
Pathology	Parietal L, Frontal; endocranial. New periostal bone formation (light, elevated) sclerotic bone with etchning of small vessles covering L parietal and slight frontal. Quite prominent periostal. Possibly meningitis.

ID	*1041*
Parish	Torslunda
SHM (grave field)	24544
Grave number	5
Year of excavation	1951
Excavator/-s	Hvarfner Rosell
MNI	2
Body position	?
Gravetype	pit
Orientation	NA
Sex	male
Age group	young/mature
Age	
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	24
^{87}Sr/^{86} Sr	0.7116
δ^{18}O$_{carb}$ VPDB. ‰	-6.2
δ^{13}C (VPDB) ‰ apatite	-14.7
δ^{13}C (VPDB) ‰ collagen	-20.3
δ^{15}N (AIR) ‰ collagen	11.9
Sampled bone (δ^{13}C δ^{15}N)	cranium
Date, typology and 14C	Pre Roman Iron Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Pre Roman Iron Age
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	1
Trauma	1
Enthesopathy	0
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	Multiple trauma. 1, Parietal, R, superiorly. Rectangular hole, 45x25 mm. Internal beveling of margins. Radiating fractures. No healing, perimortem BFT. 2, Frontal, middle and superior. Vaguely circular defect, 25 mm diameter. Possible perimortem trauma. Very slight internal bevelling. Four radiating fractures are splitting the entire frontal. BFT or projectile? 3, Occipital, R side. No internal bevelling just some external irregular margin surface Fragment missing. Projectile possibly? Perimortem. 4, Clavicle, mid-diaphysis, medial. Possible partial fracture/trauma to inferior surface. Porosity and slight displacement in the anterior plane. OP with the diaphysis possibly slightly thickend. Antemortem, healing.

ID	*1042*
Parish	Torslunda
SHM (grave field)	24544
Grave number	2
Year of excavation	1951
Excavator/-s	Hvarfner, Rosell
MNI	2
Body position	mixed
Gravetype	cist
Orientation	NA
Sex	male
Age group	young/mature
Age	
Measurement details	Humerus 1; L;1; 202 mm; est. Total 349.9 mm; stature estimation from calculated total measurement 180. 65±4.94 cm
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	44
^{87}Sr/^{86} Sr	0.7115
δ^{18}O$_{carb}$ VPDB. ‰	-5.7
δ^{13}C (VPDB) ‰ apatite	-13.2
δ^{13}C (VPDB) ‰ collagen	-19.9
δ^{15}N (AIR) ‰ collagen	12.3
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Pre Roman Iron Age
^{14}C conventional age, BP	2125 +/-45
^{14}C calibrated	191+/-95 BC
Date, typology as given in ÖJG	Early Iron Age
Cribra orbitalia	0
Porotic hyperstosis	9
Non-specific Periostitis	0
Trauma	0
Enthesopathy	1
OD	9
OA	9
Schmorls nodes	9
LEH	1
Pathology	

ID	*1043*
Parish	Stenåsa
SHM (grave field)	24847
Grave number	3
Year of excavation	1953
Excavator/-s	CO Rosell
MNI	1
Body position	supine
Gravetype	cist
Orientation	NS
Sex	female?
Age group	juvenile
Age	16-17
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	44
^{87}Sr/^{86}Sr	0.7121
$\delta^{18}O_{carb}$ VPDB. ‰	-5.9
δ^{13}C (VPDB) ‰ apatite	-13.3
δ^{13}C (VPDB) ‰ collagen	-19.8
δ^{15}N (AIR) ‰ collagen	12.9
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Pre Roman Iron Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Pre Roman Iron Age (per. I)
Cribra orbitalia	9
Porotic hyperstosis	0
Non-specific Periostitis	9
Trauma	0
Enthesopathy	1
OD	1
OA	0
Schmorls nodes	1
LEH	1
Pathology	

ID	*1044*
Parish	Stenåsa
SHM (grave field)	27764
Grave number	
Year of excavation	1964
Excavator/-s	M Beskow
MNI	1
Body position	supine
Gravetype	cist
Orientation	NS
Sex	male?
Age group	old
Age	
Measurement details	Femur 1; L ; 434 mm
Stature (Sjovold 1990)	163.5 ±4.52 cm
local/non-local?	non-local
Sampled tooth (FDI)	44
^{87}Sr/^{86} Sr	0.7258
δ^{18}O$_{carb}$ VPDB. ‰	-5.2
δ^{13}C (VPDB) ‰ apatite	-12.5
δ^{13}C (VPDB) ‰ collagen	-19.5
δ^{15}N (AIR) ‰ collagen	14.2
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Early Roman Period
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	0
Trauma	1
Enthesopathy	0
OD	0
OA	0
Schmorls nodes	1
LEH	0
Pathology	Hand, phalanx I ; possibly R (in the same bag as all R carpals and Mc´s). Skewing of the diaphysis distal half. OP on dorsal surface. Very large potruding OP from med/lat margin in palmar direction. Muscular trauma with myostitis ossificans or, possibly, well healed fracture.

ID	*1045*
Parish	Långlöt
SHM (grave field)	29352
Grave number	24
Year of excavation	1968-1969
Excavator/-s	Johansson-Lundh
MNI	2
Body position	supine
Gravetype	pit
Orientation	NS
Sex	male
Age group	old
Age	60+
Measurement details	Femur 1; L ; 414 mm
Stature (Sjovold 1990)	158.1 ±4.52 cm
local/non-local?	non-local
Sampled tooth (FDI)	44
$^{87}Sr/^{86}Sr$	0.7110
$\delta^{18}O_{carb}$ VPDB. ‰	-3.6
$\delta^{13}C$ (VPDB) ‰ apatite	-12.2
$\delta^{13}C$ (VPDB) ‰ collagen	-19.0
$\delta^{15}N$ (AIR) ‰ collagen	11.4
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Viking Age
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	1
Enthesopathy	1
OD	0
OA	0
Schmorls nodes	1
LEH	0
Pathology	1: Skull. The fusion of the coronal suture is not complete. R and L parietals are assymetric. L is larger and more bulging to lateral especially from posterior. Premature suture (sagittal) fusion? 2: T12. Wedge vertebrae. Body compressed diagonally anteriorly/ superiorly in the most anterior portion. Fracture line is distinct. Slight healing.

ID	*1046*
Parish	Ventlinge
SHM (grave field)	22291
Grave number	-
Year of excavation	1939
Excavator/-s	C O Rosell
MNI	1
Body position	supine
Gravetype	cist
Orientation	NS
Sex	male
Age group	juvenile-young
Age	ca 20
Measurement details	Femur 1; L ; 440 mm (Femur 1; R ; 432 mm)
Stature (Sjovold 1990)	165.1 ±4.52 cm
local/non-local?	local
Sampled tooth (FDI)	14
^{87}*Sr/*^{86} *Sr*	0.7158
δ^{18}*O*$_{carb}$ *VPDB. ‰*	-5.7
δ^{13}*C (VPDB) ‰ apatite*	-14.1
δ^{13}*C (VPDB) ‰ collagen*	-19.4
δ^{15}*N (AIR) ‰ collagen*	13.4
Sampled bone (δ^{13}*C δ*^{15}*N)*	mandible
Date, typology and 14C	Viking Age
^{14}*C conventional age, BP*	1180 +/-45
^{14}*C calibrated*	847 +/-65 AD
Date, typology as given in ÖJG	Viking Age
Cribra orbitalia	1
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	0
Enthesopathy	1
OD	1
OA	0
Schmorls nodes	1
LEH	1
Pathology	

ID	*1047*
Parish	Smedby
SHM (grave field)	23981
Grave number	47
Year of excavation	1948
Excavator/-s	Stenström
MNI	1
Body position	unobservable
Gravetype	cist
Orientation	NS
Sex	male
Age group	young-old
Age	
Measurement details	Tibia 1; L ; 408 mm
Stature (Sjovold 1990)	181.57 ± 4.11 cm
local/non-local?	local
Sampled tooth (FDI)	44
$^{87}Sr/^{86}Sr$	0.7116
$\delta^{18}O_{carb}$ VPDB. ‰	-5.7
$\delta^{13}C$ (VPDB) ‰ apatite	-12.9
$\delta^{13}C$ (VPDB) ‰ collagen	-19.8
$\delta^{15}N$ (AIR) ‰ collagen	14.4
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	1990+-45
^{14}C calibrated	3 +-46 AD
Date, typology as given in ÖJG	Roman Iron Age
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	9
Trauma	0
Enthesopathy	0
OD	1
OA	9
Schmorls nodes	9
LEH	0
Pathology	

ID	*1048*
Parish	Smedby
SHM (grave field)	23981
Grave number	35a
Year of excavation	1948
Excavator/-s	S Stenström
MNI	2
Body position	unobservable
Gravetype	pit
Orientation	NS
Sex	male?
Age group	young-mature
Age	
Measurement details	Humerus 1; R ; 338 mm
Stature (Sjovold 1990)	175.15 ± 4.94 cm
local/non-local?	local
Sampled tooth (FDI)	14
$^{87}Sr/^{86}Sr$	0.7123
$\delta^{18}O_{carb}$ VPDB. ‰	-5.3
$\delta^{13}C$ (VPDB) ‰ apatite	-13.6
$\delta^{13}C$ (VPDB) ‰ collagen	-19.9
$\delta^{15}N$ (AIR) ‰ collagen	13.9
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	1965 +/-45
^{14}C calibrated	25 +/-47 AD
Date, typology as given in ÖJG	Iron Age?
Cribra orbitalia	9
Porotic hyperstosis	0
Non-specific Periostitis	9
Trauma	9
Enthesopathy	1
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	

ID	*1051*
Parish	Stenåsa
SHM (grave field)	24846
Grave number	1
Year of excavation	1953
Excavator/-s	CO Rosell
MNI	1
Body position	mixed
Gravetype	cist
Orientation	NS
Sex	female
Age group	old
Age	60-70
Measurement details	Femur 1; L ; 431 mm (R 425 mm)
Stature (Sjovold 1990)	162.7 ± 4.52 cm
local/non-local?	non-local
Sampled tooth (FDI)	34
^{87}Sr/^{86}Sr	0.7246
δ^{18}O$_{carb}$ VPDB. ‰	-5.7
δ^{13}C (VPDB) ‰ apatite	-14.3
δ^{13}C (VPDB) ‰ collagen	-19.7
δ^{15}N (AIR) ‰ collagen	13.7
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Pre Roman Iron Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Iron Age
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	1
Trauma	0
Enthesopathy	1
OD	0
OA	1
Schmorls nodes	1
LEH	0
Pathology	1: A urinary stone, very small. Could be a lot more as some fragments are so eroded it is difficult to tell if they could also be smaller/fragmented stones. 2: Ribs, L and unknown side. Varied occurrence of: OP (flecks) on visceral surface, mostly on the margin and vertebral part. Pits on the inferior surface. Superior build up/thickening. Pits on the superior surface. One or more of these features on all L ribs except for T1. Possibly pneumonia.

ID	*1052*
Parish	Stenåsa
SHM (grave field)	24846
Grave number	2 (?)
Year of excavation	1953
Excavator/-s	CO Rosell
MNI	1
Body position	mixed
Gravetype	pit
Orientation	NS
Sex	male
Age group	juvenile
Age	19
Measurement details	Femur 1; L ; 433 mm
Stature (Sjovold 1990)	163.2 ±4.52 cm
local/non-local?	local
Sampled tooth (FDI)	24
^{87}Sr/^{86} Sr	0.7125
δ^{18}O$_{carb}$ VPDB. ‰	-6.0
δ^{13}C (VPDB) ‰ apatite	-15.1
δ^{13}C (VPDB) ‰ collagen	-20.3
δ^{15}N (AIR) ‰ collagen	11.2
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Pre Roman Iron Age
^{14}C conventional age, BP	2325 +/-45
^{14}C calibrated	386+/-80 BC
Date, typology as given in ÖJG	Early Iron Age
Cribra orbitalia	9
Porotic hyperstosis	1
Non-specific Periostitis	9
Trauma	1
Enthesopathy	0
OD	0
OA	0
Schmorls nodes	1
LEH	0
Pathology	Radius and Ulna; diaphysis, L. Just distal of middaphysis on ulna and just on/slightly proximal middle diaphysis radius. Single, angular trauma? Ulna: fracture of diaphysis leaning from lateral-medial-margin. The area is very porous and reformed morphology. No fusion with the distal (missing) part. The radius is very poorly preserved.

ID	*1053*
Parish	Gärdslösa
SHM (grave field)	27702
Grave number	90
Year of excavation	1964
Excavator/-s	
MNI	1
Body position	supine, crouched
Gravetype	cist
Orientation	NS
Sex	undetermined
Age group	mature
Age	
Measurement details	Femur 1; R ; circa 132-151 cm
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	44
$^{87}Sr/^{86}Sr$	0.7148
$\delta^{18}O_{carb}$ VPDB. ‰	-5.5
$\delta^{13}C$ (VPDB) ‰ apatite	-13.6
$\delta^{13}C$ (VPDB) ‰ collagen	-20.0
$\delta^{15}N$ (AIR) ‰ collagen	13.9
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Early Roman Period
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	0
Enthesopathy	0
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	

ID	*1054*
Parish	Gärdslösa
SHM (grave field)	27702
Grave number	140
Year of excavation	1965
Excavator/-s	
MNI	1
Body position	supine
Gravetype	pit
Orientation	NS
Sex	NA
Age group	child
Age	9-10
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	24
$^{87}Sr/^{86}Sr$	0.7120
$\delta^{18}O_{carb}$ VPDB. ‰	-5.0
$\delta^{13}C$ (VPDB) ‰ apatite	-14.4
$\delta^{13}C$ (VPDB) ‰ collagen	-20.3
$\delta^{15}N$ (AIR) ‰ collagen	14.1
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	humerus
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Early Roman Period
Cribra orbitalia	1
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	0
Enthesopathy	9
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	

ID	*1055*
Parish	Böda
SHM (grave field)	22231
Grave number	4
Year of excavation	1938
Excavator/-s	Anderbjörk, Oxenstierna
MNI	
Body position	unobservable
Gravetype	boat
Orientation	NA
Sex	NA
Age group	juvenile-young
Age	
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	gray
Sampled tooth (FDI)	44
^{87}Sr/^{86}Sr	0.7104
δ^{18}O$_{carb}$ VPDB. ‰	-6.1
δ^{13}C (VPDB) ‰ apatite	-14.2
δ^{13}C (VPDB) ‰ collagen	-20.1
δ^{15}N (AIR) ‰ collagen	13.3
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Vendel Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Circa AD 700
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	9
Trauma	9
Enthesopathy	9
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	

ID	*1056*
Parish	Hulterstad
SHM (grave field)	27125
Grave number	
Year of excavation	1962
Excavator/-s	M Beskow
MNI	2
Body position	supine
Gravetype	cist
Orientation	SN
Sex	NA
Age group	juvenile
Age	13-15
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	44
$^{87}Sr/^{86}Sr$	0.7113
$\delta^{18}O_{carb}$ VPDB. ‰	-5.4
$\delta^{13}C$ (VPDB) ‰ apatite	-14.4
$\delta^{13}C$ (VPDB) ‰ collagen	-19.6
$\delta^{15}N$ (AIR) ‰ collagen	13.1
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Pre Roman Iron Age
^{14}C conventional age, BP	2010 +/-45
^{14}C calibrated	22 +/- 55 BC
Date, typology as given in ÖJG	Iron Age?
Cribra orbitalia	1
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	0
Enthesopathy	9
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	Occipital and atlas; The condyles are displaced with the R slightly higher than the L (towards pars basilaris) and irregularly elongated. The foramen magnum is more oval than round.

ID	*1057*
Parish	Långlöt
SHM (grave field)	29352
Grave number	13
Year of excavation	1968
Excavator/-s	Johansson-Lund
MNI	2
Body position	Unavailable
Gravetype	pit
Orientation	NS
Sex	male?
Age group	old
Age	
Measurement details	Femur 1; L ; 470 mm
Stature (Sjovold 1990)	173.2 ±4.52 cm
local/non-local?	local
Sampled tooth (FDI)	45
^{87}Sr/^{86}Sr	0.7124
δ^{18}O$_{carb}$ VPDB. ‰	-5.1
δ^{13}C (VPDB) ‰ apatite	-14.0
δ^{13}C (VPDB) ‰ collagen	-19.2
δ^{15}N (AIR) ‰ collagen	11.7
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Viking Age
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	0
Enthesopathy	0
OD	0
OA	0
Schmorls nodes	9
LEH	9
Pathology	

ID	*1058*
Parish	Gärdslösa
SHM (grave field)	28364
Grave number	134
Year of excavation	
Excavator/-s	
MNI	2
Body position	Unavailable
Gravetype	cist
Orientation	WE
Sex	female
Age group	mature
Age	
Measurement details	Femur 1; R ; 453 mm
Stature (Sjovold 1990)	168.6 ±4.52 cm
local/non-local?	gray
Sampled tooth (FDI)	34
^{87}Sr/^{86} Sr	0.7108
$\delta^{18}O_{carb}$ VPDB. ‰	-5.5
δ^{13}C (VPDB) ‰ apatite	-14.5
δ^{13}C (VPDB) ‰ collagen	-19.4
δ^{15}N (AIR) ‰ collagen	13.3
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	1005 +/-45
^{14}C calibrated	1049 +/-58 AD
Date, typology as given in ÖJG	Iron Age?
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	9
Enthesopathy	0
OD	0
OA	0
Schmorls nodes	1
LEH	0
Pathology	Wedgeshaped vertebrae, L2. The vertebral body is tilting to anterior and clearly fractured. There is a destruction/lytic focus on the inferior of the vertebral body.

ID	*1059*
Parish	Smedby
SHM (grave field)	23494
Grave number	20
Year of excavation	1945
Excavator/-s	Lagerholm
MNI	3
Body position	Unavailable
Gravetype	cist
Orientation	SN
Sex	male
Age group	juvenile
Age	19
Measurement details	Femur 1; L ; 500 mm
Stature (Sjovold 1990)	181.4 ± 4.52 cm
local/non-local?	gray
Sampled tooth (FDI)	44
^{87}Sr/^{86}Sr	0.7103
δ^{18}O$_{carb}$ VPDB. ‰	-5.8
δ^{13}C (VPDB) ‰ apatite	-14.3
δ^{13}C (VPDB) ‰ collagen	-18.6
δ^{15}N (AIR) ‰ collagen	13.9
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	1180 +/-45
^{14}C calibrated	847 +/-65 AD
Date, typology as given in ÖJG	Roman Iron Age
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	1
Trauma	0
Enthesopathy	1
OD	0
OA	0
Schmorls nodes	1
LEH	1
Pathology	1, Spondylolysis of L4 (bilateral), OP, PO. 2: Spina bifida.

ID	*1060*
Parish	Smedby
SHM (grave field)	23494
Grave number	19
Year of excavation	1945
Excavator/-s	
MNI	1
Body position	Unavailable
Gravetype	cist
Orientation	NS
Sex	NA
Age group	child
Age	11-12
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	non-local
Sampled tooth (FDI)	45
^{87}Sr/^{86}Sr	0.7107
$\delta^{18}O_{carb}$ VPDB. ‰	-7.0
δ^{13}C (VPDB) ‰ apatite	-13.1
δ^{13}C (VPDB) ‰ collagen	-20.0
δ^{15}N (AIR) ‰ collagen	11.4
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Viking Age
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	9
Trauma	9
Enthesopathy	9
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	

ID	*1061*
Parish	Stenåsa
SHM (grave field)	24543
Grave number	3
Year of excavation	1951
Excavator/-s	Hvarfner Rosell
MNI	2
Body position	supine
Gravetype	pit
Orientation	NS
Sex	male
Age group	mature
Age	
Measurement details	Femur 1; R ; 465 mm
Stature (Sjovold 1990)	171.9 ±4.52 cm
local/non-local?	local
Sampled tooth (FDI)	24
^{87}Sr/^{86} Sr	0.7127
δ^{18}O$_{carb}$ VPDB. ‰	-5.4
δ^{13}C (VPDB) ‰ apatite	-13.8
δ^{13}C (VPDB) ‰ collagen	-19.7
δ^{15}N (AIR) ‰ collagen	15.0
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Late Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Late Roman Period
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	1
Trauma	0
Enthesopathy	1
OD	1
OA	1
Schmorls nodes	1
LEH	0
Pathology	

ID	*1062*
Parish	Gräsgård
SHM (grave field)	19197
Grave number	2?
Year of excavation	1929
Excavator/-s	Hofrén
MNI	1
Body position	supine
Gravetype	cist
Orientation	NS
Sex	female?
Age group	young-mature
Age	
Measurement details	Femur 1; L ; 456 mm
Stature (Sjovold 1990)	169.4 ±4.52 cm
local/non-local?	local
Sampled tooth (FDI)	24
^{87}Sr/^{86}Sr	0.7160
δ^{18}O$_{carb}$ VPDB. ‰	-5.0
δ^{13}C (VPDB) ‰ apatite	-14.0
δ^{13}C (VPDB) ‰ collagen	-19.9
δ^{15}N (AIR) ‰ collagen	14.3
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	1915+/-50 BP
^{14}C calibrated	88 +/-57 AD
Date, typology as given in ÖJG	Roman Iron Age
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	9
Trauma	0
Enthesopathy	0
OD	9
OA	9
Schmorls nodes	9
LEH	1
Pathology	

ID	*1063*
Parish	Gräsgård
SHM (grave field)	22126
Grave number	
Year of excavation	1938
Excavator/-s	Anderbjörk
MNI	1
Body position	supine
Gravetype	cist
Orientation	NS
Sex	male
Age group	old
Age	65-70
Measurement details	Humerus 1; L ; 317 mm
Stature (Sjovold 1990)	165.45 ± 4.94 cm
local/non-local?	local
Sampled tooth (FDI)	44
$^{87}Sr/^{86}Sr$	0.7116
$\delta^{18}O_{carb}$ VPDB. ‰	-5.5
$\delta^{13}C$ (VPDB) ‰ apatite	-14.2
$\delta^{13}C$ (VPDB) ‰ collagen	-19.7
$\delta^{15}N$ (AIR) ‰ collagen	12.1
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Pre Roman Iron Age
^{14}C conventional age, BP	2425+/-50
^{14}C calibrated	576 +/-130 BC
Date, typology as given in ÖJG	Early Iron Age?
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	1
Enthesopathy	1
OD	0
OA	1
Schmorls nodes	1
LEH	1
Pathology	1: Trapezium and Metacarpus I, L. and R. Extensive contour remodelling. EB only slight, possibly missing due to extensive destruction of the joint surfaces. Symmetric. Bilateral. The other joints in the hand are not remodeled similarly. 2: Trauma, antemortem. Manus Ph I & II-locked in 90 degree angle to palmar. Extensive dorsal OP on Ph I around distal joint. EB only in flexed postion, on both Ph I and II. OA secondary to trauma? 3: Bifid neural arch L5; antemortem;; arch; incomplete fusion of neural arch center and consequetive pseudojoint with PO OP.

ID	*1064*
Parish	Hulterstad
SHM (grave field)	22394
Grave number	
Year of excavation	1939
Excavator/-s	Anderbjörk
MNI	1
Body position	Unavailable
Gravetype	cist
Orientation	NS
Sex	male
Age group	mature
Age	
Measurement details	Femur 1; L ; 455 mm
Stature (Sjovold 1990)	169.2 ± 4.52 cm
local/non-local?	local
Sampled tooth (FDI)	44
$^{87}Sr/^{86}Sr$	0.7125
$\delta^{18}O_{carb}$ VPDB. ‰	-5.8
$\delta^{13}C$ (VPDB) ‰ apatite	-14.6
$\delta^{13}C$ (VPDB) ‰ collagen	-19.3
$\delta^{15}N$ (AIR) ‰ collagen	12.7
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Viking Age)
^{14}C conventional age, BP	1170 +/-45
^{14}C calibrated	858 +/- 68 AD
Date, typology as given in ÖJG	Iron Age?
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	0
Enthesopathy	1
OD	0
OA	0
Schmorls nodes	1
LEH	0
Pathology	Symmetric joint destruction in basically all joints. Slightly assymetrical severity in bilateral joints, shifting from R to L sides. Porosities from macro to small pits and larger lesions. Healed and unhealed. Active and healing, varied distribution. Minor new bone formation, some remodelling. Most of the bones of the hands, feet, thoracic, and cervical spine are missing or severly fragmented. Tooth root erosions, typical appearance for caries.

ID	*1065*
Parish	Köpinge
SHM (grave field)	6393/75
Grave number	3
Year of excavation	1975
Excavator/-s	H Schulze
MNI	1
Body position	Unavailable
Gravetype	coffin
Orientation	WE
Sex	female?
Age group	mature/old
Age	
Measurement details	Femur 1; R ; 375 mm
Stature (Sjovold 1990)	147.49 ± 4.52 cm
local/non-local?	non-local
Sampled tooth (FDI)	45
^{87}Sr/^{86} Sr	0.7391
δ^{18}O$_{carb}$ VPDB. ‰	-6.1
δ^{13}C (VPDB) ‰ apatite	-11.1
δ^{13}C (VPDB) ‰ collagen	-19.4
δ^{15}N (AIR) ‰ collagen	13.2
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Viking Age
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	0
Enthesopathy	0
OD	9
OA	9
Schmorls nodes	9
LEH	9
Pathology	Patella, L. Very large extension (OP) in the distal part of the lateral side. Extreme enthesopaty, trauma?

ID	*1066*
Parish	Köpinge
SHM (grave field)	6393/75
Grave number	10
Year of excavation	1975
Excavator/-s	Sjöberg, Schulze
MNI	1
Body position	Unavailable
Gravetype	coffin
Orientation	WE
Sex	NA
Age group	juvenile
Age	12-15
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	14
^{87}Sr/^{86} Sr	0.7120
$\delta^{18}O_{carb}$ VPDB. ‰	-5.4
δ^{13}C (VPDB) ‰ apatite	-13.5
δ^{13}C (VPDB) ‰ collagen	~~-20.0~~ (too poor quality)
δ^{15}N (AIR) ‰ collagen	~~11.9~~ (too poor quality)
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Viking Age
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	9
Trauma	0
Enthesopathy	9
OD	9
OA	9
Schmorls nodes	9
LEH	1
Pathology	

ID	*1067*
Parish	Köpinge
SHM (grave field)	6393/75
Grave number	20
Year of excavation	1975
Excavator/-s	Sjöber, Schulze
MNI	1
Body position	Unavailable
Gravetype	coffin
Orientation	WE
Sex	male
Age group	old
Age	72+-
Measurement details	Femur 1; L ; 504 mm
Stature (Sjovold 1990)	182.4 ±4.52 cm
local/non-local?	non-local
Sampled tooth (FDI)	45
^{87}Sr/^{86}Sr	0.7180
δ^{18}O$_{carb}$ VPDB. ‰	-6.6
δ^{13}C (VPDB) ‰ apatite	-14.1
δ^{13}C (VPDB) ‰ collagen	-19.1
δ^{15}N (AIR) ‰ collagen	13.5
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Viking Age
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	0
Enthesopathy	1
OD	1
OA	1
Schmorls nodes	9
LEH	0
Pathology	1: Bilateral Ulnar impaction/abutement syndrome. Ulna has a pseudojoint with the lunate and triquetral. Highly symmetrical bilaterally. Very strong EB and a platform present on all the three joint surfaces. Also pitting and new bone around sites. OP on styloid process in ulna. All changes slightly more severe in R. All carpals have porosities around joints, some are large. There are also porosities around many other joints, for example humero-glenoid, tarsals etc. Strong green staining on ulna in this joint in R (artefact related ?). 2: Clavicle, R. Slight misalignment and ridge in ant/sup view. Possibly a wellhealed incomplete fracture, X ray inconclusive. The bony ridge slopes to lateral inferiorly from superior/anterior. 3: Depression in diaphysis in L metatarsals III and IV as if localized trauma here.

ID	*1068*
Parish	Långlöt
SHM (grave field)	29352
Grave number	18
Year of excavation	1968
Excavator/-s	Johansson-Lundh
MNI	2
Body position	Unavailable
Gravetype	pit
Orientation	NS
Sex	male
Age group	young-mature
Age	30-40
Measurement details	Femur 1; L ; 455 mm
Stature (Sjovold 1990)	169.2 ±4.52 cm
local/non-local?	non-local
Sampled tooth (FDI)	34
$^{87}Sr/^{86}Sr$	0.7265
$\delta^{18}O_{carb}$ VPDB. ‰	-4.6
$\delta^{13}C$ (VPDB) ‰ apatite	-10.8
$\delta^{13}C$ (VPDB) ‰ collagen	-19.1
$\delta^{15}N$ (AIR) ‰ collagen	13.2
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Viking Age
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	1
Enthesopathy	0
OD	0
OA	0
Schmorls nodes	0
LEH	0
Pathology	1: Site for psoas minor in pubis/ ischium, R. Periostal and subperiostal. Iirregular formation and very fine trabeculae. Also cloace. A possible healed fracture rougly in the site for the epiphysial line? 2: Femur, L. Subperiostal build up. Irregular & lumpy. Possibly fracture/trauma site. Circa 1/3 from the distal joint. No cloace. Involvning cortex.

ID	*1069*
Parish	Föra
SHM (grave field)	29764
Grave number	-
Year of excavation	1968
Excavator/-s	U E Hagberg?
MNI	2, see 1070
Body position	unobservable
Gravetype	wetland
Orientation	NA
Sex	NA
Age group	juvenile
Age	13-15
Measurement details	Femur 1; not fused so minimum 162 cm
Stature (Sjovold 1990)	
local/non-local?	gray
Sampled tooth (FDI)	34
^{87}Sr/^{86}Sr	0.7105
$\delta^{18}O_{carb}$ VPDB. ‰	-5.1
δ^{13}C (VPDB) ‰ apatite	-15.0
δ^{13}C (VPDB) ‰ collagen	-20.1
δ^{15}N (AIR) ‰ collagen	9.9
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Pre Roman Iron Age
^{14}C conventional age, BP	2050+/-50
^{14}C calibrated	75 +/-69 BC
Date, typology as given in ÖJG	?
Cribra orbitalia	1
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	0
Enthesopathy	9
OD	9
OA	9
Schmorls nodes	9
LEH	1
Pathology	

ID	*1075*
Parish	Gärdslösa
SHM (grave field)	28364
Grave number	164
Year of excavation	1965
Excavator/-s	Hagberg
MNI	2
Body position	supine
Gravetype	cist
Orientation	NS
Sex	male
Age group	mature
Age	
Measurement details	Femur 1; R ; 432 mm
Stature (Sjovold 1990)	162.9 ±4.52 cm
local/non-local?	local
Sampled tooth (FDI)	14
^{87}Sr/^{86} Sr	0.7713
δ^{18}O$_{carb}$ VPDB. ‰	-6.0
δ^{13}C (VPDB) ‰ apatite	-14.5
δ^{13}C (VPDB) ‰ collagen	-19.1
δ^{15}N (AIR) ‰ collagen	13.2
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	1175 +/-45
^{14}C calibrated	853 +/- 67 AD
Date, typology as given in ÖJG	?
Cribra orbitalia	0
Porotic hyperstosis	9
Non-specific Periostitis	0
Trauma	0
Enthesopathy	0
OD	0
OA	0
Schmorls nodes	9
LEH	0
Pathology	

ID	*1076*
Parish	Gärdslösa
SHM (grave field)	28364
Grave number	136
Year of excavation	1965
Excavator/-s	Hagberg
MNI	2
Body position	supine
Gravetype	pit
Orientation	WE
Sex	female
Age group	mature
Age	50-60
Measurement details	Femur 1; L ; 424 mm
Stature (Sjovold 1990)	160.8 ±4.52 cm
local/non-local?	non-local
Sampled tooth (FDI)	44
^{87}Sr/^{86}Sr	0.7337
δ^{18}O$_{carb}$ VPDB. ‰	-4.8
δ^{13}C (VPDB) ‰ apatite	-14.0
δ^{13}C (VPDB) ‰ collagen	-19.9
δ^{15}N (AIR) ‰ collagen	14.2
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Late Roman Period (V:1)
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	1
Enthesopathy	1
OD	0
OA	0
Schmorls nodes	9
LEH	0
Pathology	1: Rotator cuff syndrome. Clavicle, scapula, humerus. OP and PO -. Clavicular acromial facet L. Humerus supraspinatus, L, R. Clavicula, medial, L. Possibly bilateral. 2: Metacarpus III, R. Mid-diaphysis, palmar surface. Probably partial fracture with displacement of diaphysis to palmar and proximal. Considerable shortening of diaphysis, estimated to at least 3 mm. Potrusion in. Hhealed. Mc IV, V were not present.

ID	*1077*
Parish	Böda
SHM (grave field)	22231
Grave number	8
Year of excavation	1938
Excavator/-s	Anderbjörk
MNI	
Body position	unobservable
Gravetype	boat
Orientation	NA
Sex	NA
Age group	juvenile-young
Age	
Measurement details	Femur 1; R, L; circa 154-165 cm
Stature (Sjovold 1990)	
local/non-local?	non-local
Sampled tooth (FDI)	35
^{87}Sr/^{86} Sr	0.7269
δ^{18}O$_{carb}$ VPDB. ‰	-5.8
δ^{13}C (VPDB) ‰ apatite	-14.5
δ^{13}C (VPDB) ‰ collagen	-19.8
δ^{15}N (AIR) ‰ collagen	13.1
Sampled bone (δ^{13}C δ^{15}N)	Radius
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Circa AD 700
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	1
Trauma	0
Enthesopathy	9
OD	9
OA	9
Schmorls nodes	9
LEH	9
Pathology	Ribs, visceral surface, sternal portion primarily. Periostal bone deposition (very fine striation and light coloured plaque) deposit on visceral surface sternal portion. Apparently unilateral, only R.

ID	*1078*
Parish	Böda
SHM (grave field)	21367
Grave number	A5
Year of excavation	1935
Excavator/-s	TJ Arne
MNI	1
Body position	mixed
Gravetype	cist
Orientation	NS
Sex	NA
Age group	juvenile
Age	12-15
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	gray
Sampled tooth (FDI)	44
$^{87}Sr/^{86}Sr$	0.7184
$\delta^{18}O_{carb}$ VPDB. ‰	-5.3
$\delta^{13}C$ (VPDB) ‰ apatite	-15.6
$\delta^{13}C$ (VPDB) ‰ collagen	-19.0
$\delta^{15}N$ (AIR) ‰ collagen	12.0
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Viking Age
Cribra orbitalia	1
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	0
Enthesopathy	9
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	

ID	*1079*
Parish	Glömminge
SHM (grave field)	31890
Grave number	12
Year of excavation	
Excavator/-s	
MNI	2
Body position	mixed
Gravetype	cist
Orientation	NS
Sex	male?
Age group	young-mature
Age	
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	44
^{87}Sr/^{86}Sr	0.7115
δ^{18}O$_{carb}$ VPDB. ‰	-5.2
δ^{13}C (VPDB) ‰ apatite	-14.5
δ^{13}C (VPDB) ‰ collagen	-19.8
δ^{15}N (AIR) ‰ collagen	13.7
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Early Roman Period (IV:2)
Cribra orbitalia	0
Porotic hyperstosis	9
Non-specific Periostitis	0
Trauma	0
Enthesopathy	1
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	

ID	*1080*
Parish	Glömminge
SHM (grave field)	31890
Grave number	5
Year of excavation	
Excavator/-s	
MNI	1
Body position	mixed
Gravetype	cist
Orientation	NS
Sex	female
Age group	young-mature
Age	
Measurement details	Tibia 1; 351 mm
Stature (Sjovold 1990)	164.94 ±4 .11 cm
local/non-local?	local
Sampled tooth (FDI)	14
$^{87}Sr/^{86}Sr$	0.7134
$\delta^{18}O_{carb}$ VPDB. ‰	-5.8
$\delta^{13}C$ (VPDB) ‰ apatite	-14.3
$\delta^{13}C$ (VPDB) ‰ collagen	-19.8
$\delta^{15}N$ (AIR) ‰ collagen	13.7
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	tibia
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Early Roman Period (IV:2)
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	9
Trauma	0
Enthesopathy	0
OD	0
OA	0
Schmorls nodes	9
LEH	1
Pathology	

ID	*1081*
Parish	Glömminge
SHM (grave field)	31890
Grave number	6
Year of excavation	
Excavator/-s	
MNI	2
Body position	mixed
Gravetype	cist
Orientation	NS
Sex	NA
Age group	young-mature
Age	
Measurement details	Femur 1: 431 mm
Stature (Sjovold 1990)	165.25 ± 4.52 cm
local/non-local?	gray
Sampled tooth (FDI)	44
$^{87}Sr/^{86}Sr$	0.7106
$\delta^{18}O_{carb}$ VPDB. ‰	-5.3
$\delta^{13}C$ (VPDB) ‰ apatite	-13.5
$\delta^{13}C$ (VPDB) ‰ collagen	-19.9
$\delta^{15}N$ (AIR) ‰ collagen	15.1
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Early Roman Period (IV:1)
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	9
Trauma	0
Enthesopathy	0
OD	1
OA	0
Schmorls nodes	9
LEH	0
Pathology	

ID	*1082*
Parish	Stenåsa
SHM (grave field)	24543
Grave number	2
Year of excavation	1951
Excavator/-s	Hvarfner
MNI	2
Body position	supine
Gravetype	pit
Orientation	NS
Sex	male
Age group	mature
Age	45-55
Measurement details	Femur 1; L ; 452 mm
Stature (Sjovold 1990)	167.8 ± 4.52 cm
local/non-local?	local
Sampled tooth (FDI)	34
$^{87}Sr/^{86}Sr$	0.7110
$\delta^{18}O_{carb}$ VPDB. ‰	-5.4
$\delta^{13}C$ (VPDB) ‰ apatite	-14.0
$\delta^{13}C$ (VPDB) ‰ collagen	-19.9
$\delta^{15}N$ (AIR) ‰ collagen	15.0
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	1930 +/-45
^{14}C calibrated	67 +/-48 AD
Date, typology as given in ÖJG	Early Iron Age
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	0
Enthesopathy	1
OD	0
OA	0
Schmorls nodes	1
LEH	0
Pathology	

ID	*1083*
Parish	Stenåsa
SHM (grave field)	24543
Grave number	1
Year of excavation	1951
Excavator/-s	Hvarfner
MNI	1
Body position	supine
Gravetype	pit
Orientation	NS
Sex	male
Age group	old
Age	60
Measurement details	Femur 1; R ; 519 mm
Stature (Sjovold 1990)	186.5 ± 4.52 cm
local/non-local?	non-local
Sampled tooth (FDI)	34
^{87}Sr/^{86} Sr	0.7209
$\delta^{18}O_{carb}$ VPDB. ‰	-5.1
δ^{13}C (VPDB) ‰ apatite	-14.2
δ^{13}C (VPDB) ‰ collagen	-19.7
δ^{15}N (AIR) ‰ collagen	12.0
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Roman Iron Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Roman Iron Age
Cribra orbitalia	0
Porotic hyperstosis	9
Non-specific Periostitis	1
Trauma	1
Enthesopathy	1
OD	0
OA	0
Schmorls nodes	1
LEH	0
Pathology	1: Mc V, L. Fracture mid-diaphysis. Significant angulation to palmar in the distal half. OP on palmar surface. Probably partial fracture. Healed byt not aligned. 2: Fracture with displacement of rib diaphysis to visceral. Side and rib number unkown. Well healed.

ID	*1084*
Parish	Smedby
SHM (grave field)	24542
Grave number	25
Year of excavation	1951
Excavator/-s	CO Rosell, Hvarfner
MNI	1
Body position	supine
Gravetype	pit
Orientation	NS
Sex	female
Age group	old
Age	60+
Measurement details	Femur 1; R ; 428 mm
Stature (Sjovold 1990)	161.8 ± 4.52 cm
local/non-local?	non-local
Sampled tooth (FDI)	34
^{87}Sr/^{86}Sr	0.7090
δ^{18}O$_{carb}$ VPDB. ‰	-3.9
δ^{13}C (VPDB) ‰ apatite	-13.7
δ^{13}C (VPDB) ‰ collagen	-19.2
δ^{15}N (AIR) ‰ collagen	13.0
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	895 +/-45
^{14}C calibrated	1122 +/-63
Date, typology as given in ÖJG	Viking Age?
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	1
Trauma	0
Enthesopathy	1
OD	0
OA	1
Schmorls nodes	9
LEH	0
Pathology	Bilateral impingement syndrome. Severe OP, PO, and EB on the superior pole of humerus –acromion. Os acromiale in R side.

ID	*1085*
Parish	Smedby
SHM (grave field)	24866
Grave number	G
Year of excavation	1953
Excavator/-s	CO Rosell
MNI	1
Body position	supine
Gravetype	cist
Orientation	NS
Sex	female?
Age group	young-mature
Age	
Measurement details	Femur 1; R ; 430 mm
Stature (Sjovold 1990)	162.4 ± 4.52 cm
local/non-local?	gray
Sampled tooth (FDI)	24
$^{87}Sr/^{86}Sr$	0.7108
$\delta^{18}O_{carb}$ VPDB. ‰	-5.6
$\delta^{13}C$ (VPDB) ‰ apatite	-12.9
$\delta^{13}C$ (VPDB) ‰ collagen	-19.6
$\delta^{15}N$ (AIR) ‰ collagen	12.1
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Early Roman Period
Cribra orbitalia	1
Porotic hyperstosis	9
Non-specific Periostitis	9
Trauma	0
Enthesopathy	9
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	

ID	*1086*
Parish	Långlöt
SHM (grave field)	29352
Grave number	25
Year of excavation	1968-73
Excavator/-s	K Johansson-Lundh
MNI	2
Body position	hocker
Gravetype	pit
Orientation	WE
Sex	female
Age group	young
Age	38
Measurement details	Femur 1; L ; 419 mm
Stature (Sjovold 1990)	159.4 ± 4.52 cm
local/non-local?	non-local
Sampled tooth (FDI)	44
^{87}Sr/^{86} Sr	0.7087
$\delta^{18}O_{carb}$ VPDB. ‰	-4.2
δ^{13}C (VPDB) ‰ apatite	-13.2
δ^{13}C (VPDB) ‰ collagen	-19.6
δ^{15}N (AIR) ‰ collagen	11.9
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Vendel Period
^{14}C conventional age, BP	1210 +/-45
^{14}C calibrated	799 +/-68 AD
Date, typology as given in ÖJG	Viking Age?
Cribra orbitalia	1
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	1
Enthesopathy	0
OD	0
OA	0
Schmorls nodes	0
LEH	1
Pathology	Rudimentary (very small) cervical ribs fused to C7.

ID	*1087*
Parish	Smedby
SHM (grave field)	23267
Grave number	2
Year of excavation	1944
Excavator/-s	EB Lundberg
MNI	1
Body position	supine
Gravetype	cist
Orientation	NS
Sex	female?
Age group	juvenile
Age	17-21
Measurement details	Femur 1; R;1; 81,6 mm; est. Total 46.66 mm; stature estimation from calculated total measurement 172.3 ± 4.52 cm
Stature (Sjovold 1990)	
local/non-local?	non-local
Sampled tooth (FDI)	24
^{87}Sr/^{86} Sr	0.7112
$\delta^{18}O_{carb}$ VPDB. ‰	-7.3
δ^{13}C (VPDB) ‰ apatite	-14.6
δ^{13}C (VPDB) ‰ collagen	-19.5
δ^{15}N (AIR) ‰ collagen	13.8
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	1955 +/-45
^{14}C calibrated	36 +/-49 AD
Date, typology as given in ÖJG	Iron Age
Cribra orbitalia	1
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	1
Enthesopathy	1
OD	9
OA	9
Schmorls nodes	1
LEH	1
Pathology	1: Tibia, medial projection, callus formation with smooth outline. Probably not fracture but sof tissue lesion. 2:Vertebrae; ;T6-T7. Pseudojoint.

ID	*1088*
Parish	Smedby
SHM (grave field)	23267
Grave number	3
Year of excavation	1944
Excavator/-s	EB Lundberg
MNI	1
Body position	supine
Gravetype	pit
Orientation	NS
Sex	male
Age group	mature
Age	45-60
Measurement details	Femur 1; L ; 464 mm
Stature (Sjovold 1990)	171.6 ±4.52 cm
local/non-local?	local
Sampled tooth (FDI)	34
$^{87}Sr/^{86}Sr$	0.7140
$\delta^{18}O_{carb}$ VPDB. ‰	-4.6
$\delta^{13}C$ (VPDB) ‰ apatite	-14.0
$\delta^{13}C$ (VPDB) ‰ collagen	-19.3
$\delta^{15}N$ (AIR) ‰ collagen	13.2
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	1170 +/-45
^{14}C calibrated	858 +/-68 AD
Date, typology as given in ÖJG	Iron Age?
Cribra orbitalia	1
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	0
Enthesopathy	1
OD	0
OA	0
Schmorls nodes	9
LEH	0
Pathology	Possibly bilateral rotator cuff syndrome. OP, PO in sites clavicle and humerus.

ID	*1089*
Parish	Smedby
SHM (grave field)	23267
Grave number	4?
Year of excavation	1944
Excavator/-s	Lundberg
MNI	1
Body position	
Gravetype	cist
Orientation	NS
Sex	male
Age group	juvenile
Age	18-21
Measurement details	Femur 1; L ; circa 173.8-175.4 cm
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	34
^{87}Sr/^{86} Sr	0.7122
δ^{18}O$_{carb}$ VPDB. ‰	-6.3
δ^{13}C (VPDB) ‰ apatite	-13.1
δ^{13}C (VPDB) ‰ collagen	-19.5
δ^{15}N (AIR) ‰ collagen	13.5
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	1890 +/-45
^{14}C calibrated	125 +/-57 AD
Date, typology as given in ÖJG	Early Roman Period?
Cribra orbitalia	1
Porotic hyperstosis	1
Non-specific Periostitis	9
Trauma	0
Enthesopathy	1
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	

ID	*1090*
Parish	Gärdslösa
SHM (grave field)	27702
Grave number	37
Year of excavation	
Excavator/-s	
MNI	2
Body position	supine
Gravetype	cist
Orientation	NS
Sex	male
Age group	young-mature
Age	
Measurement details	Tibia 1; 407 mm
Stature (Sjovold 1990)	181.24 ± 4.11 cm
local/non-local?	non-local
Sampled tooth (FDI)	34
^{87}Sr/^{86}Sr	0.7112
$\delta^{18}O_{carb}$ VPDB. ‰	-6.6
δ^{13}C (VPDB) ‰ apatite	-15.4
δ^{13}C (VPDB) ‰ collagen	-20.0
δ^{15}N (AIR) ‰ collagen	14.6
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Early Roman Period (IV:2)
Cribra orbitalia	1
Porotic hyperstosis	9
Non-specific Periostitis	1
Trauma	1
Enthesopathy	0
OD	0
OA	0
Schmorls nodes	1
LEH	0
Pathology	

ID	*1091*
Parish	Långlöt
SHM (grave field)	29352
Grave number	113
Year of excavation	
Excavator/-s	
MNI	1
Body position	mixed
Gravetype	cist
Orientation	NS
Sex	male
Age group	young-mature
Age	
Measurement details	Femur 1; L ; 476 mm
Stature (Sjovold 1990)	174. 86 ±4.52 cm
local/non-local?	gray
Sampled tooth (FDI)	24
^{87}Sr/^{86} Sr	0.7106
δ^{18}O$_{carb}$ VPDB. ‰	-5.7
δ^{13}C (VPDB) ‰ apatite	-13.9
δ^{13}C (VPDB) ‰ collagen	-19.3
δ^{15}N (AIR) ‰ collagen	14.2
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Early Roman Period (IV:1)
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	9
Trauma	1
Enthesopathy	1
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	Maxilla. Loss of all anterior teeth (incisors), alveoli almost completely closed. Not advanced PD enough to account for this. Likely trauma and violence since it is localized.

ID	*1092*
Parish	Mörbylånga
SHM (grave field)	12142
Grave number	9 över?
Year of excavation	1904
Excavator/-s	TJ Arne
MNI	4
Body position	unobservable
Gravetype	cist
Orientation	NS
Sex	male
Age group	mature-old
Age	
Measurement details	Femur 1; R;1; 107.5 mm; est. Total 452.8 mm; stature estimation from calculated total measurement 168.57 ±4.52 cm
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	44
$^{87}Sr/^{86}Sr$	0.7158
$\delta^{18}O_{carb}$ VPDB. ‰	-5.8
$\delta^{13}C$ (VPDB) ‰ apatite	-13.1
$\delta^{13}C$ (VPDB) ‰ collagen	-19.5
$\delta^{15}N$ (AIR) ‰ collagen	14.6
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Early Roman Period (IV:2)
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	1
Trauma	1
Enthesopathy	0
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	Perimortem BFT and SFT. Perimortem. 1, SFT to left side. Spanning the frontal (eye) to mid parietal bones. Sharp margin. Exact length undeterminable. 2, BFT to left parietal/frontal crossed by (2a, 2b) a small lesion on coronal suture where a part of the external table is missing. There is also bone missing here and one trauma is just indicated by radiating fractures (2c) and one has possible radiating fractures (2d).

ID	*1093*
Parish	Mörbylånga
SHM (grave field)	12142
Grave number	9 under
Year of excavation	1904
Excavator/-s	TJ Arne
MNI	4
Body position	unobservable
Gravetype	cist
Orientation	NS
Sex	male
Age group	young
Age	
Measurement details	Femur 1; L ; 497 mm
Stature (Sjovold 1990)	180.5 ± 4.52 c m
local/non-local?	local
Sampled tooth (FDI)	44
^{87}Sr/^{86} Sr	0.7158
δ^{18}O$_{carb}$ VPDB. ‰	-5.5
δ^{13}C (VPDB) ‰ apatite	-13.1
δ^{13}C (VPDB) ‰ collagen	-20.1
δ^{15}N (AIR) ‰ collagen	14.9
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Early Roman Period)
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Early Roman Period (IV:2)
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	1
Enthesopathy	1
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	Partly healed but misaligned fractures of tibia and fibula, L. Tibia: There is a diagonal fracture of the distal third of tibia with extensive misalignment and overlap in the lateral plane. Very prominent reduction in length. Cloace present. Extensive callus formation. Fibula: diagonal fracture of distal third with extensive misalignment (matching tibial injury) to lateral. Callus formation, cloace. Overlap, reduction in legnth.

ID	*1094*
Parish	Hulterstad
SHM (grave field)	25132
Grave number	
Year of excavation	1954
Excavator/-s	KG Petersson
MNI	1
Body position	prone
Gravetype	pit
Orientation	NS
Sex	female
Age group	old
Age	60
Measurement details	Femur 1; R ; 438 mm
Stature (Sjovold 1990)	164.5 ±4.52 cm
local/non-local?	local
Sampled tooth (FDI)	24
^{87}Sr/^{86}Sr	0.7116
δ^{18}O$_{carb}$ VPDB. ‰	-5.4
δ^{13}C (VPDB) ‰ apatite	-13.1
δ^{13}C (VPDB) ‰ collagen	-19.8
δ^{15}N (AIR) ‰ collagen	15.9
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	1890+-50 BP
^{14}C calibrated	125 +/-62 AD
Date, typology as given in ÖJG	Early Roman Period (B2/C1a)
Cribra orbitalia	1
Porotic hyperstosis	0
Non-specific Periostitis	9
Trauma	1
Enthesopathy	1
OD	0
OA	9
Schmorls nodes	0
LEH	0
Pathology	1: Multiple perimortem BFT and SFT, mainly involving parietals and frontal. (D) is a BFT with radiating fractures in the frontal bone. The impact site fragment is missing and it has irregular margins, slight internal bevelling. The location is circa 5 cm above the supraorbital margin. (A) is likely a grazing SFT. It is just above the site (D). This lesion also penetrates throught the internal tabulae. (A) is transversed by the radiating fractures from (D), so consequently before it in sequence. (C) is a lesion of unkown location (the fragment is missing) and is a BFT. The radiating fractures from (D) all stop at a transverse fracture crossing both parietals from L to R coming from the unkown site of (D). (B) is a grazing SFT. It is located traversing the fracture line of (C) and consequently afflicted before (C) and (D). (E) is a possible BFT impact site directly below (B) is a faint depression into the fracture line from (C). No signs of healing for any of these injuries. 2: Spondylolysis of L4. Secondary OA (also EB, not just OP and PO) in R side.

ID	*1095*
Parish	Norra Möckleby
SHM (grave field)	25605
Grave number	
Year of excavation	1956
Excavator/-s	Hofrén
MNI	1
Body position	supine
Gravetype	cist
Orientation	NS
Sex	male
Age group	young
Age	ad
Measurement details	Femur 1; R ; 461 mm
Stature (Sjovold 1990)	170.8 ±4.52
local/non-local?	local
Sampled tooth (FDI)	34
^{87}Sr/^{86} Sr	0.7112
δ^{18}O$_{carb}$ VPDB. ‰	-6.3
δ^{13}C (VPDB) ‰ apatite	-14.0
δ^{13}C (VPDB) ‰ collagen	-20.5
δ^{15}N (AIR) ‰ collagen	11.4
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	2255+/-50 BP
^{14}C calibrated	305 +/-69 BC
Date, typology as given in ÖJG	Iron Age?
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	0
Enthesopathy	0
OD	1
OA	0
Schmorls nodes	9
LEH	0
Pathology	1: First cuneiform. True bipartite form in R and partial bipartite in L. 2: Clearly asymmetric skull. L part of the facial skeleton is more potruding than the R From the anterior view the L side of the face is more superior than the L. The R side of the skull is more potruding in both parietals and occipital. Premature suture fusion seems likely.

ID	*1096*
Parish	Torslunda
SHM (grave field)	24813
Grave number	II
Year of excavation	1952
Excavator/-s	Lakocinski
MNI	2
Body position	mixed
Gravetype	cist
Orientation	NS
Sex	male?
Age group	young-mature
Age	
Measurement details	Femur 1; L; 116.6 mm; est. Total 458.26 mm; stature estimation from calculated total measurement 170.05 ± 4.52 cm
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	34
$^{87}Sr/^{86}Sr$	0.7133
$\delta^{18}O_{carb}$ VPDB. ‰	-6.5
$\delta^{13}C$ (VPDB) ‰ apatite	-13.9
$\delta^{13}C$ (VPDB) ‰ collagen	-19.4
$\delta^{15}N$ (AIR) ‰ collagen	13.4
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	1965 +/-45
^{14}C calibrated	25 +/-47 AD
Date, typology as given in ÖJG	Early Roman Period (IV:1)
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	1
Trauma	0
Enthesopathy	0
OD	1
OA	9
Schmorls nodes	9
LEH	0
Pathology	

ID	*1097*
Parish	Kastlösa
SHM (grave field)	22763
Grave number	-
Year of excavation	1941
Excavator/-s	Rosell
MNI	1
Body position	supine
Gravetype	pit
Orientation	WE
Sex	female?
Age group	mature
Age	
Measurement details	Femur 1; R ; 428 mm
Stature (Sjovold 1990)	161.8 ± 4.52 cm
local/non-local?	non-local
Sampled tooth (FDI)	34
$^{87}Sr/^{86}Sr$	0.7090
$\delta^{18}O_{carb}$ VPDB. ‰	-3.6
$\delta^{13}C$ (VPDB) ‰ apatite	-13.4
$\delta^{13}C$ (VPDB) ‰ collagen	-19.5
$\delta^{15}N$ (AIR) ‰ collagen	12.9
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	1000 +/-50 BP
^{14}C calibrated	1053 +/-60 AD
Date, typology as given in ÖJG	Viking Age?
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	9
Trauma	0
Enthesopathy	1
OD	9
OA	0
Schmorls nodes	9
LEH	0
Pathology	

ID	*1098*
Parish	Källa
SHM (grave field)	4186/73
Grave number	3
Year of excavation	1973
Excavator/-s	Kenth Holgersson
MNI	1
Body position	supine
Gravetype	cist
Orientation	WE
Sex	male?
Age group	mature-old
Age	
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	34
^{87}Sr/^{86}Sr	0.7117
δ^{18}O$_{carb}$ VPDB. ‰	-5.7
δ^{13}C (VPDB) ‰ apatite	-13.8
δ^{13}C (VPDB) ‰ collagen	-20.1
δ^{15}N (AIR) ‰ collagen	11.3
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Pre Roman Iron Age
^{14}C conventional age, BP	NA
^{14}C calibrated	160-140 fkr*
Date, typology as given in ÖJG	
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	9
Trauma	0
Enthesopathy	1
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	1: Perio-/postmortem. Partial burning. The coloring of the bones range from brown to black/bluegrey. The skull is more severly burned on the L side than the R. The L arm is more burned than the R and especially mid diaphysis on humerus. The spine is burned heavily in the anterior part and the ribs more on the first/upper than the lower. 2: Antemortem. Rib II, R. There is an area with lighter bone and thickening, likely a dorsal and sagittal fracture line. A healed partial fracture.

ID	*1099*
Parish	Mörbylånga
SHM (grave field)	1785/67
Grave number	5
Year of excavation	1966-67
Excavator/-s	ES Köningsson, B Falk-Gehlin
MNI	1
Body position	unobservable
Gravetype	cist
Orientation	NA
Sex	female
Age group	juvenile
Age	18-19
Measurement details	Femur 1; R ; 399 mm
Stature (Sjovold 1990)	154.0 ±4 .52 cm
local/non-local?	local
Sampled tooth (FDI)	34
$^{87}Sr/^{86}Sr$	0.7131
$\delta^{18}O_{carb}$ VPDB. ‰	-6.1
$\delta^{13}C$ (VPDB) ‰ apatite	-13.5
$\delta^{13}C$ (VPDB) ‰ collagen	-19.8
$\delta^{15}N$ (AIR) ‰ collagen	13.7
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Late Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Late Roman Period (V)
Cribra orbitalia	1
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	0
Enthesopathy	1
OD	0
OA	0
Schmorls nodes	9
LEH	1
Pathology	

ID	*1100*
Parish	Långlöt
SHM (grave field)	25021
Grave number	
Year of excavation	1953
Excavator/-s	KG Petersson
MNI	1
Body position	
Gravetype	pit
Orientation	NS
Sex	male
Age group	juvenile
Age	16-18
Measurement details	Femur 1; L/R minimum 179 cm
Stature (Sjovold 1990)	
local/non-local?	non-local
Sampled tooth (FDI)	24
$^{87}Sr/^{86}Sr$	0.7310
$\delta^{18}O_{carb}$ VPDB. ‰	-6.9
$\delta^{13}C$ (VPDB) ‰ apatite	-14.1
$\delta^{13}C$ (VPDB) ‰ collagen	-19.7
$\delta^{15}N$ (AIR) ‰ collagen	14.1
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	1935 +/-50 BP
^{14}C calibrated	61 +/-54 AD
Date, typology as given in ÖJG	?
Cribra orbitalia	1
Porotic hyperstosis	9
Non-specific Periostitis	0
Trauma	1
Enthesopathy	1
OD	9
OA	9
Schmorls nodes	1
LEH	0
Pathology	

ID	*1101*
Parish	Böda
SHM (grave field)	21367
Grave number	24
Year of excavation	1935
Excavator/-s	TJ Arne
MNI	2
Body position	supine
Gravetype	coffin
Orientation	WE
Sex	male
Age group	young
Age	ca 23
Measurement details	Femur 1; L ; 476 mm
Stature (Sjovold 1990)	174.9 ±4.52 cm
local/non-local?	non-local
Sampled tooth (FDI)	44
$^{87}Sr/^{86}Sr$	0.7319
$\delta^{18}O_{carb}$ VPDB. ‰	-5.0
$\delta^{13}C$ (VPDB) ‰ apatite	-14.5
$\delta^{13}C$ (VPDB) ‰ collagen	-19.2
$\delta^{15}N$ (AIR) ‰ collagen	12.4
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Viking Age
Cribra orbitalia	0
Porotic hyperstosis	1
Non-specific Periostitis	1
Trauma	0
Enthesopathy	0
OD	0
OA	0
Schmorls nodes	9
LEH	0
Pathology	A periostal reaction with thickening and micropores is present on many bones. There are traces of blood vessles in the periostal depositions and no sequestra. The surface has spicules sometimes and is sometimes more of a smooth candlewax texture. The distribution appears very symmetrical bilaterally. The femoral-tibial joints show moderate detoriation (notable due to age). There are no apparent lesions to the skull except for a small depression in the frontal. The lesions mostly appear in surfaces with little soft tissue but are also occasionally present in sites with much soft tissue. Occurence of leisons in: Frontal, parietal, occipital, nasal, tibia, femur, radius, ulna (diaphysis), ribs, hand ph III (palmar quite prominent), ph II andI, Mt, tarsals. Appears largely bilateral but not necessarily symmetrical. A few vertebral body fragments, all show very fine densified trabeculae. The spine, Ph II and III of feet are missing. The distribution and appearance of lesions is comparable to hypertrophic pulmonary osteoarthropaty, verified by x-ray imaging. 2: Rib, L . Partial fracture. There is a depression in the outer surface and displacement (slight) to inferior. Other ribs appear undamaged. 3: Mt II;. Dorsal, medial, and lateral surfaces show heavy OP (callus) and remodeling. The distal end is angulated to inferior. The plantar surface is unremodeled. Partial fracture or trauma. 4: Frontal. A small round depression above L eye, possibly well healed BFT.

ID	*1102*
Parish	Smedby
SHM (grave field)	23349
Grave number	3 (?)
Year of excavation	1945
Excavator/-s	E B Lundberg
MNI	4
Body position	supine
Gravetype	cist
Orientation	NS
Sex	NA
Age group	child
Age	7-8
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	36
^{87}Sr/^{86}Sr	0.7121
δ^{18}O$_{carb}$ VPDB. ‰	-5.2
δ^{13}C (VPDB) ‰ apatite	-13.8
δ^{13}C (VPDB) ‰ collagen	-19.8
δ^{15}N (AIR) ‰ collagen	13.2
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Roman Iron Age
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Roman Iron Age
Cribra orbitalia	9
Porotic hyperstosis	0
Non-specific Periostitis	1
Trauma	0
Enthesopathy	0
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	

ID	*1103*
Parish	Persnäs
SHM (grave field)	21368
Grave number	37 undre
Year of excavation	1935?
Excavator/-s	TJ Arne
MNI	2
Body position	unavailable
Gravetype	cist
Orientation	NS
Sex	female
Age group	old
Age	
Measurement details	Femur 1; L;1; 139.4 mm; est. Total 471.94 mm; stature estimation from calculated total measurement 173.76 ± 4.52 cm
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	14
^{87}Sr/^{86} Sr	0.7139
δ^{18}O$_{carb}$ VPDB. ‰	-5.5
δ^{13}C (VPDB) ‰ apatite	-13.7
δ^{13}C (VPDB) ‰ collagen	-19.9
δ^{15}N (AIR) ‰ collagen	13.3
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Early Roman Period (B2)
Cribra orbitalia	0
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	1
Enthesopathy	0
OD	0
OA	1
Schmorls nodes	1
LEH	0
Pathology	1: Rib; Transverse possible fracture. A depression in the dorsal surface. Superior and inferior margins are displaced towards inwards. Rib number and side=unkown, one of the middle-lower ribs. 2: Spondylolysis of L5, bilateral.

ID	*1104*
Parish	Persnäs
SHM (grave field)	21368
Grave number	37 övre
Year of excavation	1935
Excavator/-s	TJ Arne
MNI	2
Body position	unavailable
Gravetype	cist
Orientation	NS
Sex	male?
Age group	young-mature
Age	
Measurement details	Femur 1; L ; 465 mm
Stature (Sjovold 1990)	171.9 ± 4.52 cm
local/non-local?	local
Sampled tooth (FDI)	44
^{87}Sr/^{86}Sr	0.7129
$\delta^{18}O_{carb}$ VPDB. ‰	-6.5
δ^{13}C (VPDB) ‰ apatite	-15.3
δ^{13}C (VPDB) ‰ collagen	-19.8
δ^{15}N (AIR) ‰ collagen	12.1
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Early Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Early Roman Period (B1-B2)
Cribra orbitalia	1
Porotic hyperstosis	9
Non-specific Periostitis	0
Trauma	0
Enthesopathy	1
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	

ID	*1105*
Parish	Gärdslösa
SHM (grave field)	28364
Grave number	108:I:169
Year of excavation	1965
Excavator/-s	
MNI	4
Body position	unobservable
Gravetype	cist
Orientation	NS
Sex	male?
Age group	young
Age	
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	non-local
Sampled tooth (FDI)	34
$^{87}Sr/^{86}Sr$	0.7099
$\delta^{18}O_{carb}$ VPDB. ‰	-3.4
$\delta^{13}C$ (VPDB) ‰ apatite	-15.6
$\delta^{13}C$ (VPDB) ‰ collagen	-20.0
$\delta^{15}N$ (AIR) ‰ collagen	11.6
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Viking Age
^{14}C conventional age, BP	1175 +/-50
^{14}C calibrated	853 +/-71 AD
Date, typology as given in ÖJG	Early Roman Period
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	9
Trauma	9
Enthesopathy	9
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	

ID	*1106*
Parish	Gärdslösa
SHM (grave field)	28364
Grave number	108:IV:282
Year of excavation	1965
Excavator/-s	
MNI	4
Body position	supine
Gravetype	cist
Orientation	NS
Sex	male
Age group	mature-old
Age	
Measurement details	Femur 1; L;1; 92.7 mm; est. Total 492.21 mm; stature estimation from calculated total measurement 179.25 ±4.52 cm
Stature (Sjovold 1990)	
local/non-local?	non-local
Sampled tooth (FDI)	44
^{87}Sr/^{86} Sr	0.7343
δ^{18}O$_{carb}$ VPDB. ‰	-5.7
δ^{13}C (VPDB) ‰ apatite	-13.7
δ^{13}C (VPDB) ‰ collagen	-19.9
δ^{15}N (AIR) ‰ collagen	13.1
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Pre Roman Iron Age
^{14}C conventional age, BP	2065 +/-45
^{14}C calibrated	91 +/-61 BC
Date, typology as given in ÖJG	Early Roman Period
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	0
Trauma	0
Enthesopathy	0
OD	0
OA	0
Schmorls nodes	9
LEH	0
Pathology	

ID	*1107*
Parish	Persnäs
SHM (grave field)	19765
Grave number	13
Year of excavation	1931
Excavator/-s	TJ Arne
MNI	2
Body position	supine
Gravetype	cist
Orientation	NS
Sex	male
Age group	young
Age	25-30
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	14
^{87}Sr/^{86} Sr	0.7131
δ^{18}O$_{carb}$ VPDB. ‰	-5.4
δ^{13}C (VPDB) ‰ apatite	-12.9
δ^{13}C (VPDB) ‰ collagen	-19.7
δ^{15}N (AIR) ‰ collagen	12.8
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Late Roman Period
^{14}C conventional age, BP	
^{14}C calibrated	
Date, typology as given in ÖJG	Late Roman Period
Cribra orbitalia	1
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	1
Enthesopathy	1
OD	0
OA	0
Schmorls nodes	1
LEH	0
Pathology	The skull has a great deal of fractures caused by either (both) SFT’s or BFT´s to the skull. The R Parietal has sharp margins, possibly indicating a SFT. There are also radiating fractures from an oval/circular hole. The margins are partly missing and damaged (either a BFT or a SFT). The L Parietal has two circular fractures, one larger and one smaller and a sagittal SFT. The larger circle is a continuation of the SFT, a terminal fracture. The injuries are a mixture of BTF and SFT, all in a perimortem event.

ID	*1108*
Parish	Sandby
SHM (grave field)	Sb
Grave number	Individ I
Year of excavation	2011-2012
Excavator/-s	Victor
MNI	
Body position	supine
Gravetype	house
Orientation	NA
Sex	male
Age group	juvenile
Age	17-19
Measurement details	Femur 1; L ; 462 mm
Stature (Sjovold 1990)	171.1 ± 4.52 cm
local/non-local?	local
Sampled tooth (FDI)	44
^{87}Sr/^{86} Sr	0.7110
δ^{18}O$_{carb}$ VPDB. ‰	-6.1
δ^{13}C (VPDB) ‰ apatite	-13.7
δ^{13}C (VPDB) ‰ collagen	-18.9
δ^{15}N (AIR) ‰ collagen	15.0
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Migration Period
^{14}C conventional age, BP	**
^{14}C calibrated	(400-550) **
Date, typology as given in ÖJG	Migration Period
Cribra orbitalia	1
Porotic hyperstosis	0
Non-specific Periostitis	0
Trauma	1
Enthesopathy	0
OD	0
OA	0
Schmorls nodes	0
LEH	1
Pathology	1: SFT covering the L parietal and temporal. Fragmented skull (sutures open). Localized outer flaking, inner single flakes. See photos. Perimortem. 2: Scapula, R; There are at least three SFT injuries and at least two parallell SFT´s through the spina and one vertical from posterior/anterior. Very sharp margins and no signs of healing. No SFT visible on preserved Ribs 2-4. Perimortem. 3: Rib, R. A transverse callus formation with a thickening of the diaphysis (more sternal than vertebral part of the diaphysis). Antemortem fracture.

ID	*1109*
Parish	Sandby
SHM (grave field)	Sb
Grave number	Individ 2
Year of excavation	2012-2013
Excavator/-s	Victor
MNI	
Body position	prone
Gravetype	house
Orientation	NA
Sex	male
Age group	young
Age	19-22
Measurement details	Femur 1; R ; 468 mm
Stature (Sjovold 1990)	175.4 ± 4.52 cm
local/non-local?	local
Sampled tooth (FDI)	34
^{87}Sr/^{86}Sr	0.7109
δ^{18}O$_{carb}$ VPDB. ‰	-5.5
δ^{13}C (VPDB) ‰ apatite	-12.7
δ^{13}C (VPDB) ‰ collagen	-18.5
δ^{15}N (AIR) ‰ collagen	15.2
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Migration Period
^{14}C conventional age, BP	**
^{14}C calibrated	(400-550) **
Date, typology as given in ÖJG	Migration Period
Cribra orbitalia	0
Porotic hyperstosis	9
Non-specific Periostitis	1
Trauma	1
Enthesopathy	1
OD	9
OA	9
Schmorls nodes	1
LEH	0
Pathology	1: Transverse SFT in one rib. Both parts of rib present, see photos. Perimortem. 2: Mc 5, L; lateral; superior; trauma to the lateral side. See photos. Antemortem.

ID	*1111*
Parish	Gärdslösa
SHM (grave field)	26733/26732
Grave number	26
Year of excavation	
Excavator/-s	
MNI	1
Body position	unavailable
Gravetype	wetland
Orientation	NA
Sex	female?
Age group	young-mature
Age	
Measurement details	Femur 1; L ; 82.2 mm; est. Total 46.09 mm; stature estimation from calculated total measurement 170.70 ±4.52 cm
Stature (Sjovold 1990)	
local/non-local?	non-local
Sampled tooth (FDI)	37
^{87}Sr/^{86}Sr	0.7155
$\delta^{18}O_{carb}$ VPDB. ‰	-7.6
δ^{13}C (VPDB) ‰ apatite	-14.7
δ^{13}C (VPDB) ‰ collagen	-20.1
δ^{15}N (AIR) ‰ collagen	11.3
Sampled bone (δ^{13}C δ^{15}N)	mandible
Date, typology and 14C	Pre Roman Iron Age
^{14}C conventional age, BP	2085 +/-30BP
^{14}C calibrated	112 +- 45 BC***
Date, typology as given in ÖJG	
Cribra orbitalia	9
Porotic hyperstosis	0
Non-specific Periostitis	9
Trauma	1
Enthesopathy	9
OD	9
OA	9
Schmorls nodes	9
LEH	9
Pathology	1: Parietal, R. SFT, sharp margins. See photos. Perimortem. 2: Parietal, L. Depression in the endocranial surface with tilting margins that are smooth. Corresponding convexity endocranially. Circa 24x24 mm .See photos. Antemortem, BFT (?). 3: Endocranial, parietals. A lighter periostal deposition is present on/along the sagittal suture. Possibly meningitis?

ID	*1112*
Parish	Gärdslösa
SHM (grave field)	27121
Grave number	2
Year of excavation	
Excavator/-s	
MNI	1
Body position	unavailable
Gravetype	wetland
Orientation	NA
Sex	undetermined
Age group	juvenile-young
Age	
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	47
$^{87}Sr/^{86}Sr$	0.7120
$\delta^{18}O_{carb}$ VPDB. ‰	-6.3
$\delta^{13}C$ (VPDB) ‰ apatite	-13.6
$\delta^{13}C$ (VPDB) ‰ collagen	-19.6
$\delta^{15}N$ (AIR) ‰ collagen	12.7
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Pre Roman Iron Age
^{14}C conventional age, BP	2110 +-35 BP
^{14}C calibrated	134 +/-49 BC***
Date, typology as given in ÖJG	
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	9
Trauma	9
Enthesopathy	9
OD	9
OA	9
Schmorls nodes	9
LEH	9
Pathology	

ID	*1113*
Parish	Gärdslösa
SHM (grave field)	26239
Grave number	8
Year of excavation	
Excavator/-s	
MNI	1
Body position	unavailable
Gravetype	wetland
Orientation	NA
Sex	NA
Age group	juvenile
Age	15+/-1
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	gray
Sampled tooth (FDI)	47
$^{87}Sr/^{86}Sr$	0.7107
$\delta^{18}O_{carb}$ VPDB. ‰	-5.4
$\delta^{13}C$ (VPDB) ‰ apatite	-14.2
$\delta^{13}C$ (VPDB) ‰ collagen	-18.8
$\delta^{15}N$ (AIR) ‰ collagen	13.9
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Vendel Period
^{14}C conventional age, BP	1265 +- 30BP
^{14}C calibrated	729 +/-36 AD***
Date, typology as given in ÖJG	
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	9
Trauma	9
Enthesopathy	9
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	

ID	*1114*
Parish	Gärdslösa
SHM (grave field)	26732
Grave number	15
Year of excavation	
Excavator/-s	
MNI	1
Body position	unavailable
Gravetype	wetland
Orientation	NA
Sex	female?
Age group	young-old
Age	
Measurement details	
Stature (Sjovold 1990)	
local/non-local?	local
Sampled tooth (FDI)	48
$^{87}Sr/^{86}Sr$	0.7150
$\delta^{18}O_{carb}$ VPDB. ‰	-6.4
$\delta^{13}C$ (VPDB) ‰ apatite	-11.4
$\delta^{13}C$ (VPDB) ‰ collagen	-20.2
$\delta^{15}N$ (AIR) ‰ collagen	10.7
Sampled bone ($\delta^{13}C$ $\delta^{15}N$)	mandible
Date, typology and 14C	Pre Roman Iron Age
^{14}C conventional age, BP	2250 +-35BP
^{14}C calibrated	308 +-65 BC***
Date, typology as given in ÖJG	
Cribra orbitalia	9
Porotic hyperstosis	9
Non-specific Periostitis	9
Trauma	9
Enthesopathy	9
OD	9
OA	9
Schmorls nodes	9
LEH	0
Pathology	

Animals

Id	Species	Site (SHM)	Subperiod	Bone element	δ^{13}C (VPDB) ‰	δ^{15}N (AIR) ‰
1223	Cattle	27362	EIA	Malleolar, R	-22.0	6.7
1225	Cattle	28361	IA (Roman Iron Age-Vendel period)	Maxilla	-21.7	6.2
1246	Cattle	Sandby borg	LIA (Migration period)	Humerus, R	-21.6	6.1
1244	Sheep/goat	23280	EIA (Late Roman period)	Astragalus, L	-21.5	8.6
1235	Sheep/goat	27702	EIA (Early Roman period)	Astragalus, R	-21.4	8.0
1230	Cattle	27362	EIA	Frontal	-21.3	5.4
1204	Cattle	27702	EIA (Early Roman period)	Astragalus, L	-21.3	5.6
1245	Pig	27362	EIA	Metacarpal V, L	-21.0	9.4
1241	Chicken	23280	EIA (Late Roman period)	Humerus , L	-20.9	11.2
1216	Sheep/goat	27362	E I A	Atlas	-20.9	8.2
1224	Sheep/goat	27362	E I A	Calcaneum	-20.5	8.9
1238	Sheep/goat	10302	IA	Phalanx I	-20.3	7.1
1214	Pig	31597	IA	Canine	-19.7	9.7
1242	Pig	10302	IA	Humerus, L	-19.5	8.0
1205	Chicken	25570	IA	Humerus, R	-16.0	11.3
1213	Flounder	31597	IA	Anal	-13.3	8.3
1211	Pike	27362	EIA	Vertebrae	-11.8	10.8
1231	Cat	31597	IA	Humerus, L	-17.8	11.9
1201	Dog	12142	EIA (Early Roman period)	Mandible	-18.1	12.3
1202	Dog	22231	LIA (Vendel period)	Mandible	-19.8	12.1
1237	Dog	27702	EIA (Early Roman IA)	Mc2, L	-20.0	11.3
1239	Dog	10302	IA	Radius, R	-15.9	12.5
1247	Dog	Sandby borg	LIA (Migration period)	Ulna ,L	-17.6	12.6
1222	Horse	28549	LIA (Viking Age)	Petrous portion, L	-21.6	7.1
1210	~~Seal~~	~~27362~~	~~IA (Roman-Vendel period)~~	~~Petrous portion, R~~	~~-16.2~~	~~16.2~~
1217	Seal	27362	IA (Roman-Vendel period)	Occipital	-15.7	14.0

Lab id	Animal	Tooth	87Sr/86Sr	δ18O (VPDB) ‰	δ13C (VPDB) ‰	Site (SHM)	Bone id	Feature id
F8185	Dog	m1sin	0.71208	-18.4	-12.6	31890	1228	A17
F8187	Dog	P3 max dxt	0.72042	-7.9	-13.4	27513	1232	3
F8191	Dog	Canine	0.70978	-7.4	-12.4	10302	1240	A1:1
F8173	Dog	M2 lower	0.72147	-7.4	-12.3	22231	1202	A4
F8172	Dog	PM4 lower	0.71472	-6.9	-11.5	12142	1201	
F8189	Dog	I3 max sin	0.71154	-6.2	-14.0	27702	1234	A2
F8179	Dog	I2 max sin	0.71635	-4.8	-13.2	31890	1218	A5
F8176	Microfauna	Mandible/molars	0.71576	-19.5	-13.8	27362	1209	F99
F8178	Microfauna	Mandible/molars	0.71774	-18.9	-14.5	28364	1215	108. F231
F8183	Microfauna	dentes	0.71228	-18.2	-13.7	27362	1226	F13
F8190	Microfauna	dentes	0.71747	-16.5	-14.2	27702	1236	A2
F8184	Microfauna	dentes	0.71347	-16.4	-12.4	31890	1227	A17
F8180	Microfauna	Enamel	0.71416	-16.0	-11.2	31890	1219	A5
F8177	Microfauna	Mandible/molars	0.71239	-15.5	-12.6	27362	1211	F112
F8186	Microfauna	dentes	0.71176	-14.5	-12.5	28364	1229	108 F169. I
F8174	Pig	Enamel fragment molar/premolar	0.71201	-12.3	-14.1	27362	1206	F112
F8175	Pig	P3 dxt	0.71890	-9.2	-12.9	28364	1207	A85
F8181	Sheep/goat	M3 max sin. adult	0.71392	-16.6	-13.3	SANDBYBORG	1220	house 40
F8192	Sheep/goat	P4 max sin	0.71268	-15.7	-13.1	10302	1243	A1:1
F8188	Sheep/goat	M1 max	0.71156	-13.7	-12.3	27702	1233	A2
F8182	Sheep/goat	M1 mand. subadult/adult	0.71213	-13.1	-14.2	SANDBYBORG	1221	house 40

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For those people not working as osteologists and not used to coming face to face with human remains on a daily basis, I realize the images on the cover may stir emotions of curiosity and interest, but also possibly fear or concern. These images are not random photos of a skull to catch attention and capitalize on the visuality of human skeletal remains. On the contrary, they represent the entire point of this study, as well as hinting at the value of skeletal remains for archaeology today.

The image on the front cover is the back of a fragmented skull, the back cover is the facial skeleton of the same individual as the skull was being excavated in the lab. This is ID 1109, a man 19–21 years of age who died probably very violently at the hand of another person. He was not buried. He was left lying face down on the floor of a house until the house collapsed on top of him and fragmented his skull. At one point when he was skeletonized, a part of his right elbow was gnawed by a rodent to access the mineral content of his bones. By studying his bones during and after excavation, I am able to discuss what happened to him in death, his mortography, and in life, his biography.

I retrieved the skull *en bloc* (still encapsulated largely in the soil of the floor layer of the house) and proceeded to excavate in the lab. As he was lying face down when we found him, it was not until I turned the soil block upside down that his face was visible again for the first time in over 1500 years. For me, looking at his face was fascinating and, of course, I began to analyse its features. But there is something about looking at a face, albeit a skeletal one, that affects you, osteologist or not.

It is well established in neurology and cognition that a human looking at both animate and inanimate faces experiences a neural mechanism (an electromagnetic reaction) that is different from when looking at images of animals or objects (e.g. review in Rivolta et al., 2016; Roisson, 2014; Haxby et al., 2000; Kanwisher et al., 1997; Bentin et al., 1996). Seeing something identifiable as a face literally activates your brain differently than any other image would. Perhaps this is why even skeletal remains, skulls in particular, hold fascination in art, as well as in other cultural representations, and its connotations are strong even in humans today. It is something we recognize across time and space, and that, like it or not, actually provokes a brain response. This is why I wish to put you, the reader, face to face with this individual, so you can experience the past at an individual level while at the same time appreciating a sense of the content and aims of this book. Looking at this image and reading this thesis I hope to show how important it is to consult skeletal remains – once living persons – when trying to understand the past.

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