Osteological Markers of Nutritional Stress on the Swedish Island of Öland:

Physiological Effects of Environmental Fluctuations during the Scandinavian Iron Age

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ABSTRACT

The shift to agriculture as the main form of subsistence practice allowed past peoples the freedom and potential to exploit their natural and man-made environment for personal and societal gain. Decades of archaeological excavations conducted on the Swedish island of Öland have amassed a wealth of information regarding the subsistence and settlement patterns of Iron Age societies. This thesis aims to contextualize the compiled Iron Age osteological material within a reconstructed environment in order to understand the nutritional and general physiological stressors faced by people at the time. The Old World Drought Atlas (OWDA) was utilized to isolate drought/pluvial data pertaining to the relative geography of Öland in order to generate a reconstruction of soil-moisture trends from 0-1050AD. When compared to OWDA data from the Baltic region, the analysis indicates that the climate of Öland was typically drier than within the greater Baltic area. Rates of skeletal pathologies were calculated and compared to the climatic fluctuations on Öland, to determine whether periods of overly wet or dry conditions may have had physiological affects upon the local population. The osteological analysis indicates periods of no (or relatively few) skeletons with recorded pathologies or accurate dating, leaving a period of roughly 300 years without any osteological record. While this thesis was unable to accredit these periods to any specific environmental extremes, it is noteworthy that this timeframe encapsulates two hypothesized incidences of societal crisis on Öland. The analysis also indicates several periods of increased frequencies in skeletal pathologies, following years of climate fluctuations from dry to wet. Further analyses concluded that a dietary shift occurred within the population over the Iron Age, perhaps as a cause of shifting climate or heavier reliance on agriculture and animal husbandry. A Multiple Correspondence Analysis (MCA) was run to highlight possible relationships between the osteological variables, indicating potential relationships between 1. stature and linear enamel hypoplasia and stature, 2. the two dietary isotopes, and 3. porotic hyperostosis (PH), cribra orbitalia (CO) and trauma. Ultimately, further research is required to determine the exact effects of climate fluctuations upon Öland and how subsistence practices and nutrition intake was associated with the dry Öland climate.

Keywords: Old World Drought Atlas; Dendroclimatology; Nutrition; Osteology; Multiple Correspondence Analysis; Skeletal Pathology; Dietary Isotopes; Environmental Reconstructions; Historic Climate; Iron Age; Sweden; Baltic Region

INTRODUCTION

Throughout history, societies and their inhabitants have had to adapt to changes in local and global climates. Evolving environments and erratic weather fluctuations put great pressures on all aspects of human life and the social structures in place to protect them. Bearing the brunt of the effects of weather fluctuation were the yields of harvests, where too much or too little precipitation and varying temperatures had drastic effects on all who relied on those harvests (Armit *et al* 2014).

Agrarian societies are at the mercy of their local climates. Through the combination of labor and a favorable climate, agriculture and animal husbandry can flourish. However, even with human ingenuity farming communities are subject to the whims of the weather, either directly (through too much or too little precipitation, favorable or unfavorable temperatures, severe weather conditions, etc.) or indirectly (pests, plant or animal disease, etc.). Diminished quantity and quality of food may leave individuals in a state of malnutrition in which the immune system is weakened, resulting in increased susceptibility to infection, disease, and dietary deficiency related pathologies.

There are several notable moments throughout history when entire societies have been crippled by the blight of their local food sources, perhaps none so well-known as the Great Famine in Ireland, a period of mass starvation and disease spanning from 1845-1849. Although it is not known exactly how many people died over the course of the famine, it is believed that more died from disease brought on by the unfavorable conditions than by starvation itself. Diseases listed by the contemporary census include such malignancies as fever, diphtheria, dysentery, cholera, smallpox and influenza during the decade between 1841-1851. Some historians have disputed the death tables, arguing that the census likely underestimated the actual degree of disease-related mortality at the time, perhaps exhibiting bias due to the political conditions but more likely because death and emigration had disabled the administration of local population structures.

While easy to assume that the greatest part of the mortality of the Irish Potato Famine was caused by nutritional deficiency diseases, this is not the case. Rather, famine-induced ailments due to a weakened immune system left malnourished individuals very susceptible to infections (Geber 2017). Measles, diphtheria, diarrhea, tuberculosis, respiratory infections, whooping cough, intestinal parasites, and cholera infection rates during the Famine are clearly related to nutritional status. Additional diseases, such as smallpox and influenza, ravaged the weakened population and the congregation of victims in crowded places such as soup kitchens, workhouses and food depots exacerbated conditions that were ideal for spreading fevers and infectious disease.

While the extremity of the Irish Potato Famine is a significant contributing factor to the high mortality rates at the time, even lesser instances of malnutrition can lead to a decreased quality of health. While malnutrition occurs population-wide during periods of famine, famine is not necessary for individual instances of malnutrition to occur (Caine *n.d.*). For instance, varying degrees of vitamin and iron deficient diets will have impact the skeleton (Geber 2017). It may be only the skeletal remains which indicate that any dietary hindrances were faced in historical instances of lesser nutritional deficits.

To learn from the past is to understand the present and plan for the future. The impact of climatic shifts is of contemporary concern, and by analyzing the effects of past environmental changes on historic populations, we may hope to apply this information in years to come. The link between climate change and changing population dynamics has been theorized (and proven, to various degrees) previously. This study will approach climate change not as a typical temperature-based study but will instead utilize newly published data regarding variation in soil moisture contents across the European continent. Combined with previously compiled osteological material, drought data will be looked upon as a potential driver of nutritional variation and resulting mortality rates.

Purpose and Aims

The purpose of this thesis is to explore the relationships between historical environmental reconstructions of periods of extreme climate and the resulting pathology/mortality rates in Öland from the Iron Age through the Viking Age (from 0-1050 AD). Past studies and ongoing investigations are expanding our knowledge of life on Öland during the Early and Late Iron Ages, and this investigation will support past findings while increasing attention of the impact of local and global environments upon life around the Baltic. Through a comparative analysis of osteology, climate data and settlement patterns, this thesis will seek to provide a glimpse into the agricultural society of Öland.

Research Questions

This thesis seeks to answer the following research questions:

- As an isolated landmass the island of Öland provides an opportunity to understand and interpret localized societal stresses within the greater context of the Baltic Area. Does the reconstructed climate of Öland represent an outlier in the Baltic Area during the Iron Age?
- Does the OWDA scPDSI index indicate any extremes in soil moisture content on Öland during the study period? Do soil moisture values correspond with known or hypothesized periods of cultural/societal upheaval?
- Is there a correlation between the occurrence of osteological pathologies and chronology on Öland? Are the rates of pathologies associated with times of extreme climate?

Agriculture in Sweden: An Iron Age Shift

The Iron Age is a designation of a period generally accepted to encompass the final stage of human prehistory, having been preceded by the Stone and Bronze Ages. The Iron Age marks the transition of technology in both tools and weaponry, from bronze-made to iron. Iron working was introduced to Europe during the late 11th century BC and spread at differing rates across the continent from the southeast towards the north and west. The Iron Age in Scandinavia is marked by several subperiods: the Pre-Roman Iron Age (circa 500BC-0 AD), the Early Roman Iron Age (0-200 AD), the Late Roman Iron Age (200-400 AD), the Migration Period (400-550AD), the Vendel Period (550-800 AD), culminating in the Viking Age (800-1050 AD). These subperiods are themselves often grouped into distinct and important divisions: The Early Iron Age (500 BC-400 AD) and Late Iron Age (400-1050 AD).

The expansion of agrarian subsistence varies chronologically, depending on location. In Sweden, the agricultural systems typical of Iron Age Scandinavia developed gradually during the Nordic Bronze Age (first millennium BC) (Pedersen and Widgren 2011). As forests and woodlands were cleared, cultivated lands expanded for use in both agriculture and grazing. Human influence upon the land led to a general transformation of the landscape, with a shift in the character of farming to include permanent field systems and pastures, hay-meadows, and the use of iron tools (Pedersen and Widgren 2011).

Öland: An Archaeological and Agricultural Landscape

Located ten kilometers off the Southeastern coast of Sweden in the Baltic Sea, Öland is the second largest Swedish island with an area of 1,342 square kilometers (Königsson 1968; Wilhelmson 2017). The island is long and narrow in shape, running approximately 140 km from north to south and 15 km across at its widest point - and until a bridge was built in the late 1900s was only accessible by sea. Archaeological excavations have established the presence of Paleolithic era hunter-gatherers on the island as early as 8000 BC., and evidence indicates that an ice bridge connecting the island to the mainland across the Kalmar Strait at the end of the most recent Ice Age provided migratory access during the early Stone Age. Neolithic settlers left their mark in the landscape in the form of graves, occasionally Megalithic passage chambers (Königsson 1968). Archaeological evidence of continued settlement and habitation on the island from the Bronze Age onwards is preserved notably in the numerous burial grounds, farmsteads, and ringforts found across the island (Königsson 1968; Fallgren 2006; Pedersen and Widgren 2011).

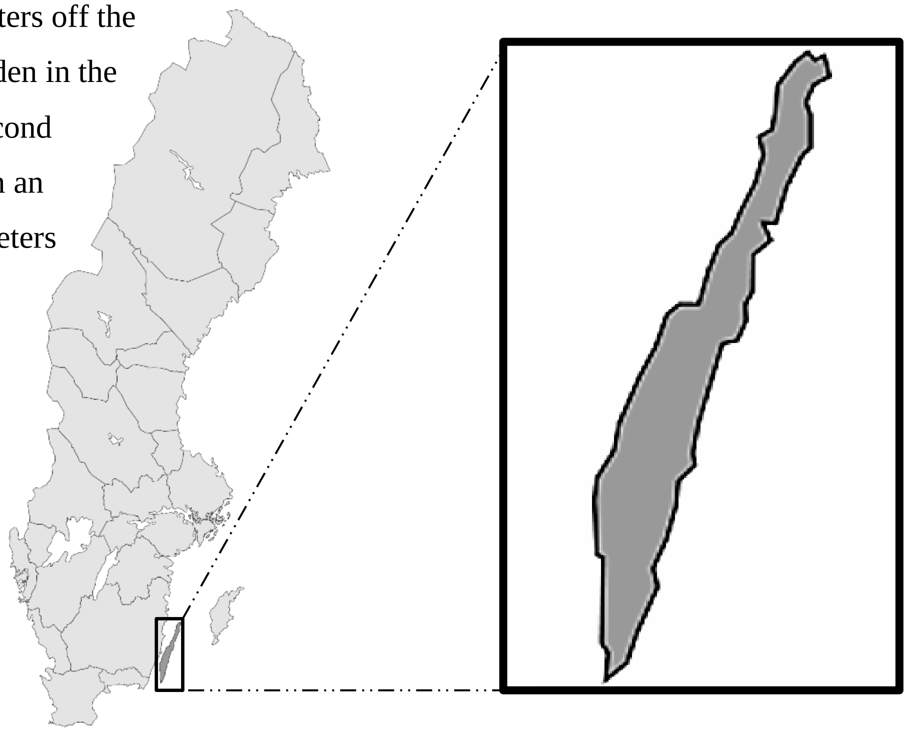


Figure 1: The location of Öland off of the southeastern coast of Sweden in the Baltic Sea.

Evidence of settlements on Öland at Alby and other locations indicate that steady habitation of the island occurred at least as early as 6000 BC (Fallgren 2006). During early settlement, the people of Öland maintained a predominantly hunter-gatherer lifestyle, sheltering in wooden huts in landscapes of arable grassland. This foraging lifestyle was supplemented by fishing and harvesting along the island's coastline, in which archaeological excavations have revealed bone spears, moose antler harpoons and flint tools alongside the remains of bear, marten, seal and porpoise. One of the earliest dwelling-sites at Köpingsvik belongs to the

Scandinavian Pitted Ware culture (Stenberger 1962), a site which suggests people combined fishing and the keeping of domestic animals with collection of plant resources (Stenberger 1966; Hagberg 1967a). By 4000 BC, agriculture and farming had taken over as the main source of subsistence (Pedersen and Widgren 2011), although archaeological evidence maintains that the sea was still a source of resources for the people of Öland well into the first millennium BC (Pedersen and Widgren 2011).

The soils of Öland provide great swaths of arable land. Topologically Öland consists of an underlying layer of sandstone bedrock formed through phases of sedimentation during the Cambrian and Ordovician geological periods (Königsson 1968; Rosén and van der Maarel 2000). This sandstone is topped by several layers of silty clay shales and limestone glacial deposits. The high clay content of the soils on Öland are courtesy of several glaciofluvial deposits left over from melting ice fields at the terminus of the last Ice Age, roughly 11,000 years ago. The natural geography of Öland provides a landscape rich in fertile lands, providing an attractive basis for the introduction and dissemination of agriculture on the island - agriculture and associated animal husbandry remain important enterprises on the island even today (Königsson 1968; UNESCO 1999).

Located close to the mainland but still greatly affected by maritime weather patterns, Öland is subject to seasonal fluctuations in climate. The climate of Öland is classified as mild and semi-arid, with temperature fluctuations and a relative degree of variance between the north and south of the island (Königsson 1968). Located within the rain shadow of the southern Swedish highland, Öland has a relatively low annual precipitation rate - although during spring and autumn large swaths of the thin silty soils are often inundated with rainwater (Königsson 1968; Rosén and van der Maarel 2000). As with other seasonal fluctuations, precipitation varies along the north-south axis of the island, as the middle of the island receives slightly higher quantities of precipitation (Königsson 1968). These periods of excess soil moisture are contrasted by periods of drought as the summer season delivers months of high winds, low precipitation, and many hours of sunshine (Rosén and van der Maarel 2000; UNESCO 1999).

The greatest and perhaps most influential geographic area on Öland is a 300 km^2 tree and brushless grassland, known on the island as the Great Alvar (Königsson 1968), indeed the largest alvar in Europe. On an official investigative trip to the island, Carl Linneaus described the type and character of the Alvar, "… which forms the greatest part of Öland and which is a horizontal plateau which is quite dry, bare and sharp, because she only consists of red limestone covered by a soil to a finger's thickness or by no soil at all" (Linneaus 1745, transl. Königsson 1968). While outwardly barren in appearance, there are some seasonal wetlands and alvar lakes, and the thin soil mantle and high soil pH levels supports a great assortment of vegetation and makes the region ideal for grazing (Königsson 1968).

More recent ecological and archaeological surveys of the Alvar have indicated periods of different degrees of human interference and influence upon the landscape (specifically agricultural activity and tendencies reflected in pollen diagrams). During the Roman Iron Age, the continued development and high degree of human influence upon the Alvar has been interpreted as a climatic period of increased moisture (Fairbridge 1962; Königsson 1968). Around 500AD an overgrowth period on the Alvar has been suggested, which may indicate decreased human influence. Human influence on the landscape increases again during the late Vendel or Viking Age, an increase in activity which is considered likely to be correlated with climatic oscillations (Fairbridge 1962; Königsson 1968).

The spread of agriculture and attendant prosperity across Öland is clearly evident in the numerous remains of self-sustaining farmsteads and villages across the island. By area Öland has the largest number of visible building foundations in Iron Age Scandinavia (more than 1,300) (Fallgren 2006; Wilhelmson 2017), having transitioned from using organic housing materials to erecting stone walls outside wooden building frameworks around 400-500 AD (Fallgren 2006). The oldest verified ^{14}C dating of these housing foundations has been assigned to 200 AD and the latest to 700 AD. Tracing across the landscape, the foundations of houses, animal fields and barns and agricultural structures connect clusters of houses and farmsteads into greater village units. The surviving stone foundations represent structures of varying size, form and function, from single-home settlements to yards of 4-5 houses, clustered in groups of few to many farmsteads (Fallgren 2006).

There are over 296 known villages on Öland from historic times, most of which were self-sustaining units established through social or kinship bonds. Cemeteries and grave sites were often situated on the margins of farmsteads in the common lands between villages. Marked by standing stones in an undulated barrow landscape, burial grounds have been suggested as an extension of the village's domain, a claim of power in the unregulated lands between it and the next settlement (Fallgren 2006). Cemeteries and graves were often placed facing the nearest neighboring village on areas of raised ground and in the vicinity of roads and entrances to the village.

The cemeteries and grave sites of Öland have been the subject of many excavations and meta-studies since the 1900s. However, until only relatively recently the bulk of bio-archaeological findings of the grave fields have been published in volumes describing burial practices and artifact assemblages - with few osteological analyses having been done on the skeletal remains themselves. (Wilhelmson 2017) The well-preserved burial remains of Öland represent an opportunity to gain insight to several aspects of the development of Iron Age society on the island (namely: taphonomy, pathology, diet, migration, and social organization).

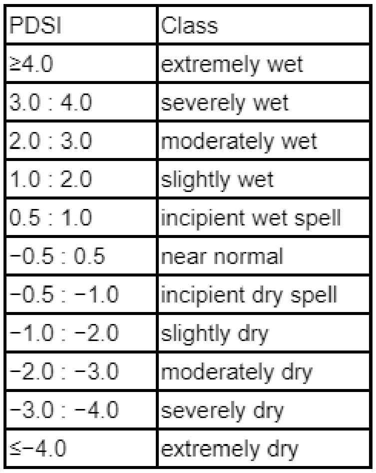
Historical Environmental Reconstructions

Climate modeling is an essential tool for analyzing past, present and future climate change. Complementing historical accounts (occasionally incomplete and/or of uncertain veracity), environmental reconstructions are the most reliable way to track past climate and weather fluctuations. Historical reconstructions are based upon understanding of climate dynamics and human impact upon local (and global) landscapes, modeled through analyses of sedimentary and biological materials over time in terrestrial and aquatic landscapes. These models are derived from a vast range of environmental data sources including tree-ring data, pollen data, glacial ice cores, ocean sedimentation, isotope analysis, etc.

A great portion of currently published environmental reconstructions focus on general temperature fluctuations across continents and time periods. There are, however, subsets of climate simulations that seek to model natural climate variability in the form of wetting and drying trends. These types of models acknowledge not only natural weather events but also anthropogenic forcing upon the environment.

The Old World Drought Atlas is a map of year-to-year drought/pluvial trends using living trees, as well as historical, archaeological and subfossil tree-ring specimens to generate a longitudinal spatial reconstruction of hydroclimatic variability across Europe and the Mediterranean Basin extending back from 2000CE to 0. In more detail, the OWDA is a 5414-point half-degree longitude-by-latitude grid map depicting reconstructed spring-summer soil moisture conditions based upon the self-calibrating Palmer Drought Severity Index (scPDSI).

The scPDSI is a scaled-index of local water-cycle supply and demand calculated from longitudinal studies of precipitation and temperature, together with fixed parameters related to the soil and surface characteristics at each location (such as substrate make-up, density, proportion of stone and larger debris, etc.). The index produces values ranging from -4 (extremely dry) to +4 (extremely wet) depending on local characteristics and historical records of precipitation and potential evapotranspiration. In terms of this index, a "normal" value would suggest that the precipitation cycle is in equilibrium, or that precipitation and evapotranspiration equal each other and that there is neither excess nor want for more moisture in the system.



PDSI	Class
≥4.0	extremely wet
3.0 : 4.0	severely wet
2.0 : 3.0	moderately wet
1.0 : 2.0	slightly wet
0.5 : 1.0	incipient wet spell
−0.5 : 0.5	near normal
−0.5 : −1.0	incipient dry spell
−1.0 : −2.0	slightly dry
−2.0 : −3.0	moderately dry
−3.0 : −4.0	severely dry
≤−4.0	extremely dry

Table 1: Observable soil-moisture condition classes according to scPDSI index value

The OWDA data is generated by a network of 106 annual multi-species tree-ring chronologies extending back in time to the beginning of the Common Era. Following the accordance of previously published results, these tree-ring chronologies indicate that summer moisture availability is positively correlated with radial growth in tree-rings in the current growing season as well as the following growth season. Furthermore, the OWDA makes possible the use of tree-ring data in regions where growing seasons are limited by temperature (i.e. the cool, moist forests of the European Alps as well as in more northern latitudes) by drawing inverse associations to indirectly reconstruct soil moisture availability (through negative correlations of soil moisture and tree growth in cool, moist environments).

The OWDA has been shown to successfully reconstruct drought and pluvial trends based on both ring-width and maximum latewood density, despite tree-ring samples having been collected from areas of negative soil moisture-growth period correlations (i.e. the European Alps and northern latitudes).

Extreme climate fluctuations have been recorded throughout history, a notable example being the events of 535-536 AD, in which a major volcanic eruption or comet impact at northern high-latitudes is believed to have projected ash and debris into the atmosphere, thus blocking the sun's rays (Baillie 1994; Bondeson and Bondesson 2014; Büntgen *et al* 2016). Although it is disputed what the actual cause of this dust veil was, tree-ring and ice core data record a significant event whose effects likely lasted and were felt for years after the initial event. Several sources of historical climate reconstructions have shown that cooler summers after 535 resulted in reduced tree-growth globally for a period of at least one year, and perhaps extending for decades after the initial event (Baillie 1994; Bondeson and Bondesson 2014; Büntgen *et al* 2016). The initial event of 536 was likely followed in 540 by another eruption in the tropical latitudes, and a further smaller eruption in 547 (Baillie 1994; Bondeson and Bondesson 2014; Büntgen *et al* 2016). The successive cooling event was then further exasperated and sustained by positive feedback loops from ocean convection currents and sea-ice extension, a solar minimum, and an increased inclination angle of the Earth's axis (Büntgen *et al* 2016). The compounding terrestrial, solar and arctic events collectively resulted in a striking cold phase from 536 to roughly 660 AD, a period which has been termed the Late Antique Little Ice Age (Baillie 1994; Bondeson and Bondesson 2014; Büntgen *et al* 2016; Widgren 2012).

The extreme climatic events of the 500s and resulting cooler growing periods have not only been linked to reduced tree growth but also to a reduction in harvests and population growth (Bondeson and Bondesson 2014; Widgren 2012).The introduction and spread of agriculture in Scandinavia coincided with what is known to have been a time of declining mean temperatures and shifting shorelines, and it is possible that a deteriorating local environment encouraged increasing reliance upon agriculture after 0 AD (Widgren 2012). In Scandinavia, the dust veil event of 536 has been linked with general population decline and the reforestation of swaths of land which had previously been cleared for the use of farming and building (Widgren 2012). Archaeological pollen diagrams indicate a distinct but often short-lived reforestation of grazing lands, supporting theories of the movement and/or abandonment of settlements in Southern Sweden (Widgren 2012). Remains of house foundations and stone-walled animal enclosures dating from the mid-first millennium AD suggest that the social expansion of the Roman Iron Age (1AD - 400AD) came to a halt as villages and arable lands were abandoned in many parts of Sweden and the rest of Scandinavia more generally (Fallgren 2006; Widgren 2012). Failed summer harvests possibly resulted in famine and plague and it has been proposed that reduced temperatures also may have spread ergot fungi (*Claviceps purpurea*) in crops, fodder and pastures. If this was the case, the ecological and toxicological characteristics of ergotism are consistent with irregularly distributed depopulation, in which several generations were likely required for the recovery of society. This Late Antique Little Ice Age has been proposed as a driving impetus for the migration of settlements from lowland regions to higher grounds during the Migration Period of Scandinavia (Bondeson and Bondesson 2014; Widgren 2012). High-resolution climate proxies have indicated that the Late Antique Little Ice Age might have aggravated the economic and societal crises far beyond effects on the harvest.

Osteological Markers of Diet and Nutrition

While the historical accounts and records of famines are generally well documented and accepted, evidence of famine in the bio-archaeological record can be limited (Caine *n.d.*; Roberts and Manchester 2005). The skeletal response to severe malnutrition has been documented in both archaeological and clinical studies, however it is difficult to correlate these changes directly to famine. The metabolic diseases related to malnutrition (e.g. scurvy, rickets, anemia, reduction in bone mass, etc.) are associated with a range of non-specific osteological stress indicators, including: general bone growth, linear enamel hypoplasia, stature, cribra orbitalia, porotic hyperostosis and non-specific periostitis (Caine *n.d.*; Roberts and Manchester 2005).

Linear enamel hypoplasia (LEH) is a dental indicator of general physiological stress during childhood represented by a localized decrease in the thickness of enamel formation (Goodman and Martin 2002; Guatelli-Steinberg *et al.* 2004; Hillson 1996; Miszkiewicz 2012; Steckel and Engel 2018). LEH is one of many enamel hypoplasias, but it is the most common form of hypoplastic defect and therefore has great archaeological potential to reveal information about the circumstances of the individual during enamel growth. These malformations are macroscopically detectable as horizontal lines, grooves or linear arrays of pits across the enamel surface (Goodman and Martin 2002; Guatelli-Steinberg *et al.* 2004; Hillson 1996; Miszkiewicz 2012; Roberts and Manchester 2005). LEH has archaeologically been utilized to deduce the generalized health of human populations as it is a dental pathology of non-specific nature (Goodman and Martin 2002; Guatelli-Steinberg *et al.* 2004; Hillson 1996; Steckel and Engel 2018). Although several causes have been posited for the occurrence of LEH (childhood disease and malnutrition, age at weaning, consumption of toxins, etc.) (Miszkiewicz 2012), it can be difficult to positively identify causes of pathologies in the archaeological record. For the purposes of this study, the presence of LEH serves as an indicator of childhood stress during growth and formation and will be examined in the context of other osteological pathologies.

Areas of pitting and porosity on the external surface of the cranial vault (porotic hyperostosis) and orbital roof (cribra orbitalia) caused by marrow expansion and overgrowth are the most reported skeletal lesions in human osteological studies (Angel 1966; Goodman and Martin 2002; Rinaldo *et al* 2019; Roberts and Manchester 2005; Walker *et al* 2009). The evaluation of porous bone conditions is frequently utilized in archaeological studies to assess the health and nutritional status of past populations. Caused by the expansion of spongy bone within the skull in response to marrow hypotrophy (a result of premature red blood cell death and increased erythropoiesis [red blood cell production]), both conditions have been widely accepted as having been caused by chronic instances of anemia (Angel 1966; Jáuregui-Lobera 2014; Rinaldo *et al* 2019; Roberts and Manchester 2005; Scrimshaw 1991; Walker *et al* 2009). Although historically accepted to be caused by iron-deficient anemia (Angel 1966), other forms of anemia, specifically megaloblastic and hemolytic anemias, as well as deficiencies in vitamin C (scurvy) and D (rickets), have been proposed as other likely causes (Robertson and Manchester 2005; Schultz 1993; Walker *et al* 2009). While the exact cause of these pathologies is not agreed upon, the presence of both porotic hyperostosis and cribra orbitalia are recognized nevertheless as signs of physiological stress (Angel 1966; Rinaldo *et al* 2019; Robertson and Manchester 2005; Schultz 1993; Scrimshaw 1991; Walker *et al* 2009).

Anemia, as a pathological symptom, is a deficiency in either red blood cells or the hemoglobin they contain. While genetic instances of anemia (thalassemia and sicklemia) are present in the general population, acquired cases are far more common. Caused by nutritional deficits preventing red blood cell homeostasis, acquired anemia represents most commonly an iron-deficiency, but may also be caused by a lack of essential amino acids and vitamins. In prolonged instances, anemia causes hemoglobin levels to drop and the human body to become oxygen-starved, or hypoxic. Hypoxia is often regulated by the increased production and maturation of red blood cells. However, if this reaction is inadequate to reversing the hypoxic state skeletal centers of hematopoietic (blood-cell producing) marrow are stimulated (Walker *et al* 2009). On the skull, this marrow presents itself as porous bone in the cranial vault (porotic hyperostosis) and orbital roof (cribra orbitalia) (Angel 1966; Jáuregui-Lobera 2014; Rinaldo *et al* 2019; Robertson and Manchester 2005; Scrimshaw 1991; Walker *et al* 2009). These cranial pathologies thus represent instances of prolonged anemia, and when common within a general population likely represent long-term nutrient deficiencies.

With the transition to an agrarian society, increases in population size and density, along with migration, sanitation methods, nutritional changes and increases in trade, are believed to have led to an increase in the susceptibility to infection (Mays 2000). Commonly within the archaeological record, non-specific infections have been traced osteologically through rates and intensities of non-specific periostitis. Non-specific periostitis is a condition of inflammation in the surface membrane of bones, the periosteum, caused by trauma or infection (Ortner 2003; Robertson and Manchester 2005; Slaus 2008; Weston 2012; White *et al* 2012). The pathology is non-specific as it does not represent any one disease or condition, but is rather a symptom of multiple conditions and can be both acute or chronic. It should be denoted as different from periostitis, generally, which is caused by trauma and from specific infectious diseases such as leprosy, tuberculosis, etc. (Ortner 2003; Robertson and Manchester 2005; Slaus 2008; Weston 2012). Macroscopically, non-specific periostitis is recognized as new bone formation: as osseous plaques or irregular elevations of bone surfaces (Slaus 2008).

Individual stature is affected greatly by both intrinsic (genetic) and extrinsic factors (environmental and temporal) during growth and development (Robertson and Manchester 2005; Steckel 1995). Although stature values vary significantly between populations globally (affected by differences in climate, altitude, etc.), deviations from normal skeletal morphology within a local population can indicate metabolic differences in regards to nutrition and specific pathologies (Anzellini 2016; Robertson and Manchester 2005; Steckel 1995). Within bio-archaeological studies, stature can be estimated using complete long bones either through anatomical approximations by using multiple skeletal elements or through linear regressions based upon a single osteological element (Anzellini 2016). In extreme cases of nutrient deficiencies, most notably osteomalacia and rickets (both associated with vitamin D deficiency), the overall morphology and stature of an individual can be greatly affected. However, stunted growth is an osteological indicator even in cases of less severe nutritional deficiency, such as iron and zinc deficiencies (Anzellini 2016). Physiological stress of individuals manifested in reduced stature can indicate differential access to resources and inadequate access to high-value foods (specifically meat proteins) that are necessary for normal bone growth (Anzellini 2016; Riley 1994; Steckel 1995), and in combination with other osteological markers can indicate the relative health of an individual.

Besides the physical appearance of the skeleton, isotope analysis of osteological material can provide a wealth of information about an individual's nutritional history and health. Dietary isotope analysis is based upon the principle that specific isotopes are metabolized within the body and will be integrated into bone and tooth enamel (Bäckström *et al* 2018; Wilhelmson 2017). Collagen is the most common protein in the human body and, as such, constitutes the majority of the organic content of bone (White *et al* 2012) and it is most commonly from the collagen of a bone that isotope analysis is performed. Bone is continuously growing and remodeling throughout life, and as such, the dietary intake of an individual will change the isotopic profile within the osteological material (this is not the case in terms of enamel, in which isotope measurements reflect the state of the individual at the time when the teeth were formed during childhood) (Bäckström *et al* 2018; Katzenberg 2000; Wilhelmson 2017).

Investigating human diet through isotope analysis can be done in a myriad of ways. However, for the purposes of this study, the results of $\delta^{13}C$ (correlates with salinity, and is widely used within bioarchaeology to gain insight on marine vs. terrestrial food intake of an individual [Bäckström *et al* 2018; Eriksson *et al* 2008]) and $\delta^{15}N$ collagen (used to determine where within the hierarchy of the local food web from which the diet was comprised) analyses were used (Bäckström *et al* 2018; Eriksson *et al* 2008; Wilhelmson 2017). Sampled from the mandible of individuals, $\delta^{13}C$ and $\delta^{15}N$ isotope levels within the bone collagen allow for the investigation of dietary and subsistence patterns across the local population of Öland (Wilhelmson 2017). In order to make any conclusions on dietary makeup using isotope analysis a local proxy must be established, and Wilhelmson's work with isotope analysis provided the proxy utilized for this study. By analyzing local zoological material and food webs, an estimated expectation of the make-up of animal and/or plant species within the human diet was established for Öland (Wilhelmson 2017).

The "typical" diet of Iron Age Öland is established to be more terrestrial-based, demonstrated in $\delta^{13}C$ isotope values that skew more negative and with higher $\delta^{15}N$ values, reflecting an intense use of terrestrial areas for animal husbandry and grazing (Bäckström *et al* 2018; Eriksson *et al* 2008; Wilhelmson 2017). Baseline proxies for comparing diet from collagen isotopes often indicate changing dietary and social practices along the chronology of Iron Age life on Öland. Variation in dietary isotopes suggest the introduction of a more diverse diet to the general populace during the Late Iron Age, perhaps a result of an increase in migration and intra-societal contact (Wilhelmson 2017).

Considering the osteological material available from Öland it must be stated that the grave-information data used in this study are all from inhumation burials of various kinds.

Unavoidably this excludes cremation burials, which were common at the time (having become the prevailing burial tradition during the Late Bronze Age [Eriksson *et al* 2008]). The graves were selected from within previous studies as being possible to date (either by ^{14}C or contextually), as having permanent teeth with "...preserved enamel and bone from a mandible or similar bone of prominent cortical robustness" (Wilhelmson 2017, p. 75), and criteria further allowing the entire island to be investigated without bias for sex, location or time period (Wilhelmson 2017, p. 76).

Theoretical Perspectives

Historical climate change and the modern concept of global warming are inextricably linked both in outward expression and theoretical understanding. The diffusion of climate-change research across academia and beyond has increased societal interest in the topic and the need to properly understand the role that we, as humans, play in shaping the world around us. Populations and society are constantly locked within a feedback loop with their environment in which both forces propel responses from the other in perpetuity. Historical ecology theory proposes that "...the existence of culture gave humans the power to not only survive in but also redesign the natural world" (Harrod and Martin 2014, p. 23).

Shifts in climate phenomena thus are compounded by human influence and activities. Besides naturally occurring environmental fluctuations (both on the short- and long-term), anthropogenic interactions within local and global climates are clearly a factor of climate change. Whether these interactions are relatively small-scale (i.e. top-soil erosion caused by deforestation and agricultural practices, disruptions in natural bodies of water due to man-made irrigation, etc. [Harrod and Martin 2014]) or cause change on a global-scope (the Greenhouse Gas effect and rising air and ocean temperatures [Harrod and Martin 2014]), the impact of human society upon the environment cannot (and should not) be understated.

Archaeology has long been interested in and attempted to contextualize fluctuations in past climate within its examinations and reconstructions of the human perspective. The modern focus on climate change has reinvigorated interest in the eco-dynamics of past peoples and the application of historical climate change research as a tool to understanding our present and future. Archaeology as a field is well-placed to enhance the modern understanding of the socio-ecological resilience of past communities and the adaptive capacity of populations in response to climate change (Van de Noort 2011). Climate-change archaeology is a movement within the general discipline "...not only to inform about the human environmental past, but also as a guide to expanding the capacity of modern global climate response to address complexity in the current human social environment" (Rockman and Hritz 2020, p. 8296). As high-resolution climate proxies and reconstructions become increasingly available, archaeological contexts and associated climate-related social theories can provide a more accurate glimpse into how past societies responded to shifting climates (Widgren 2012). While no past society is a perfect reflection of present societies, the social and cultural drivers of populations that exist today are similar (if not entirely the same) in the past.

While it must be argued that human activity is an important climate driver, the interaction between people and their environments is not unidirectional. Humans and their early ancestors have been adapting and responding to their surroundings for millions of years. While some of these reactions are visible in genetic responses to extreme environments, many more are behavioral and cultural. Evidence for these responses is buried in history, and as a discipline archaeology can expand our understanding of how societies adapted to their environments in the past.

Bio-archaeology (or osteo-archaeology as it is sometimes called), is a subdiscipline of archaeology that primarily studies biological matters from archaeological contexts. The discipline is arguably defined by a British and an American tradition. British bio-archaeological studies draw upon flora (paleobotany), fauna (paleozoology) and human skeletal remains (osteology) to reconstruct human activity, health and disease patterns throughout history. While sometimes considered a subset of British bio-archaeology, human osteological study is the specific focus of the American discipline, being seen as the important technique for evaluating the structure and health of broader societies from individual specimens. The bio-archaeology of human remains has been utilized not only to determine demographics and health (i.e. the skeletal and dental condition of the individual during their life, isotope and chemical analyses, etc.) but been combined with social theory to examine cultural processes such as social structure, agency, individual- and group-identity.

The bio-archaeology of climate change is an evolving theoretical movement, affording a comparative, cross-disciplinary approach to examining variation in how humans have responded to environmental challenges. Comparing bio-archaeological contexts to the modern and historical environment offers a means to understand the way in which "nutrition, health, activity, and violence map on to shifts in environment, changes in social structure or periods of upheaval" (Harrod and Martin 2014, p. 2).

Previous Research on Öland: A Literature Review

Interest and participation in archaeological excavations of Iron Age sites on Öland gained momentum in the 1920-30s, especially following the publication of Mårten Stenberger's exhaustive doctoral thesis work from the early 1930s. *Öland During the Early Iron Age* (1933) proposed what are now well-established hypotheses regarding the use of the open landscape on the island for grazing and extensive animal husbandry (Fallgren 2006; Stenberger 1933; Wilhelmson 2017). Archaeological and methodological progress has since strengthened many of the theories first proposed by Stenberger but have also led to speculation regarding the chronologies being addressed (Fallgren 2006; Stenberger 1933; Wilhelmson 2017). Specifically, certain studies have argued against a hypothesized crisis having taken place during the 5th century based on continuity in settlements (Fallgren 2006; Königsson 1968; Stenberger 1933; Wilhelmson 2017) – although even these arguments have been questioned in turn by recent research developments (Fabech and Näsman 2015; Wilhelmson 2017).

Figure 2: Location of registered Iron Age graves on Öland

Map originally published in: Wilhelmson (2017). 'Perspectives from a Human-Centered Archaeology: Iron Age People and Society on Öland'. p. 57.

Following Stenberger's initial publication, several extensive excavations and published studies from the early-mid 20th century dominated primary archaeological research on Öland. In the 1960s, several volumes were published detailing the excavation of Skedemosse – a drained bog in central Öland examined under the lead of Ulf Erik Hagberg – the site from which Sweden's largest cache of gold, weapons and animal offerings were discovered (Hagberg 1967a, 1967b). As interest increased after the significant material and archaeological findings of the early-to-mid 1900s, so did the number of excavations (of various scale and scope) across the island. Many of these findings uncovered a range of materials, but in the early days of archaeology on Öland certain materials were of greater importance than others.

Osteological material (both human and animal) is one example of a specific type of find recovered yet often publicized merely as an addendum to the excavation reports (Wilhelmson 2017). As a result, there exists a large volume of skeletal material from past excavations that has never been properly examined or placed within a greater context. Recently (and most notably in terms of this paper), Helene Wilhelmson's doctoral archaeology thesis regarding Iron Age graves took a particular interest in synthesizing some osteological materials from these previous excavations. Taking a human-centered theoretical approach to the osteological remains on the island, her work explores the material, physical and visual properties of the skeletal remains of over one hundred individuals, that is, her analysis approached the physical material in an attempt to understand the lives and deaths of the individuals within their Iron Age society. Using osteology, isotope analysis and archaeology, Wilhelmson outlines several themes of research to understand Iron Age Öland society: taphonomy, diet, migration patterns, and social organization (Wilhelmson 2017, p. 20). This deliberate, interdisciplinary approach combined previous research on settlement patterns and artifact assemblages with the osteological material.

Information regarding pathologies, skeletal stature measurements, isotope values, and chronologies gathered from Wilhelmson's effort were employed as the basis of the comprehensive osteological work central to the mortality research of this paper. While Wilhelmson was focused upon the greater societal picture of life on Öland during the Iron Age, other analysis specifically utilized skeletal remains to help understand the transition of dietary resources during the Mesolithic-Neolithic. Radiocarbon dating and stable carbon and nitrogen isotope analyses of the bones and teeth of 123 human individuals and local fauna was done in 2008 (Eriksson *et al* 2008). Spanning the length of the island, material from nine sites covering a time span from the Mesolithic to the Roman Iron Age demonstrated that diversity in dietary intake could be utilized to gain insight into societal shifts during the time period. The isotope study highlighted a distinctive dietary shift during the second half of the third millennium (at the end of the Neolithic) from a marine-reliant diet to the use of exclusively terrestrial resources, thus indicating the transition and large-scale introduction of farming on the island (Eriksson *et al* 2008). This study affirms that isotope analysis can provide not only information regarding historic dietary intake but also is an extrapolative tool for understanding the introduction of farming and other societal habits on Öland.

Significant efforts to understand Iron Age society on Öland have also been made through the application of building-archaeology and settlement pattern analysis. There are more than 1,300 house foundations identified from the Iron Age on the island, representing the largest number of foundations per area in all of Scandinavia. The foundations on the island are the remains of so-called three-aisled houses with supporting inner-roof trusses and dry-stone outer walls, a common architecture form of the Scandinavian Iron Age. Visible fossilized-stone house foundations are a common feature of the landscape of Öland.

A comprehensive study of these building foundations was conducted by Jan-Henrik Fallgren in order to understand the structure of society on the island through an analysis of village and farm-yard foundations compounded with associated agricultural and cemetery plots. During the Iron Age there were approximately 230 villages on Öland, further broken down into sites with variations in number of buildings and overall size. Fallgren identified several characteristics that constitute the generalized structure of villages and housing and agricultural plots, as well as certain architectural characteristics that distinguish Öland building techniques.

Fallgren identifies an irregularity in the village and farmstead composition on Öland during the Iron Age. This irregularity is not exclusive to Öland, nor was it in fact uncommon in Iron Age Scandinavia. Villages on Öland during the time period varied significantly in size, from 70-500 hectares, most commonly consisting of 5-20 farmsteads. These villages themselves were broken down into settlement groupings, which also varied in size and in the number of distinct structures which made up a farmstead. In general, farms were centrally placed within the bounds of the fields and the pastures within its domain. These farms could be as small as a single building and as large as four or five buildings, with the majority of farms constituting of two buildings. Fallgren identifies that most farmsteads were clustered within village bounds, most commonly in pairs surrounded by arable fields and meadows. Furthermore, Fallgren addresses the division of the landscape in the form of partitioning stone walls, which appear concurrent with the house foundations on the island (although these walls remain, for the most part, undated) (Fallgren 2006; Wilhelmson 2017). These stone partitions are of particular interest because they are often attributed as a sign of the introduction and maintenance of a subsistence form relying heavily upon domesticated grazing animals (Hagberg 1967; Herschend 1980; Fallgren 2006; Wilhelmson 2017). Interestingly, these stone partitions have been linked to a change in diet (likely to a highly domesticate-based diet), although due to a lack of concrete dating the timing of this dietary shift is difficult to determine (Wilhelmson 2017).

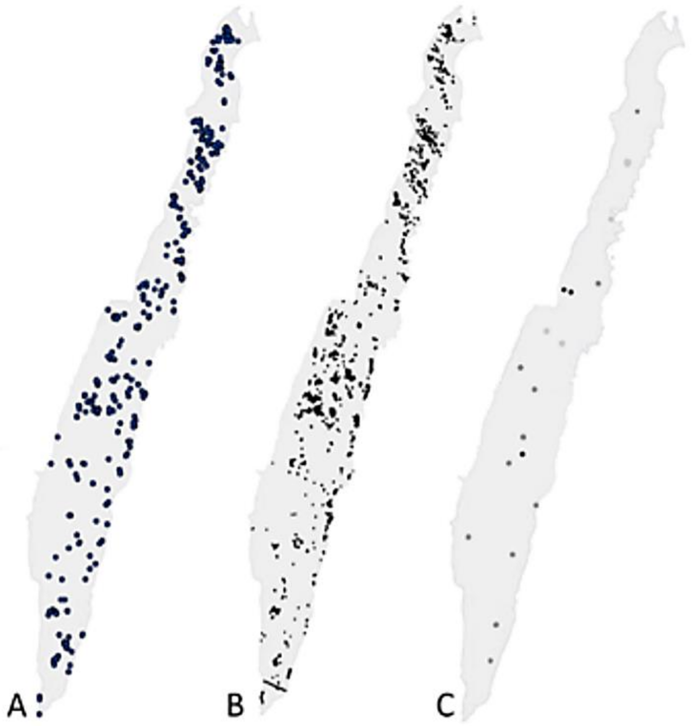


Figure 3: Building archaeology on Öland. (A) The partitioning wall system between settlements. (B) The distribution of preserved building foundations across the island (C) The island ringforts. Older forts are indicated by darker markers, younger forts by lighter markers.

Map originally published in: Wilhelmson (2017). 'Perspectives from a Human-Centered Archaeology: Iron Age People and Society on Öland'. p. 48.

The analysis of settlement patterns allowed Fallgren to propose certain conclusions about Iron Age society on Öland. Firstly, villages during the period were established foremost through social and/or familial bonds. Fallgren also notes that burial grounds on the outer bounds of the villages were often positioned near the roads on natural slopes within the landscape. These cemeteries appear to have been "... considered as a type of judicial monument where kinship, rights of inheritance, ownership of farms and lands were legitimized" (Fallgren 2006, p. 186). That is, in death the social bonds established within the village were simply extended. Secondly, Fallgren suggests that the variation in farmstead size and the number of buildings they contained reflects a form of social hierarchy of the time. This hierarchy is observable in a reasonably obvious sense: larger homesteads were signs of greater wealth and power within society**.**

Finally, Fallgren goes as far as to argue against certain previously-established hypotheses regarding life on Öland in which a 5th century crisis caused a discontinuity in the establishment and maintenance of buildings upon the island (Fabech and Näsman 2015; Fallgren 2006; Königsson 1968; Stenberger 1933; Wilhelmson 2017). First suggested during the early 20th century, crisis-theories were established through archaeological excavations and early-dating techniques of the buildings on the island (Fabech and Näsman 2015; Fallgren 2006; Königsson 1968; Stenberger 1933; Svedjemo 2014). These hypotheses were further bolstered by a similar phenomenon of discontinuous settlement patterns on the Swedish island of Gotland, an area with great archaeological, historical and geographical similarities with Öland (Fabech and Näsman 2015; Fallgren 2006; Königsson 1968; Stenberger 1933; Svedjemo 2014). The prospect of a possible crisis occurring on Öland during the 5th century is still a topic of active debate within the archaeological community.

Climate Change and the Human Condition: A Literature Review

Central to this thesis is the perspective that there is a significant relationship between climate and human health and wellbeing. Just as humans shape their surroundings the environment in turn impacts the course of their lives, and since the introduction of agriculture human interference with the environment has in many ways simplified food resource prospects. Yet however prepared and flexible farming societies may be, sedentary agrarian people are very much at the mercy of fluctuating weather, climate and environment.

As interest and insight into topics of global warming have come to the fore over recent decades, so has an increased interest in how a changing climate has and will affected humans, both on an individual and mass scale. No doubt there was interest in the effects of the environment long before the current awareness but lacking scientific basis and understanding of the workings of the environment most expositions were pure speculation. However, truly reliable measurements of climate conditions have only been possible since the early nineteenth century because systematic progress in the fields of environmental study required the development of suitable measuring instruments (Guiot *et al.* 2010; Steckel and Engel 2018). Thereafter, meteorological societies and interested individuals could create and disseminate written archives of weather patterns forming the backbone of many weather and climate proxies and models (Steckel and Engel 2018). As general knowledge (and databases) of the past, present, and future of the climate has been promulgated, so too have associations been proven between the environment and our human condition (Brooke 2014; Parker 2013; Steckel and Engel 2018; Zhang *et al.* 2011).

Multiple examples from around the globe have demonstrated the sometimes-catastrophic effects on societies of the onset of e.g. sudden temperature change or of prolonged droughts (Steckel and Engel 2018). While some societies are capable of and successful in adapting to changing climates (Berger and Want 2017; Gregoricka 2016), the decline of otherwise vibrant populations has been directly linked to a failure to adjust to novel environmental circumstances (Kintisch 2016; Lynnerup 1998). In some cases, a changing environment has been suggested as a primary cause in the collapse of entire societies and populations by increasing resource competition and provoking widespread conflict (Harrod and Martin 2014; Wade 2016).

The success of harvest yields is, quite obviously, a significant factor contributing to the health of agrarian societies. The link between nutritional level and the frequency and severity of mortality, as determined by communicable infectious diseases, has been proposed by several past researchers (Livi-Bacci 1983; McKeown 1983; Newman 1962; Scrimshaw *et al* 1968) and would therefore be reflected in changes in patterns of diet and nutrition. Despite the considerable metabolic tolerance of humans to fluctuations in nutrient availability, *Homo sp*. is without doubt constrained by diet from pre-nativity and onward. Severe nutritional stress due to acute or long-term starvation and/or dearth essential nutrients can lead to death, especially in young and underdeveloped individuals (Newman 1962; Scrimshaw *et al* 1968). Even when less severe, nutritional deficiency results in abnormal physical and cognitive development, a reduction in general physical condition, and an increased susceptibility to many (if not most) infectious diseases (Newman 1962). This suggests that improvements in historical mortality rates are due in great part to increased food availability and consumption, leading some researchers to hold relatively extreme positions such as stating that "... the slow growth of the human population before the eighteenth century was due mainly to lack of food, and the rapid increase since that time resulted largely from improved nutrition" (McKeown 1983).

However, many comments regarding the links between nutrition and health tend to mask the complexity of interrelated mechanisms and feedback loops which link nutrition-levels and mortality. Livi-Bacci lays out several points of contention to blanket statements that simplify the connection between nutrition and past mortalities, highlighting the difficulties in compiling adequate measurements of past nutritional levels and their relation to increased infections. Even gross approximation of historical measures of nutritional level and change is extremely challenging because many extreme mortality increases are not connected with famine at all, and many deadly diseases (ex. plague, typhoid and malaria) are independent of nutritional intakes. Moreover, some populations can gradually adapt (through cultural and societal changes) to changes in patterns of food availability and/or infection exposure (Livi-Bacci 1983, p. 294). To summarize, the postulated relationship between mortality and nutrition may not be the primary impetus affecting human survival rates. However, these points do not deny the vital role of nutrition in determining levels of historical mortality, they simply question that nutrition is the singular explanation of mortality trends in the past, and the primary force acting upon population growth.

Despite this difficulty in drawing direct links between nutrition and mortality, there are certain aspects of the archaeological record which may, when considered as a whole and in proper context, indicate a reduction in general health is in response to decreased resource availability. Combined with osteological reports, the availability and increased resolution of climate proxies have greatly developed the conceptual and theoretical understanding of societal vulnerability and adaptability to climate (Widgren 2012).

MATERIAL AND METHODS

Environmental Reconstruction: Old-World Drought Atlas

Of the initial 5414-point OWDA data set, two coordinate points were isolated to represent the latitude-longitude points that roughly correspond to the island of Öland. Due to the nature of the OWDA point-graph (in which half-degrees of latitude and longitude make up the grid), certain steps were taken to isolate the points referencing Öland (although it should be noted that none of the OWDA coordinate points directly refer to the natural geography of Öland). To do so, an idealized grid was drawn around the natural geography of Öland according to the system of coordinate pairs given by the OWDA map. This grid was drawn so as not to exceed one coordinate degree in any cardinal direction from the natural boundaries of the island. Two coordinate points were chosen, both along the Swedish coastline, one being further north than the other (which lies on the same latitude as Öland). While neither point directly references Öland, both were chosen for their proximity and location along the Swedish coast (thus better suggesting the type of climate experienced on the Swedish coastal island).

For each coordinate point of the OWDA data set, 2000 yearly soil-moisture index values are given, generated by tree-ring-network values. As climate is a factor based on longitudinal study, the yearly data points for each of the Öland coordinates were broken down into 10-year average values. From this more-manageable data set of 150 10-year averages, a graph was developed showing the decade-long trends in soil moisture content. The extent of geographical coverage by the Baltic data set is shown in *Figure 4*, in which the two Öland points are marked in yellow.

After selecting the coordinate points that corresponded roughly with the Öland landmass, the selected OWDA was expanded upon to better index the decade-long trends in the greater Baltic area. 105 coordinate points were selected, including the countries of Norway, Denmark, Sweden, Finland, Estonia, Latvia, Lithuania, and portions of western Russia. The original data was averaged to produce 10-year mathematical means across the coordinate points. Having compiled the expanded data set, the original Öland coordinate points were plotted against the larger Baltic data set to determine their place upon the trends of soil moisture contents of the greater Baltic area. The complete 10-year average OWDA index values are listed in *Appendix I.*

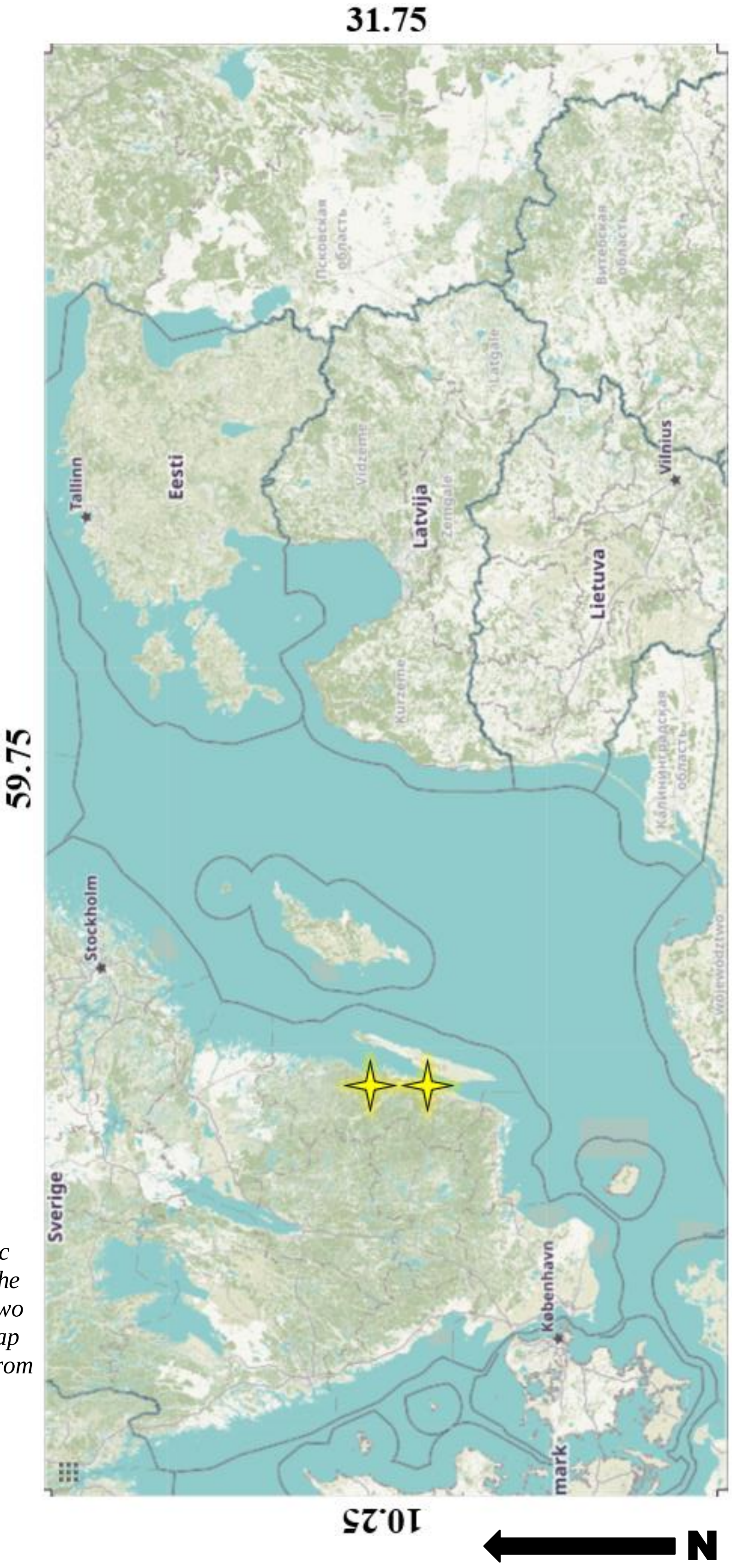


Figure 4: Map depicting the bounds of the Baltic OWDA data set used for this study. Shown are the latitude and longitude bounds of the data. The two Öland coordinate points are indicated on the map in yellow. Observe that the map is rotated 90° from its original orientation.

Map and data available under Open Database License, courtesy of OpenStreetMap.
© OpenStreetMap contributors

Osteological Reports

The osteological data used in this project was previously gathered and compiled by Helene Wilhelmson for her doctoral thesis studying human-centered osteology on Iron Age Öland. As part, osteological reports for 108 individuals buried on Öland were compiled alongside corresponding information about grave location, grave chronology, individual demographics (i.e. sex, estimated age at death, stature), and certain markers of pathology and mortality.

From this initial data set, 88 individuals were selected from within the chronology of study, namely from 0-1050CE, thus excluding 20 individuals from study. Of the 88 individuals selected for, the estimated chronological range of 7 individuals include dates that are earlier than year 0. Despite the chronological values of these individuals surpassing the date-range of this study, they were included because their estimated date-range also includes years within the study-range.

For the purposes of this study, certain osteological indicators of nutritional health were selected for. These included stature as well as several identifiable pathologies: trauma, LEH, cribra orbitalia, porotic hyperostosis and non-specific periostitis.

To begin, individual remains in which stature had been calculated were isolated from the study population, resulting in a study size of 49 individuals. These individuals were broken down into sex, including groups of questionable and unknown sex. Average statures were created for each sex, and then further broken down into averages for both the Early and Late Iron Age periods.

To quantify the nutrition-related pathologies selected for this study, individuals were categorized as either having or lacking the pathology in question. The proportion of individuals with said pathology was then calculated based on the entire osteological population of this study. Individuals with a positive expression of each pathology were then broken into chronologies of Early and Late Iron Age, so that very general pathological trends could be drawn across the time periods in question.

Further conclusions upon the nutritional quality of agricultural subsistence during the Iron Age are made based upon collagen isotope analysis. Stable carbon and nitrogen isotope values are correlated with dietary salinity intake (from i.e. marine fauna and coastline flora) and from where in the food web resources were gathered (for example, carnivorous animals will have different nitrogen isotope values from plants or herbivorous animals) respectively (Eriksson *et al* 2008; Wilhelmson 2017).

The osteological material and related data used for this thesis is listed in *Appendix II*.

Statistical Analysis

Several statistical analyses were run in order to quantify the relationships between the data and variables (both environmental and osteological) used in this study. All the statistical tests (descriptive and bivariate statistics) and their graphical outputs were generated using IBM SPSS Statistics, version 26, software package. SPSS software was provided by Lund University through a student-use license.

Linear correlation tests to determine the strength, direction, and statistical significance of linear relationships between variables were run using the Bivariate Correlation component of SPSS Statistics. This method generated a model output labeled "Correlations" and was utilized to determine strength of the linear relationship between the OWDA Öland and Baltic data sets. Linear correlation was determined significant at the 95% confidence variable ($p<0.05$).

To determine whether there is a statistically significant difference between the means in two unrelated groups, Compare Means Independent Samples T-tests were run using SPSS software. These tests were used to compare osteological variables relating to stature and chronology to each other across demographic and diet-related variables. To run an Independent T-test required the selection of dependent and independent variables which varied according to which variables were being compared. Bivariate Correlation modeling was also conducted upon the osteological data to determine if there was a significant relationship between skeletal stature and dietary isotope values. Visualization of the correlation between osteological variables was also conducted using Boxplot graphics, which were generated through the SPSS software program.

The chronology of the skeletal material was analyzed using Kernel Density Estimation (KDE), which models the frequency of dated skeletal material across the chronology of the Iron Age. Statistically, a KDE estimates the probability density of a variable, generating a model which minimizes extreme fluctuations and visualizes general trends.

To quantify the relatedness between osteological variables of different types and scales (i.e. numerical and ordinal) a Multiple Correspondence Analysis (MCA) test was run using SPSS software. The MCA creates optimally scaled quantitative values for qualitative variables so that individual skeletal remains are clustered into groups of related variables. The MCA output is an indicator if variation in osteological pathologies is in any way tied to the incidence of another pathology or related osteological variable and can therefore indicate relationships between variables.

ANALYSIS AND RESULTS

Environmental Reconstruction

Having isolated index values from the OWDA, two data sets were created representing the soil-moisture contents of Öland and the greater Baltic Area, respectively. In order to determine climatic trends (rather than isolated years of extreme weather; extreme singular index values risk misrepresenting the local climate of the isolated coordinate points, especially in regards to OWDA data sets with relatively few coordinate points - as is the case with the data corresponding to Öland), a more manageable data set was constructed using 10-year average values across the study area. These index values were plotted to visualize fluctuations and trends in the data.

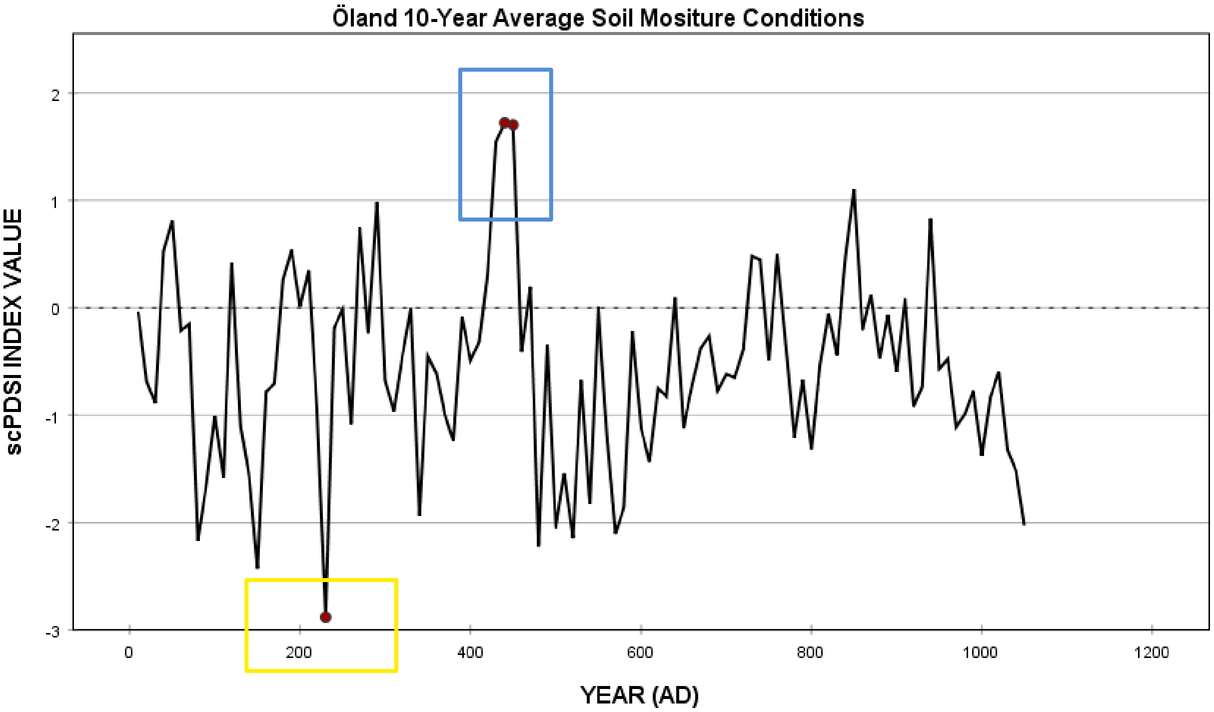


Figure 5: Plotted 10-year average soil-moisture index values for the island of Öland showing statistically significant outlying values as red marker points. The blue box indicates statistically significant outliers with moderately extreme soil moisture content, while the yellow box indicates values exceeding normal range with slightly extreme soil moisture content.

Figure 5 depicts fluctuations in scPDSI index values across the island of Öland. Each data point represents a 10-year average across the study area. Outlying index values are represented by point markers highlighted in red. These markers represent points exceeding the "normal" range of the data (selected using a 95% confidence interval). While these markers represent decades in which the index value exceeds the normal range, it should be noted that the outliers at years 440 and 450 (these points are indicated in *Fig. 5* by a b blue box) do not represent extremes in soil moisture content, as their index values fall within the slightly-wet scPDSI range (scPDSI value between 1-2). Comparatively, the outlying point at 230AD and (indicated on *Fig. 5* by a yellow box) represents slightly more extreme soil-moisture content values, within the moderately-dry range (scPDSI value between -2 and -3).

Figure 6 depicts fluctuations in scPDSI index values across the defined Baltic Area coordinate points. Each data point represents a 10-year average across the study area. Outlying index values are represented by point markers highlighted in red. These markers represent points exceeding the "normal" range of the data (selected using a 95% confidence interval). While these markers represent decades in which the index value exceeds the normal range, it should be noted that these do not represent extremes in soil moisture content, as their index values fall within the slightly-wet scPDSI positive range and slightly-dry negative index range. While these points do not necessarily suggest decades of extreme climates, they are still highlighted as years of interest. Compared to the Öland data set, the Baltic Area covers a larger geographical area.

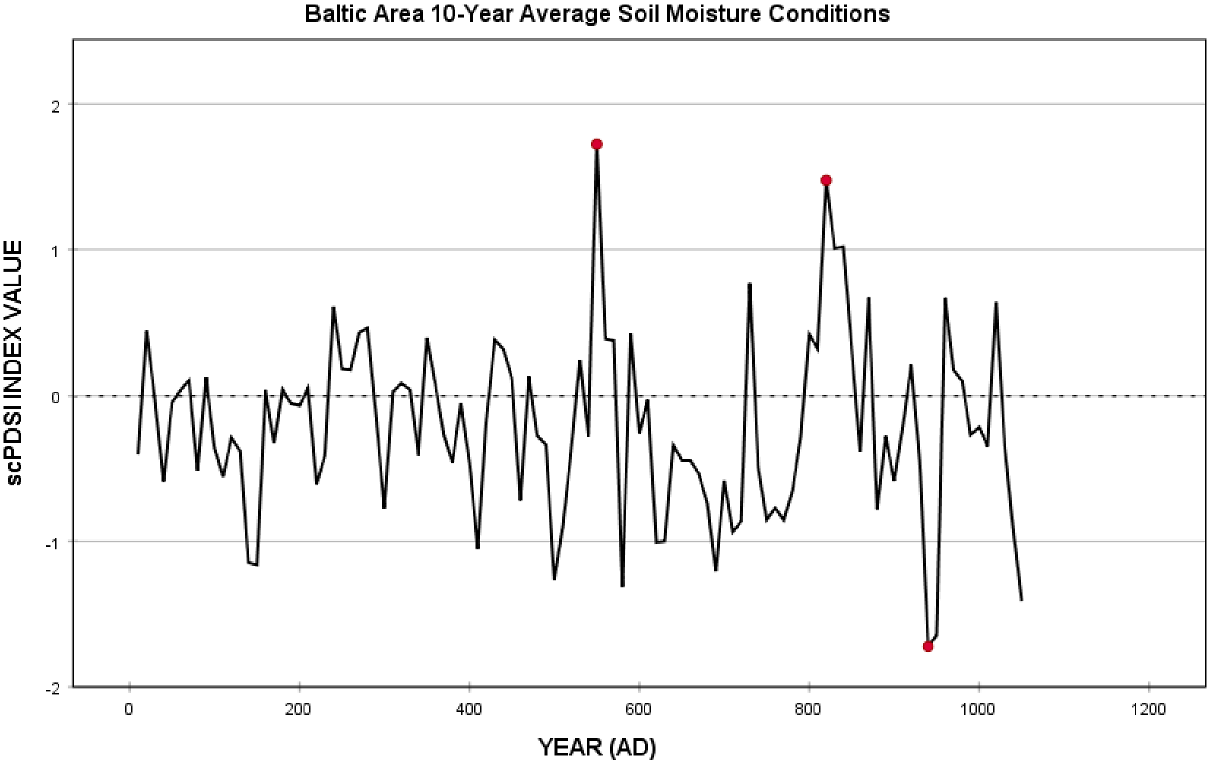


Figure 6: Plotted 10-year average soil-moisture index values for the greater Baltic Area showing outlying values as red marker points.

When computing averages, it is possible (and perhaps likely) that periods of extreme climate on the local level (i.e. according to certain coordinate points) were diluted by coordinate point values within the more-normal range. While this would perhaps represent an issue within the data, the Baltic Area data set is mainly a source of comparison for the Öland data. The purpose of the scPDSI drought index is to quantify long-term drought conditions rather than short-term events (Palmer 1965) and as such, it is suitable to consider average decade values. This Baltic Area data is intended to represent trends on a greater geographical scale in order to compare climatic trends on Öland rather than indicate possible decades of extreme climate. To facilitate the comparison, the two data sets were plotted against one another and are shown in *Figure 7*, the Öland data shown in red. Visualizing the two data sets against each other shows relative similarity in trends, although perhaps the Öland data shows more extremes in weather trends (these could perhaps be due to a smaller coordinate data set).

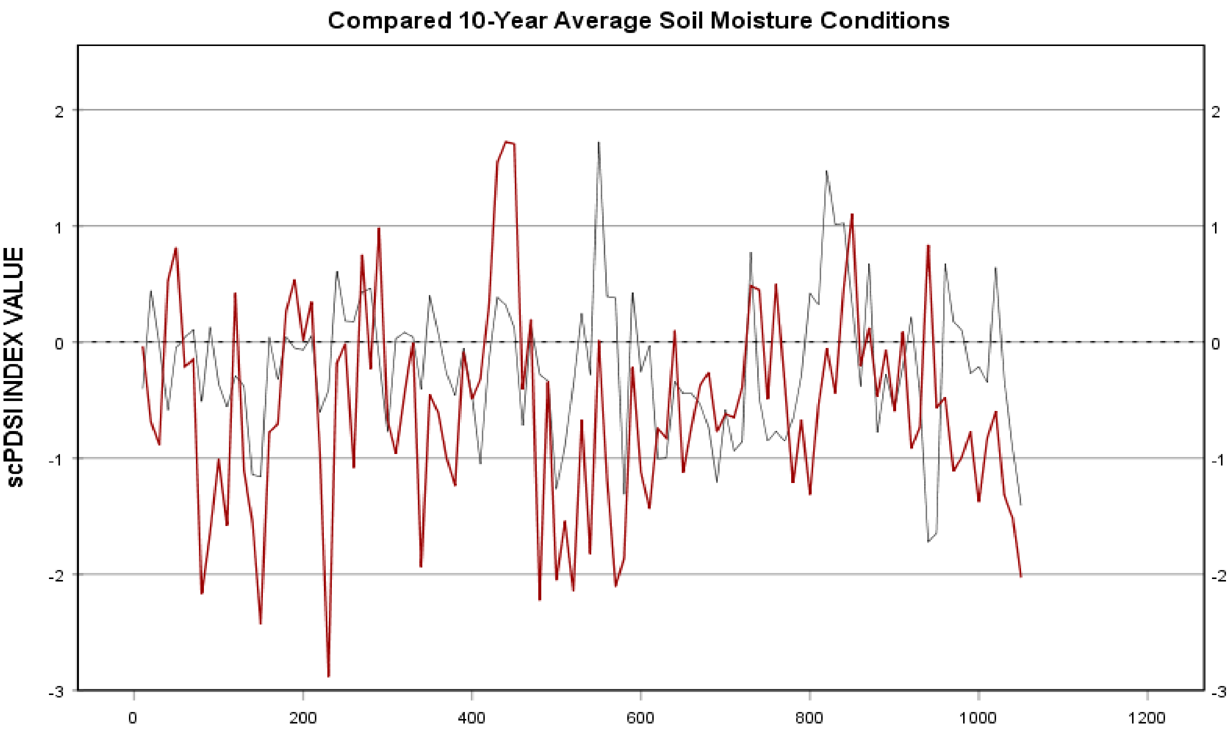
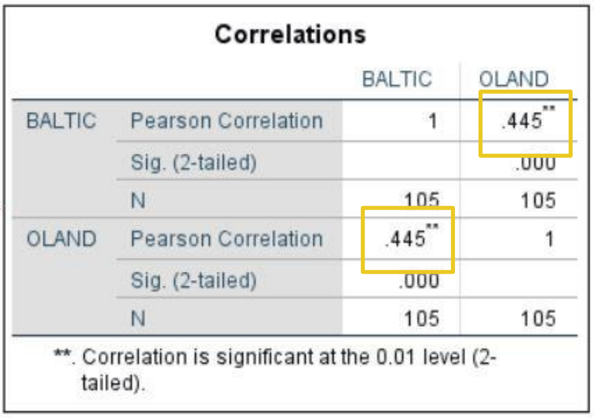


Figure 7: scPDSI index values of the two OWDA data sets plotted against one another. The Öland data is shown in red, while the Baltic Area data is shown in black.



Correlations

		BALTIC	OLAND
BALTIC	Pearson Correlation	1	.445**
	Sig. (2-tailed)		.000
	N	105	105
OLAND	Pearson Correlation	.445**	1
	Sig. (2-tailed)	.000	
	N	105	105

**. Correlation is significant at the 0.01 level (2-tailed).

Table 2: SPSS Correlation Analysis output of the linear relationship of the Öland and Baltic OWDA data, indicating a correlation-coefficient R-value of 0.445.

Graphing the Öland and Baltic data upon one another helps to visualize whether climate trends reported by the OWDA Öland data correspond to fluctuations seen in the greater Baltic Area. To test whether there exists a relationship between the Öland and Baltic data, correlation analyses were done using SPSS statistical software (*Table 2*). Correlation analyses test the strength (varying from strong to weak) and the direction of the relationship (either positive or negative) and is presented as a coefficient: the Pearson product-moment correlation coefficient, or simply, Pearson's r. The Pearson's r was found using a Bivariate Correlations test and showed a positive moderate linear correlation of 0.445, with a statistically significant p-value of the correlation at the 1% level. The Pearson's r is displayed twice in the SPSS output and are both highlighted on *Table 2* within yellow boxes.

The results of this correlations test imply that while a statistically significant correlation between the Baltic and Öland data sets exists, the linear strength of that relationship is only moderate. From this we may gather that while an association between the Baltic and Öland data sets is a viable source of comparison there exists only moderate positive similarity between the two. This result is to be expected due to multiple factors. While the Öland data is considered within the greater Baltic geography, differences between the local and larger-scaled climates are likely to fluctuate. Furthermore, while the Öland data set represents a localized spread of coordinate points, the Baltic data set encompasses a much larger and more variable geographical area, and so the general trends represent average trends across a larger set of coordinate points, in a sense diluted by the large area it covers.

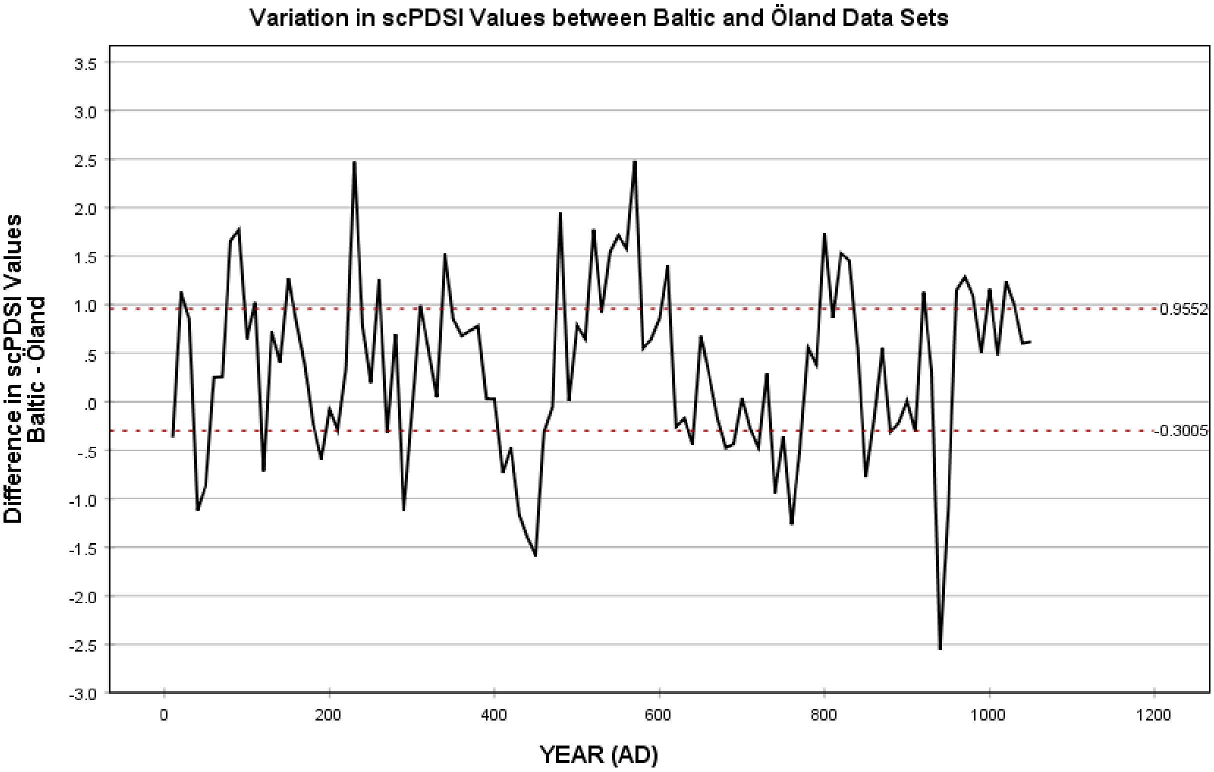


Figure 8: Plotted difference between Baltic and Öland OWDA data values. IQR is indicated by labeled red-dashed lines.

The degree of difference between the Öland and Baltic data sets is plotted in *Figure 8*. In order to recognize which years the difference in recorded scPDSI values varied between the two data sets (and respective geographic areas), the Interquartile Range (IQR) was calculated using Descriptive Statistics in SPSS, generating values for the 1st and 3rd Quartiles, which are represented on *Figure 8* as dashed red lines. Values exceeding the IQR (<0.9552 and >-0.3005) represent years in which the variation between Öland and Baltic exceeds the spread of the middle 50% of the data set (that is, values exceeding the IQR represent outliers and years in which the difference exceeds the majority of values). Values below the IQR represent years in which the Öland data recorded wetter years than the Baltic area, while those above the IQR represent years when the Öland OWDA index values recorded drier years.

There exist several decade points which trend outside of the normal Baltic values. While only a few sections trend outside of normal for multiple decades at a time (namely from 400-600AD and again from roughly 700-800AD) and the graph has few extremes, when compared with the Iron Age osteological and archaeological trends from Öland this environmental data may represent years of social and settlement disruption on the island.

Osteological Reports

In order to investigate the relationships between certain skeletal markers, chronology, and pathologies, several statistical tests were run using SPSS software across the various variables collected from the osteological material from Öland.

Stature and Chronology

As a possible indicator of nutritional stress during growth periods, stature variation was analyzed to determine if there were any fundamental differences in recorded heights during Iron Age, as well as if differences between males and females exceed “normal” stature differences according to sex. While deceptively simple, boxplots allow for a quick overview and comparison of the stature data across various categories while also indicating any possible outliers within the data set (in this case, set to a 95% confidence interval).

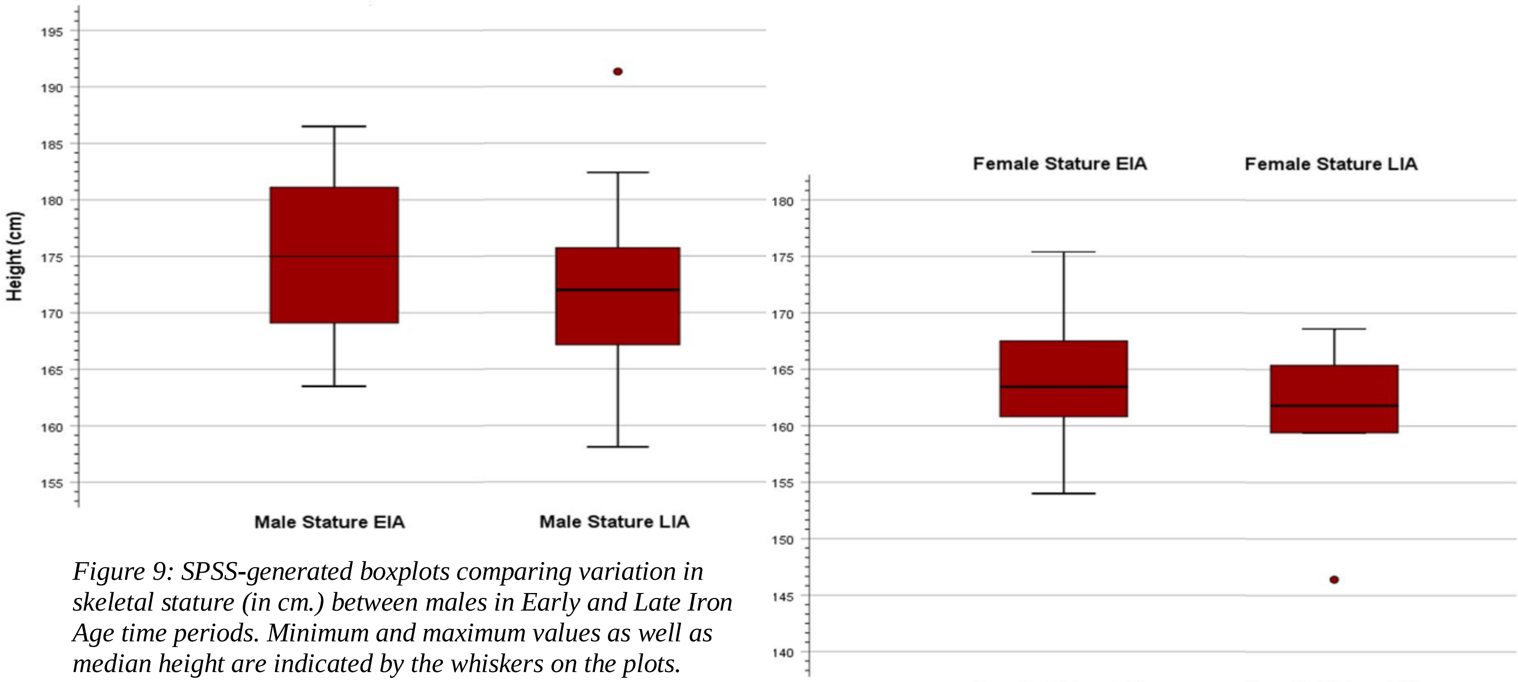
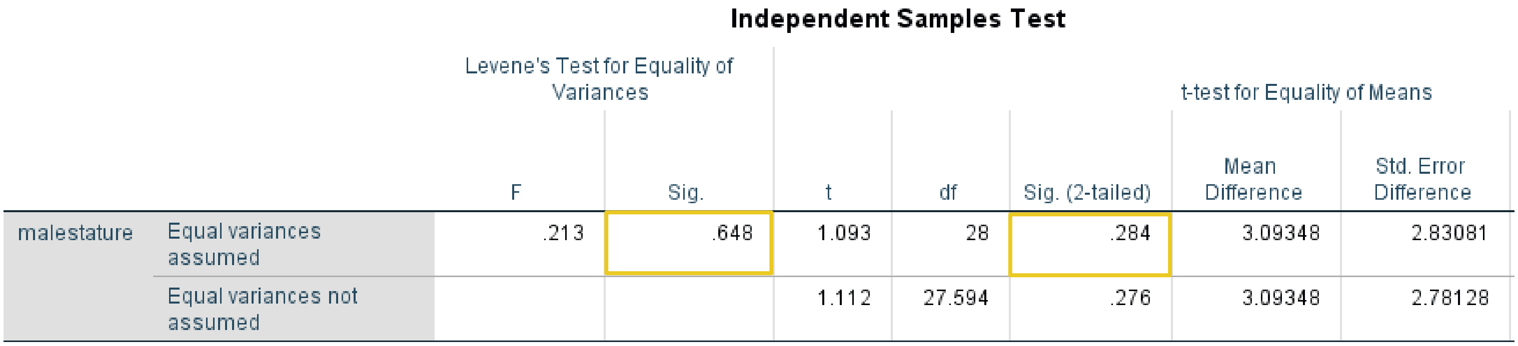


Figure 9: SPSS-generated boxplots comparing variation in skeletal stature (in cm.) between males in Early and Late Iron Age time periods. Minimum and maximum values as well as median height are indicated by the whiskers on the plots. Outliers are indicated by red dots. Note that while the scaling interval of both the male and female plots are the same the range of the height scale differs between the two sexes (male plot range: 155-195cm., female plot range: 140-180cm.). The two plots have been aligned to ease comparison.

The initial results to determine if a significant relationship exists between male and female statures respectively and chronology (in this case: Early vs. Late Iron Age) are shown in *Figure 9*. The 'whiskers' represent minimum and maximum heights within the two chronological populations while the main box of the plot shows the interquartile spread of the data values, i.e. where the bulk of the individual statures lie. Within the male data, there exists one outlier in the Late Iron Age dataset, marked by a red dot. Similarly, there is an outlier within the female Late Iron Age dataset, also marked by a red dot.

At first glance, there does not seem to be any significant differences in the "normal" range of the chronological height data (i.e. the boxplot IQRs look relatively similar in the Early and Late Iron Ages) for both males and females. To determine if there is any statistical significance between the statures of males and females respectively according to chronology (Early vs. Late Iron Age), Independent Samples T-tests were run using SPSS statistical software to compare the mean stature values (the dependent variable) across the Early and Late Iron Age (the independent variable). The results of the male data Independent Samples T-test are displayed in *Table 3* while the female results are displayed in *Table 4.*



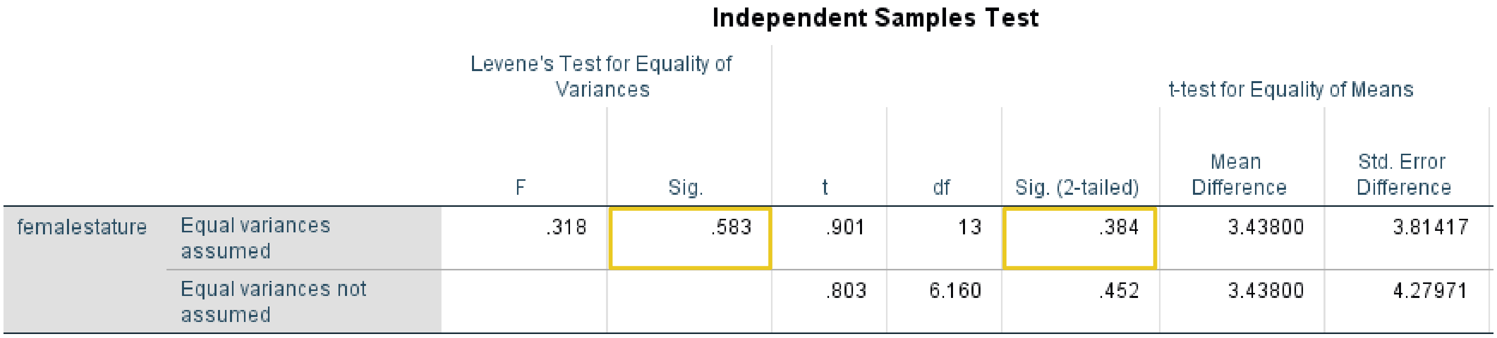
Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
malestature	Equal variances assumed	.213	.648	1.093	28	.284	3.09348	2.83081
	Equal variances not assumed			1.112	27.594	.276	3.09348	2.78128

Table 3: SPSS Independent Samples T-test output comparing variation in means of male stature and chronology (Early and Late Iron Age). Significance values are shown within yellow boxes.

Comparing the means between male stature and chronology displays multiple values of interest (*Table 3*). Lavene's Test for Equality of Variances generated a Significance value of p>0.00 (p=0.648), which indicates that the population variation between the independent variable, in this case chronology, is not significant (this is to say that there is no significant difference in male stature during the Early and Late Iron Age periods – this statement is further corroborated by the boxplot visualization of the spread of statures, which is relatively the same between the Early and Late Iron Age populations). The Lavene Test results reveal that the Independent T-test results are displayed in the "Equal Variances Assumed" row. The actual results for the T-test are displayed under "T-test for Equality of Means", giving a p-value significance of 0.284 (these results are shown in *Table 3* within yellow boxes). The test results indicate that the difference between the mean male stature in the Early and Late Iron Age is not statistically significant. These results imply that stature variation is naturally occurring within the male population, and not according to chronology.

Table 4 displays the SPSS output of the Independent Samples T-test run on the female stature data to compare the means from the Early and Late Iron Age periods.



Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
femalestature	Equal variances assumed	.318	.583	.901	13	.384	3.43800	3.81417
	Equal variances not assumed			.803	6.160	.452	3.43800	4.27971

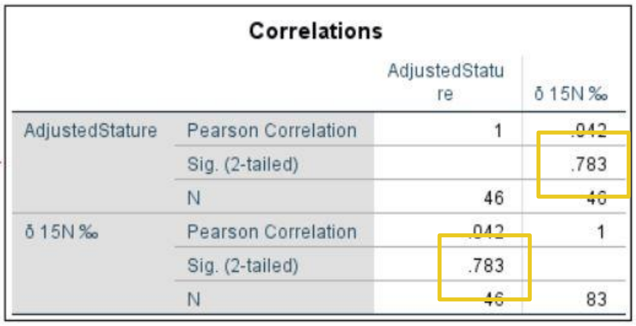
Table 4: SPSS Independent Samples T-test output comparing variation in means of female stature during the Early and Late Iron Age periods. Significance values are indicated by yellow boxes.

Lavene’s Test for Equality of Variances generated a Significance value of p>0.05 (p=0.583), which indicates that the population variation between the independent variable, in this case female stature, is roughly equal (this statement is further corroborated by the initial box plot visualization of the variance in female stature according to chronology, in which the spread of the box plots is roughly the same). The Lavene Test results reveal that the Independent T-test results are displayed under “T-test for Equality of Means” in the “Equal Variances Assumed” row, showing a p-value significance of 0.384 (the significance values are highlighted by yellow boxes within *Table 4*). The test results show that there is no statistically significant difference between the mean female stature when compared chronologically.

The tests comparing chronology and stature for both sexes show that the variation in population height is a natural occurring trait. While a shift in diet during the Iron Age has been suggested by previous studies (and will be explored further in this paper), it has not had any statistically significant effect upon the osteological sample record.

Dietary Isotope Analysis

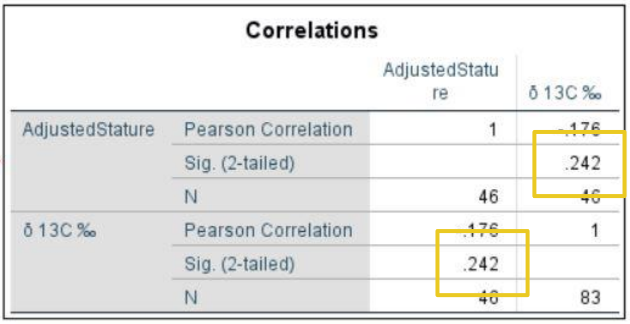
Using osteological isotope analysis, a reliable indication of dietary intake can be surmised. Statistical Bivariate tests of correlation between stature and isotope values (both ^{13}C and ^{15}N, tested separately) were run using SPSS statistical software, the outputs of which are shown in *Tables 5* and *6*.



Correlations

		AdjustedStature	δ 15N ‰
AdjustedStature	Pearson Correlation	1	.042
	Sig. (2-tailed)		.783
	N	46	46
δ 15N ‰	Pearson Correlation	.042	1
	Sig. (2-tailed)	.783	
	N	46	83

Table 5: SPSS Correlation Analysis output of the linear relationship of stature and δ^{15}N‰ osteological isotope value, indicating a non-statistically significant relationship, p>0.05 (highlighted by a yellow box).



Correlations

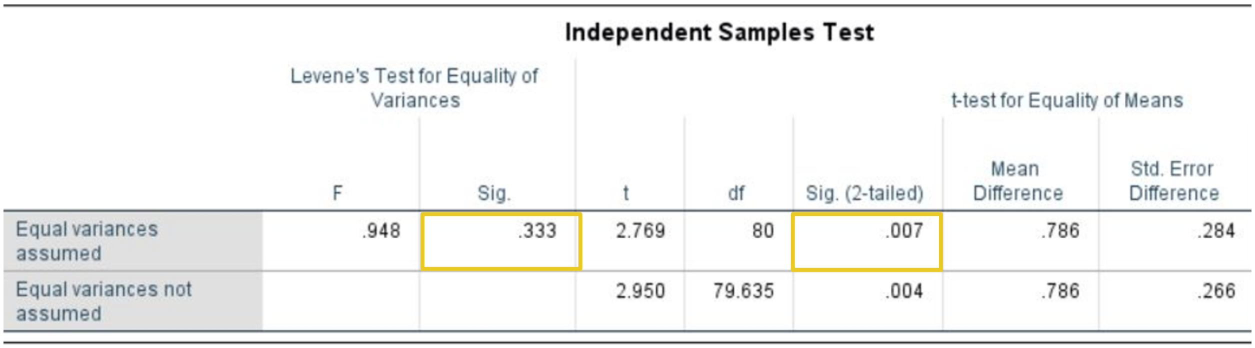
		AdjustedStature	δ 13C ‰
AdjustedStature	Pearson Correlation	1	-.176
	Sig. (2-tailed)		.242
	N	46	46
δ 13C ‰	Pearson Correlation	-.176	1
	Sig. (2-tailed)	.242	
	N	46	83

Table 6: SPSS Correlation Analysis output of the linear relationship of stature and δ^{13}C‰ osteological isotope value, indicating a non-statistically significant relationship, p>0.05 (highlighted by a yellow box).

Both correlation analyses produced insignificant statistical significance values, with the output of significance of δ^{15}N‰ value and δ^{13}C‰ being 0.783 and 0.242 respectively (both are highlighted using yellow boxes, in *Table 5* and *6* accordingly), neither of which satisfy the 95%

confidence interval which requires values of $p<0.05$. The results of this test imply that there is no correlation between dietary intake (as recorded by isotopic analysis) and stature (as neither correlation analysis generate a significance value that indicates statistical correlation). As there is no linear relationship between stature and isotope value it is possible to surmise that there is no causal relationship between isotope value and recorded stature (a relationship which would require the performance of a regression analysis).

While there is no statistically significant relationship between stature and dietary intake (as based upon δ^{15}N‰ and δ^{13}C‰ values, *Tables 5* and *6*), an independent T-test to determine whether there was a significant difference between dietary intake in the Early vs. Late Iron Age was run using SPSS statistics, the results of which are displayed in *Table 7*.

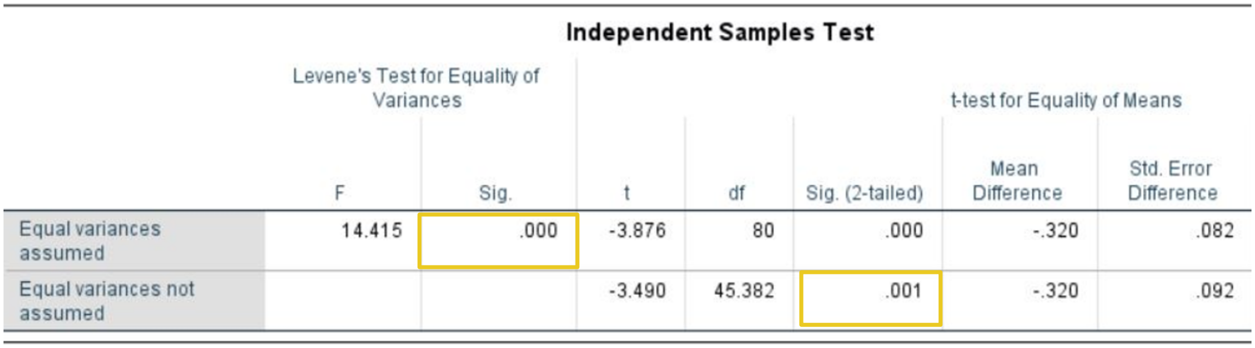


Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means				
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Equal variances assumed	.948	.333	2.769	80	.007	.786	.284
Equal variances not assumed			2.950	79.635	.004	.786	.266

Table 7: SPSS Independent Samples T-test output comparing variation in means of δ^{15}N‰ in the Early and Late Iron Age. Significance values are indicated by yellow boxes.

To run the test shown in *Table 7*, chronology (Early or Late Iron Age) was set as the independent variable while δ^{15}N‰ isotopic value was set as the dependent variable. The Independent Samples T-test output displays multiple values of interest. Lavene's Test for Equality of Variances generated a Significance value of $p>0.05$ ($p=0.333$), which implies that the population variation between the independent variable, in this case chronology (either Early or Late Iron Age), is roughly equal. The Lavene Test presents the Independent T-test results under "T-test for Equality of Means" in the "Equal Variances Assumed" row, displaying a p-value significance of 0.007 (these results are highlighted within *Table 7* with yellow boxes). This significance value indicates that the difference between the mean δ^{15}N‰ isotope value is statistically significant. These results suggest that between the Early and Late Iron Ages, a dietary intake shift occurred producing a change in δ^{15}N‰ isotope values. Changes in δ^{15}N‰ are often attributed to a shift in the trophic level of protein consumed (Bäckström *et al* 2018).



Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means				
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Equal variances assumed	14.415	.000	-3.876	80	.000	-.320	.082
Equal variances not assumed			-3.490	45.382	.001	-.320	.092

Table 8: SPSS Independent Samples T-test output comparing variation in means of δ^{13}C‰ in the Early and Late Iron Age. Significance values are indicated by yellow boxes.

Figure 8 displays the difference in means between Early and Late Iron Age (the independent variable) δ^{13}C‰ isotope value (the dependent variable). Lavene's Test for Equality of Variances output a Significance value of $p<0.05$ ($p=0.000$), which indicates that the population variation between the independent variable, in this case chronology, is not equal. The Lavene Test results indicates that the Independent T-test results are displayed under "T-test for Equality of Means" in the "Equal Variances Not Assumed" row, showing a p-value significance of 0.001 (results indicated by yellow boxes in *Table 8*). This test result indicates that the difference between the mean δ^{13}C‰ isotope value is statistically significant. These results suggest that between the Early and Late Iron Ages, a dietary intake shift occurred which altered "normal" skeletal δ^{13}C‰ isotope values. Changes in δ^{13}C‰ isotope values suggest that a dietary shift was made to the relative proportion of marine resources (both animal and plant matter) in the diet (Bäckström *et al* 2018).

Skeletal Pathologies

To visualize instances of osteological pathologies in the greater environmental landscape, rates of pathologies were plotted against the scPDSI data from Öland (displayed in *Figure 10*). Due to the nature of the dating of the skeletons (most are presented as a range of time), the median year of the chronology for each skeleton was calculated. If an individual presented a positive indication of a pathology (as observed and recorded in Wilhelmson, 2017) they were plotted upon the environmental chronology. This therefore excluded individuals with no indication of the pathology, or individuals in which a positive indicator of the pathology could not be determined (due to i.e., deteriorated material, missing skeletal material, etc.). During periods in which multiple individuals presented positive indications of a pathology, they were each plotted and therefore "stacked" (as visible in *Figure 10*).

From this visualization (*Figure 10*), certain time periods attract attention. First, there seems to be a break in the record of pathologies from roughly 500-800AD. This break could be further extended to include from the year 300-800AD, with one instance of recorded pathologies around year 500AD. This break in the skeletal record could be due to several things: a lack of complete skeletons from this time perhaps resulted in few positive identifications of a skeletal disease; this time frame perhaps indicates a lack of skeletal burials, either due to a dwindling population (fewer people resulting in fewer deaths and fewer remains surviving to discovery) or due to a greater percentage of deaths being given a cremation burial; a shift in the population health on Öland gave way to a healthier population, free of skeletal pathologies (although this theory is weakened by the resurgence of pathologies from 800AD and onward).

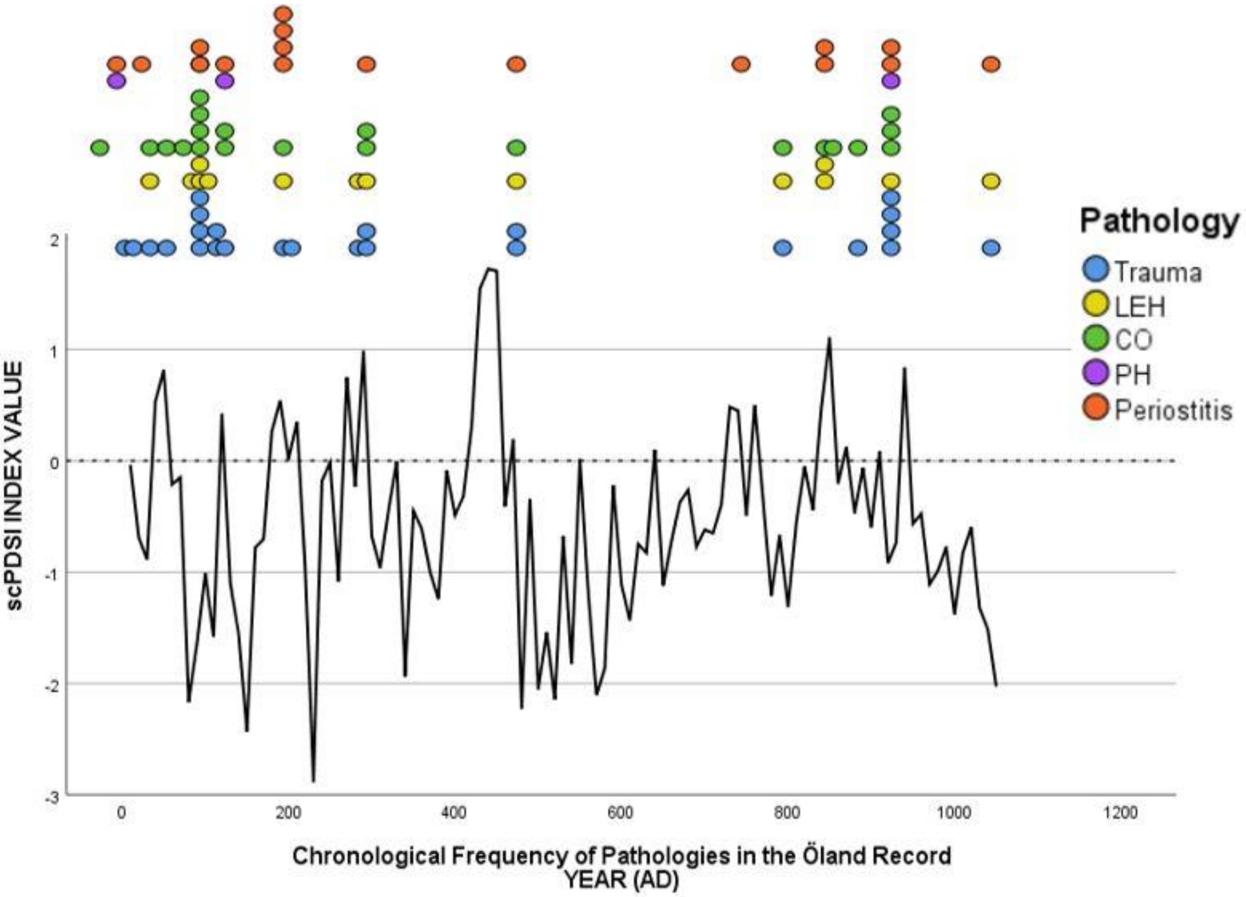


Figure 10: Instances of osteological pathologies (which are color-coded and indicated within the key on the graph) are plotted here against the scPDSI index values from Öland during the Iron Age. Each positive indication of a pathology (according to Wilhelmson 2017), are represented by a colored dot. Stacked dots of the same color indicate that multiple individuals presented the pathology at that period.

Secondly, there are two instances that stand out as far the sheer amount of skeletal pathologies recorded: occurring around 100AD and 950AD. As with a lack of recorded pathologies, peaks may represent several possible scenarios: a greater sample of complete skeletal material during this time increases the probability of discovering skeletal pathologies; a greater tendency to bury the dead rather than cremate; a greater living population essentially increases the possibility for a greater percentage of the dead to present with skeletal pathologies; or perhaps these peaks are an indication of periods of decreased or failing population health on Öland, due to shifting food sources, shifting climate, or some sort of social disruption or crisis.

Population, Housing, and Settlement Data

To further quantify the population of Iron Age Öland, information regarding house numbers and types and their accepted chronologies was gathered from Fallgren's 2006 dissertation regarding the topic. Of all the studied stone foundations on Öland, only a select few have been positively dated. These foundations are listed in Fallgren's dissertation, along with the archaeological material excavated from these foundations which were used to date each foundation in question (pg. 220). The dated chronologies of the houses are plotted in *Figure 11.* It should be noted that not all the buildings fall within the time-period of study for this paper, and that the entire time frame of the Iron Age on Öland is not represented by these houses. However, when taken in consideration with the skeletal material and the environmental data, this information may help to paint the greater picture of life on Öland during the Iron Age.

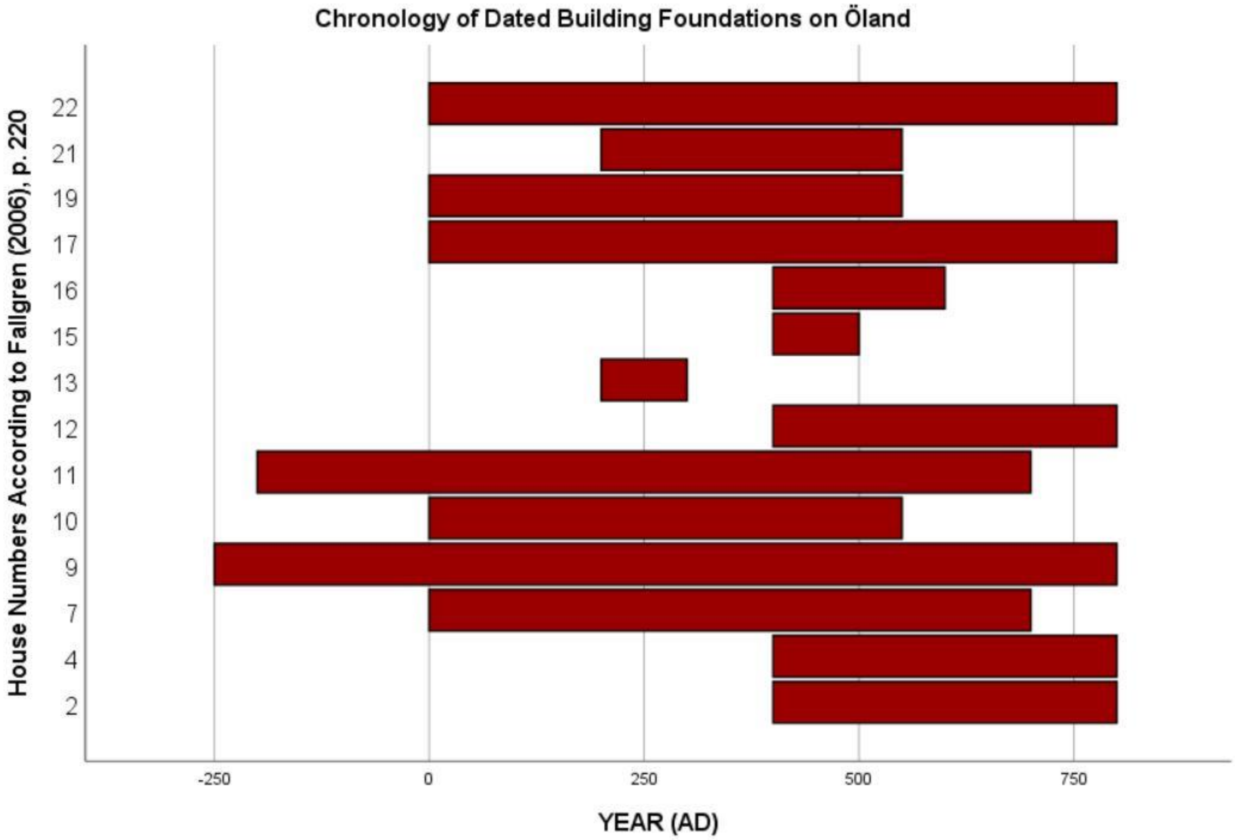


Figure 11: The chronological range of the stone building foundations according to Fallgren (2006), pg. 220. The housing numbers correspond to the given numbers by Fallgren.

To supplement Fallgren's building chronology, Wilhelmson's dissertation was referenced to formulate a frequency curve of skeletal chronology (Wilhelmson 2017). The data utilized to create a graph for this thesis was previously modeled using Kernel Density Estimation (KDE). In statistics, a KDE is a way to estimate the probability density of a variable, oftentimes smoothing out a variable with more extreme fluctuation to visualize general trends. The KDE alongside the unmodeled data is shown in *Figure 12.* The frequency of dated skeletal material refers to the frequency of material which is dated to a certain year. Years with extremes in frequency (either high or low) may indicate periods of changes in settlement or population patterns. These years may also be representative of social changes in society, for example, if burial practices changed (as cremations were also prevalent during the Scandinavian Iron Age). Together with the pathological data and the environmental data, the Kernel plot may indicate periods of shifts in settlement patterns.

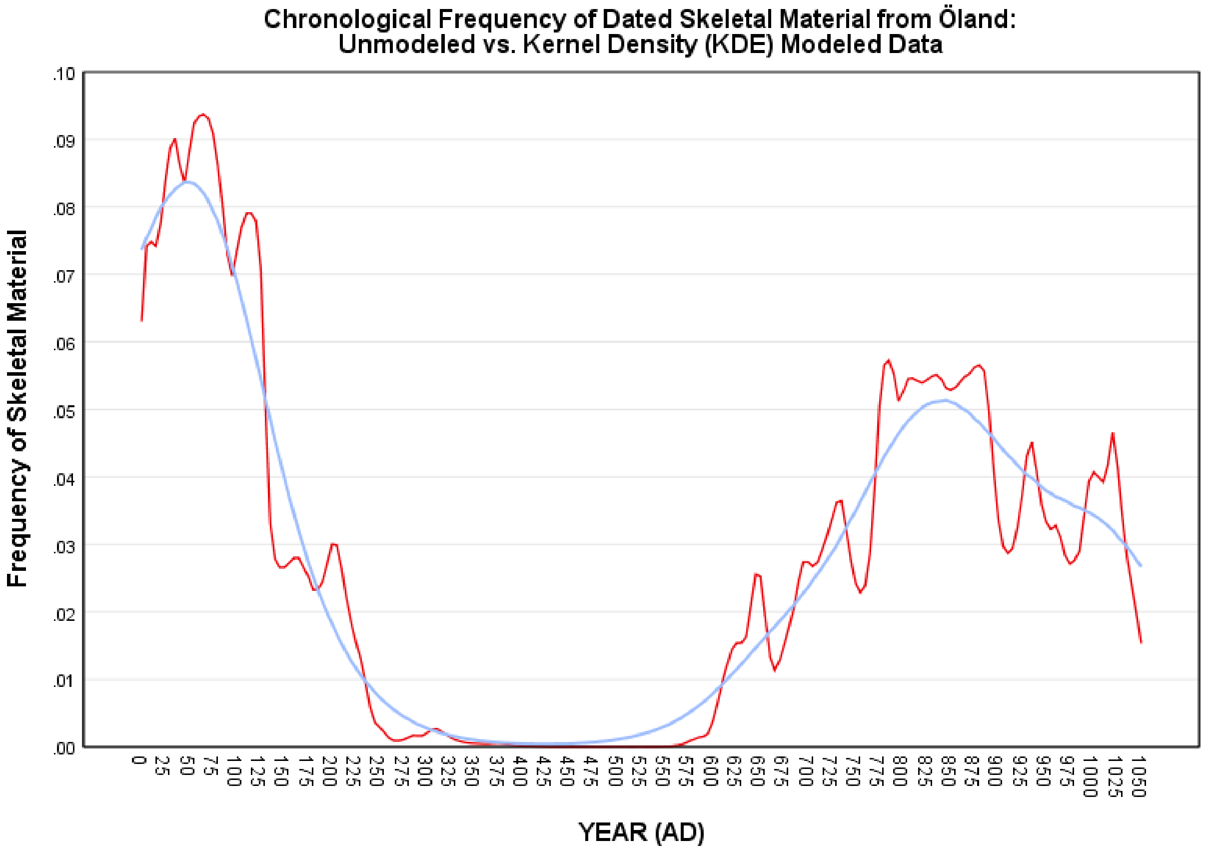


Figure 12: A graphical representation of the dating frequency of skeletal material from Öland. The unmodeled data is represented by the red line on the graph, the modeled KDE data is shown in blue. Source of KDE data: Wilhelmson 2017.

Multiple Correspondence Analysis

Multiple Correspondence Analysis (MCA) is a statistical tool for the analysis nominal categorical data. An MCA does not determine the statistical significance of relationships but rather defines the strengths of relationships between variables. An MCA test quantifies categorical data by assigning numerical values to the cases so that subjects/objects within the same category are close together and objects in different categories are far apart. Quantified nominal variables are then plotted on the same model as numerical values, thus forming a point cloud representing the strength of relationship between all the cases in the data set. The test displays subjects/objects as close as possible to the variables that apply to the specific subject/object. In this way, the test divides objects into homogenous subgroups, or classified into subgroups with other variables that share the same categorical relationships.

The MCA was run using SPSS software. To execute the MCA, several variables from the osteological data were chosen: sex (male or female), age group (child, juvenile, juvenile-young, young, young-mature, mature, mature-old, and old), Iron Age subperiod, stature (classified as quartiles based on sex), trauma (present: yes or no/undetermined), LEH (present: yes or no/undetermined), cribra orbitalia (present: yes or no/undetermined), porotic hyperostosis (present: yes or no/undetermined), and non-specific periostitis (present: yes or no/undetermined), and δ^{13}C‰ and δ^{15}N‰ isotope values. From the initial data set of 88 skeletal remains, 42 were excluded to run the MCA due to a lack of data pertaining to certain variables. Individuals with no value for stature were removed from the MCA data set as well as individuals without any record of pathologies (this however does not include individuals with a negative presence for a pathology). 5 of the individuals removed lacked values for stature and the presence of pathologies. After removing these 42 individuals, the MCA was run on a data set comprising now of 45 skeletal remains. While perhaps an extreme culling of individuals from the data, the purpose of the MCA was to determine relationships between time period and skeletal data (stature and pathologies especially). Individuals without stature and pathological data simply represent individuals who existed during the time periods in question, they do not provide any information on the skeletal health of the population at that time and are therefore not of interest for the MCA.

IQR Quartiles		**δ^{13}C‰**	**δ^{15}N‰**
	min	-20.5	8
1	Q1	-19.9	12.3
2	med	-19.7	13.2
3	Q3	-19.4	14.1
4	max	-18.5	15

Table 9: IQR values of δ^{13}C‰ and δ^{15}N‰ isotope values. The actual isotope values associated with different skeletons were recoded as quartiles (1-4) to function within the MCA.

IQR Quartiles		**female stature (cm)**	**male stature**
	min	146.4	158.1
1	Q1	159.4	169.05
2	med	162.4	172.8
3	Q3	167.5	180.65
4	max	175.4	191.33

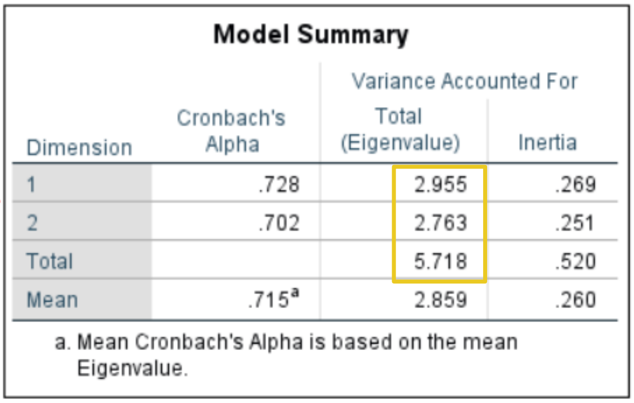
Table 10: IQR values of female and male statures. The actual height values associated with different skeletons were recoded as quartiles (1-4) to function within the MCA.

As the MCA does not present statistical significance but rather relationships between variables, it was appropriate to use robust statistics rather than exact variable values for the test. Certain variables had to be recalibrated to be able to work within the MCA-required data assumptions. The isotope values (δ^{13}C‰ and δ^{15}N‰) as well as female and male statures were reformulated to represent quartiles rather than exact values. To do so, Descriptive Statistics were employed utilizing SPSS and the minimum, median, and maximum values as well as the 1st and 3rd quartiles (Q1 and Q3 respectively) were calculated. These values then represent the spread of each quartile used to reformulate the isotope and stature values. For instance, the range between minimum and 1st quartile values became quartile 1, the range between Q1 and the median value became quartile 2 and so on. These values are presented in *Tables 9* and *10.*

Following "recalibration" of these variables, a slight re-coding of the other variables to be utilized in the MCA was done. This simply entailed renaming each categorical variable (i.e. sex, age group, and Iron Age subperiod, as well as the various pathologies) as numerical values. The number of categories for each variable dictated how many numerical values were utilized for the recoding of each variable (for example: sex, in which a skeleton is male or female (or rather, there are two options) became 1 and 2 respectively. Subperiod was broken down into 7 separate time periods and so each was recoded as a number from 1-7). In terms of the pathologies, skeletons were either coded as 1, the pathology is present or 2, the pathology is not present (alternatively, the presence is undetermined). It should be noted that (according to the SPSS output) there were 20 instances of "missing values". This number represents instances in which individuals were lacking in a value/response for a variable. This means that for certain individuals, there is no value for one or more of the given variables, for instance: certain individuals have no record of skeletal trauma, perhaps due to a lack of skeletal material or degradation of the remains. SPSS allows for individuals without variable responses to be treated in different ways, for the purposes of this MCA, SPSS excludes individuals without a response to a variable, and that individual will therefore not affect the generated output.

The MCA generates a rather substantial output, not all of which is relevant for this study. The first output table of import presents the eigenvalues for each iteration of the analysis (*Table 11*). Eigenvalues are used to determine the percentage of variance accounted for, and therefore, larger eigenvalues are preferred over smaller ones.

The SPSS output does not automatically calculate the percentage of variance accounted for by each dimension (and both dimensions together as a total), but



Model Summary

		Variance Accounted For	
Dimension	Cronbach's Alpha	Total (Eigenvalue)	Inertia
1	.728	2.955	.269
2	.702	2.763	.251
Total		5.718	.520
Mean	.715a	2.859	.260

a. Mean Cronbach's Alpha is based on the mean Eigenvalue.

Table 11: MCA Model Summary output with the eigenvalues for each dimension highlighted in yellow. These eigenvalues are used to calculate the percentage of variance accounted for by each dimension.

this can be determined simply by dividing the eigenvalues (indicated within the yellow box of *Table 11*) by the number of items/variables included in the analysis; in this case 11: *Dimension 1:* 2.955/11 = 0.2686 = 26.86% ; *Dimension 2:* 2.763/11 = 0.2512 = 25.12% ; *Total:* 5.718/11 = 0.5198 = 51.98%. The complete (therefore including both dimensions) MCA model accounts for 51.98% of the variance in the optimally scaled cases.

The Object Scores visual plot generated by the MCA is a biplot all of the individuals included in the MCA grouped by relationships to eachother. Individuals who cluster with others likely share the same responses to variables, while individuals further away from clusters represent individuals with more unique characteristics. The Object Scores plot is shown in *Figure 13.* Each point on the plot represents one individual. Each individual is color-coded according to their corresponding Iron Age subperiod. Note that no individuals dated to the Vendel period were included in the MCA due to a lack of data for these individuals in terms of stature and/or pathology.

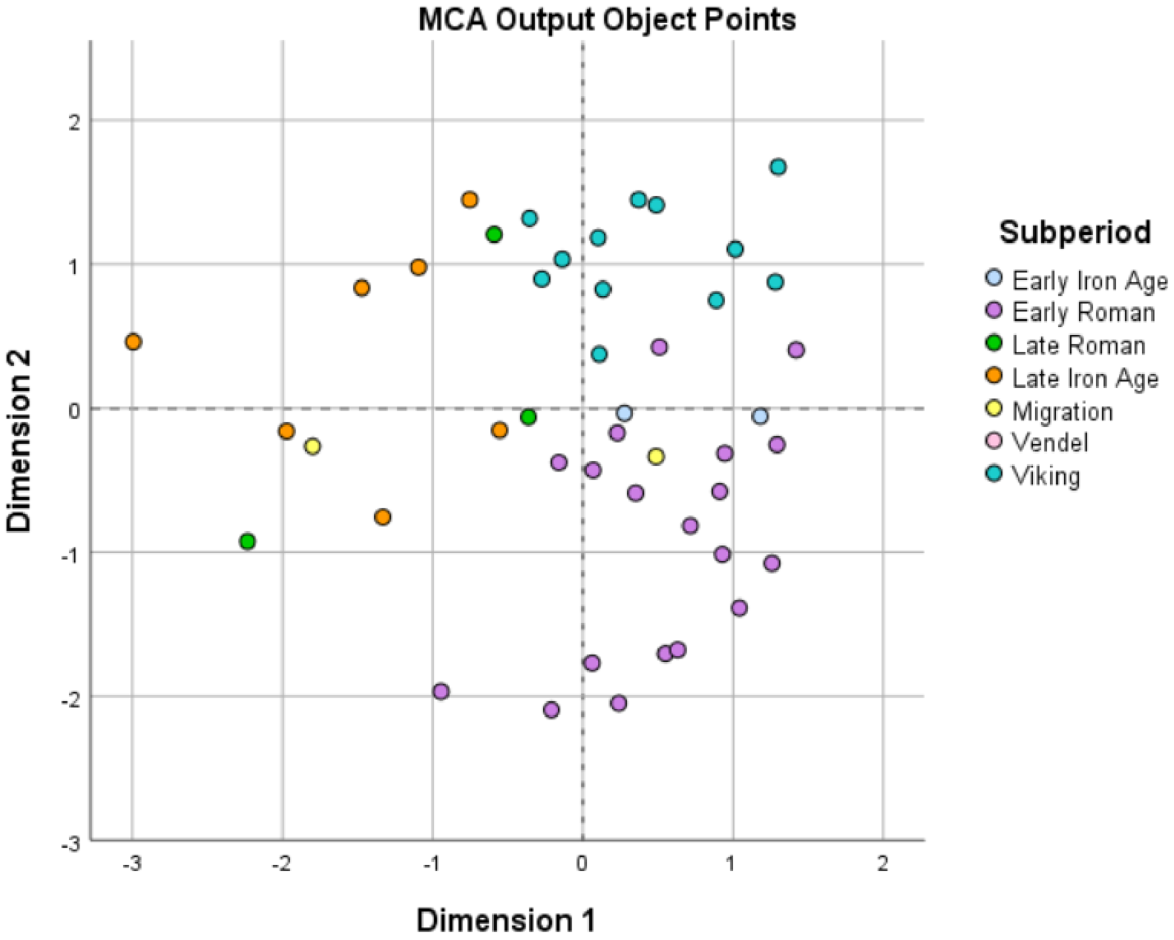


Figure 13: SPSS MCA generated plot of object scores, color-coded by Iron Age subperiod (see Legend). The darker dashed lines mark the origin.

The distance of an individual from the origin (marked by darker dashed lines in *Figure 13*) reflects variation from the "average" response pattern, or rather the most frequent response category for each variable. Individuals with many variable characteristics which correspond to the most frequent characteristics lie near the origin, while individuals with unique characteristics plot far from the origin. Of possible note are individuals who fall far away from the origin, or outliers as far as the group is concerned.

The MCA also produces a plot of discrimination measures, which is the easiest way to visualize the relationships between the variables (without considering all the individuals in the study). Discrimination measures, in their simplest form, measure the variance of the quantified variable in a given dimension. Large discrimination measures are a visual representation of a large spread among the responses of individuals according to each variable. Discrimination measures that plot close to one another may suggest relationships between the two variables. The discrimination measures produced by the MCA are shown in *Figure 14.*

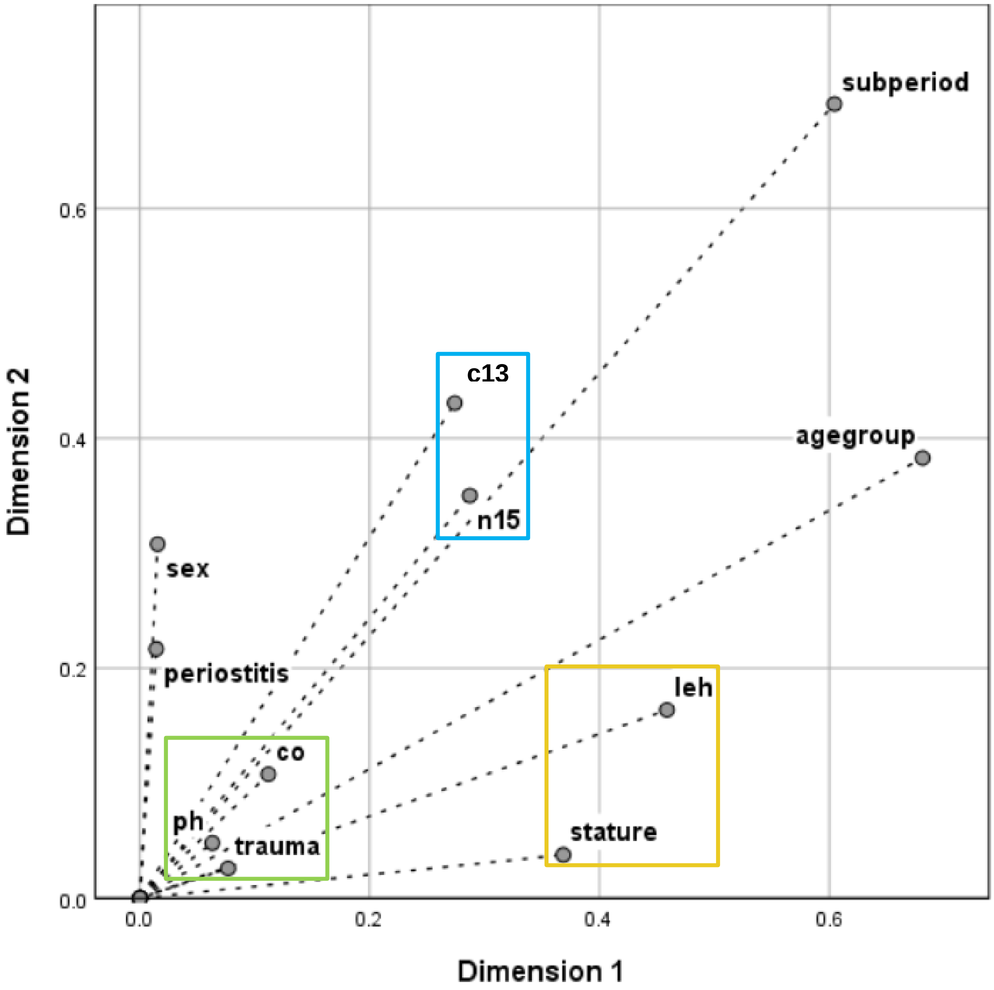


Figure 14: SPSS MCA generated plot of Discrimination measures. Each measure is labeled by its corresponding variable. Measures plotting close to the origin suggest variables with little variation within the study population.

The plotted discrimination measures can be rather subtle in its output, as it represents categorical relationships (rather than direct statistical significance), although there are certain guidelines that we may use to interpret the results.

Large discrimination measures, that is those that plot far from the origin, are indicators of variables with a high degree of variation within the sample population. That is to say, the larger the discrimination measure, the more "influential" (or discriminatory) the variable has been upon the skeletal material. From the Öland data, we can see that Iron Age subperiod and the age of the individual at death varies widely across the data. These conclusions are, however, relatively obvious due to the fact that these categorical variables are relatively random across the sample population. If we disregard these variables, due to their "random" occurance, the variables with the greatest discrimination measures are linear enamel hypoplasia (LEH), $\delta^{13}C$‰ isotope value**,** stature, and $\delta^{15}N$‰ respectively.

Discrimination measures that plot close to one another may represent relationships between variables. This general guideline is especially significant when the discrimination measures plot far away from the origin (thus indicating a high degree of variability). While no observable varible groupings plot far away from the origin, there are certain clusters that may indicate some form of relationship. First, with a relatively high value on Dimension 1, there is perhaps a cluster consisting of stature and LEH (indicated on *Figure 14* by a yellow box). This may indicate an interesting relationship, as LEH and stature are both manifestations of skeletal growth. LEH is an indicator of disruptions in normal enamel disposition due to physiological stress (ie. poor or lacking nutrition and food intake), and likewise, variability in stature can be attributed to physiological stresses and nutritional intake during adolescent growth periods. Another cluster, in this case along the 2nd Dimension, groups $\delta^{13}C$‰ and $\delta^{15}N$‰ isotope values (indicated on *Figure 14* by a blue box). Associations between these two variables is not outwardly shocking, as both variables represent the dietary intake of an individual. A final cluster of potentially related variables is indicated by the green box in *Figure 14*: PH, CO, and trauma. The possible relationship between PH and CO is a relatively obvious one, as they are both skeletal pathologies characterized by the expansion of spongey bone growth as a result of physiological stress (i.e. anemia and/or vitamin deficiencies). While associations between these pathologies and trauma is not necessarily a cause-and-effect relationship, it is possible that the underlying causes of PH and CO contribute to increased probability of skeletal trauma.

Finally, variables that plot near to the origin suggest variables with little variation within the study population. Visually, porotic hyperostosis (PH) and trauma plot near enough to the origin so that we may surmise that there is little variation in these variables within the population. While it may be easy to write-off these variables, as they lack a strong indication of variation, certain aspects of the sample population may be the root cause of the apparent absence of strong variation: within this population, skeletal pathologies may relate to one another in a cause-effect association; a large sample population generates a large pool of data, one in which the visualization of specific relationships may be "sacrificed" in order to plot dimensions representing the greatest variance; little variation within the population may be an indicator of widespread prevalence of the pathologies within the population.

While a variable that plots relatively close to the origin *probably* represents a variable with little variation within the population, this may not actually be the case. The discrimination plot represents two dimensions of the MCA, the two explaining the greatest proportion of variance, but recall that these two iterations of the MCA do not represent *all* of the variation in the population. In fact, they represent only 51.98% of the variance in the relativities (see pg. 47). In these terms, a lot of the data has been left out of the dimension summary as plotted as discrimination measures in *Figure 14.* It is possible that variables plotting close to the origin (representing little variance within the population) are highly differentiated on another dimension, one in which other variables plot as irrelevant. While this hypothetical scenario is indeed a possibility, it is important not to undermine the value of the MCA output. To represent all of the variance within this population takes multiple dimensions, while the discrimination measures output has only plotted two. The potential problem here (one in which 100% of the variance is not visualized) does not lie within the MCA, but rather the quantity of data. The greater the amount of individuals and variables included within the MCA, the greater chance that a summary of the data will miss out on details.

To simplify a rather complicated analysis technique, the MCA is only as good as the data it analyzes. As a tool that analyzes and can possibly identify variable relationships, the MCA is not a *statistical* analysis, and therefore the results of it are best served as a supplementary visualization of potential variation patterns within the population. Potential relationships between individuals and variables are simply that – *potential* relationships. In the greater scheme of things, the results of the MCA are only useful when applied to the rest of the available data to provide further insight into possible climate scenarios and their effects upon the local population.

DISCUSSION

As an isolated landmass, Öland presents a unique opportunity to identify climatic differences experienced on islands within the greater Baltic geographical area. Öland's island nature was an integral aspect of this thesis: one of the research questions intended to be answered by this study was whether the reconstructed climate of Öland is an outlier within the Baltic area. Generally, as indicated in *Figure 7* (pg. 33), the Öland data indicates that the island experienced a relatively drier climate than the greater Baltic area. This conclusion is corroborated by the scPDSI-differences plot in *Figure 8* (pg. 34), in which we can see that the greater portion of the Öland data years are drier than Baltic data, as indicated by a positive difference value (this detail is also demonstrated by the IQR range, indicated by the dashed red lines on *Figure 8*, which are skewed positive).

Several conditions specific to an island geography may have played a role in the drier-than-Baltic climate suggested by the reconstruction. The local climate of Öland is known to be strongly affected by maritime weather patterns. The island is located within the rain shadow of the south-eastern Swedish highlands and generally records a relatively low annual precipitation rate. The rain shadow casts the island into periods of semi-arid, bordering on drought, conditions throughout the summer months. While the spring and autumn seasons on the island typically bring wetter conditions, it is the summer months that the OWDA data reconstructs, as this is the typical growth period of the tree-rings from which the dataset is based upon.

Anthropogenic climate change may have also played a role in creating a drier environment on Öland. The expansion of agrarian subsistence techniques during the first millennium BC resulted in an expansion of cultivated lands with forests cleared for use in farming, grazing and settlement development. Increased human interference in the form of agricultural activity is known to have resulting effects of increasing erosion and the rate in which water flows through a landscape. Hydrological flow through a landscape has a significant impact upon scPDSI values, an index which considers the various aspects that may affect the water-cycle of the soil within an environment. While it is true that Iron Age peoples on Öland interacted and manipulated the island (as is clear for example in the remaining stone walls and foundations), the great majority of grazing opportunities likely were provided by the natural environment of the island. The central-lying grasslands of the Great Alvar were undoubtably utilized by the people of the island, thus requiring less clearing of the general landscape to maximize agricultural potential. As such, anthropogenic interaction with the environment has had some affect upon the drought-index values, but Öland's relatively drier climate is mostly attributable to its natural conditions.

While the OWDA data clearly indicates different environmental circumstances on Öland as compared to the greater Baltic area, it must be emphasized that several factors may have a varying degree of influence upon the results of this analysis. Some were mentioned in the analysis section of this paper but will be discussed here in more detail. As previously mentioned, the OWDA Öland data set is comprised of only 2 coordinate points, neither of which correspond with the exact geography of the island (*Figure 4*, pg. 27) but instead fall on the Swedish mainline coast. This technical inaccuracy is due to the nature of the OWDA data set. The original drought atlas is comprised of a grid of coordinate points, none of which are pinpointed on this small Swedish island. Accepting that the 2 points utilized for this study are technically inaccurate, they are nonetheless the closest geography to the island as represented by scPDSI OWDA values. The position of the points along the coastline allows that they might reasonably be assumed to mimic the conditions on Öland.

A separate influence upon the results of the OWDA analysis is the methodology used to condense the vast data set to make it more valuable and applicable to the purpose of the study. The original OWDA index is a data set of yearly scPDSI values for every coordinate point on the original global grid. The purpose of this study was not to study specific years of possible environmental events but rather to analyze and report on climatic trends, and so, the OWDA data (both for Öland and the Baltic) were condensed to represent 10-year average index values. Furthermore, the original intention and purpose of the scPDSI drought index is to quantify long-term soil-moisture conditions rather than short-term events (Palmer 1965). By averaging the OWDA data, it is reasonable to conclude that the resulting 10-year values do not represent 100% of the variance in the years. That is to say, the data represents an *average* which is potentially diluted by the steps taken for analysis. Years of extreme OWDA index values have likely been normalized by years of more-moderate climates. The effects of the averaged data values have a greater influence upon the Baltic data as the coordinates represent a far more extensive geographical area (with 150 corresponding coordinate points). This however is not of great concern to this study as the Baltic data set is mainly intended as a source of comparison for the Öland data.

While the issues addressed here suggest that the OWDA analysis is in certain ways slightly flawed, it is not unusable. The comparative OWDA analysis proved that Öland, perhaps as a result of its island nature, is noticeably different when compared to the greater Baltic area; it is generally drier than the Baltic area.

Narrowing the scope of the environmental analysis to focus specifically upon the Öland data and results can help clarify the results in terms of another research question: does the OWDA index indicate any extremes on Öland during the study period, and if so, do these extremes align with any known environmental or societal pressures? The simple answer to this question is a simple yes, as indicated in *Figure 5* (on pg. 31). The statistical analysis (using a 95% confidence interval) pinpointed two separate incidences of index values exceeding the "normal" range, at 230AD and at 440-450AD – although the abnormal values during 440-450AD fall only within the defined slightly-extreme range. If these dates represent *statistical* extremes, we may also look to the scPDSI index itself to highlight extremes in climate. While there are no years within the Öland data set that represent moderate soil moisture content (plotting either >3 or <-3 upon the index), there are several dates which plot within the moderately-dry range (<-2 on the scPDSI index): 80, 150, 230, 480, 500, 520, 570 and 1050AD. Several of these dates are interesting in the grand scheme of the history of Europe and, more specifically, Öland.

Extreme weather events in 535-536AD, believed to have been caused by a pervasive atmospheric dust veil, resulted in the most severe short-term cooling event in the Northern Hemisphere in the last 2,000 years. The event, likely caused by a volcanic eruption in the tropics or in Iceland, effected great swaths of the globe, resulting in atypical seasonal weather patterns, crop failures, and famines (Baillie 1994; Bondeson and Bondesson 2014). Although documentary evidence exists detailing the harsh weather, the greatest scientific evidence of this event comes from world-wide tree-ring growth patterns and from sulfate deposits in arctic ice cores. The tree-ring data for these years shows decreased growth for the summers of 535-536AD, with the effects stabilizing over the following years (Baillie 1994; Bondeson and Bondesson 2014).

While the specific effects of this event upon the people of Öland is not yet known, it is likely that an extensive weather-event such as this had some repercussions upon society at the time (Dribe *et al* 2015). The scPDSI data (recall that it has been averaged to reflect 10 year averages) show slight-to-moderately dry conditions at the time of the dust-veil (see *Figure 5*, pg. 31), with extremes at 520 and 570AD. Similar to the tree-ring evidence for the events of 535-536AD, the scPDSI utilizes tree-ring growth patterns to surmise the soil conditions of an area at a particular time. It is therefore possible that the drier conditions indicated by the scPDSI during the years in question are a reflection of decreased tree-growth resulting from a large-scale atmospheric dust veil. At this point is unclear how the dust veil affected the Iron Age settlements on Öland, but a combination of a drier climate and reduced penetration of UV rays through the atmosphere likely would have had some short-term or lasting affects upon the agrarian subsistence practices on the island (Dribe *et al* 2015). Furthermore, famines recorded on mainland Sweden as a result of the 535-536AD event likely were felt similarly on the island (Dribe *et al* 2015).

Although the exact effects of the 535-536AD event on Öland are unclear, there have been several studies regarding a hypothesized societal crisis occurring on the island during the 5th century AD. First proposed during early excavations in the 1930s (Fallgren 2006; Königsson 1968; Stenberger 1933; Svedjemo 2014), this crisis-theory is based upon an archaeologically evident discontinuity in the establishment and upkeep of buildings and foundations upon the island. While this theory has been challenged (Fallgren 2006) and revised to encompass the 6th century (Fabech and Näsman 2015), it provides two centuries of potential crisis to compare with the environmental data.

The beginning of the 5th century recorded the wettest years on Öland according to the scPDSI (*Figure 5***,** pg. 31). The climate shifted after 450AD to be markedly drier, conditions which continued on through the 6th century and onwards (see *Figure 5*). While the greater Baltic region also experienced generally wet conditions during the first half of the 5th century (*Figure 6*, pg. 32), the dry conditions experienced on Öland during the late-5th through the 6th century were a deviation from the Baltic norm at the time (*Figure 7*, pg. 33). It is possible that these fluctuating weather conditions (from wet to dry) were responsible for the decrease in Iron Age settlement creation and maintenance as theorized by early archaeologists. These fluctuations in combination with the effects of the 535-536AD dust veil were perhaps the cause of the societal crisis whether it occurred in the 5th or the 6th centuries. Unstable weather patterns in combination with the abnormal atmospheric dust veil would have undoubtably stressed established agrarian settlements on Öland. As such, this thesis provides a modest answer to one of the intended research questions: yes, Öland does experience some extremes in scPDSI index value when compared to the greater Baltic area. While these extremes (and years of prolonged wet and/or dry climate) do tend to align with hypothesized climate and social crises, the environmental data alone does not indicate whether these events were prolonged or extreme enough to cause significant societal disruptions. For a more complete picture, we can turn to the osteological and archaeological data at hand.

The Kernel Density Estimate (KDE) plot (*Figure 12*, pg. 44) may be indicative of potential societal crises as related to chronology and environment. The KDE model (indicated by a blue line in *Figure 12,* the red line is the unmodeled frequency data) is a chronological visualization of the frequency of dated skeletal material from a given time. Simply put, it shows how much skeletal data is available during any point in time. The KDE model clearly indicates that there is a sharp decrease in skeletal material beginning after the 1st century AD and continuing through the 6th century, increasing in frequency after roughly year 500AD. If we accept the early theory that a crisis occurred at some point during the 5th or 6th centuries (Fabech and Näsman 2015; Fallgren 2006; Königsson 1968; Stenberger 1933), it is possible that the diminishing frequency of skeletal material from this time period is a sign of a dwindling population.

This however may be an attempt to fit the data to an already published theory. In order for the population demographics to reflect the extremely low frequencies of dated skeletal material (which for a period of time during the 5th century reaches zero), there would have to be a crisis of such an extent that it is likely the archaeological evidence could not be contested. Instead, as is proposed by others (Fallgren 2006; Wilhelmson 2012), it is likely that this lack of skeletal material is rather a reflection on changing Iron Age burial practices (Rasch 1994; Wilhelmson 2012) and to incomplete excavations and analysis of the skeletal material. Furthermore – what is perhaps the most understated issue when dealing with the osteological material from Öland – a great portion of the gravesites on Öland remain undated or reflect long continuity which makes accurate dating difficult, if not impossible (Näsman 1994; Wilhelmson 2012). While this fact does not render the KDE frequency plot useless, it does reflect a common conclusion when working with skeletal material from Öland: the conditions of the island and its demographics can introduce inadvertent bias in analytical results and conclusions. The KDE, although potentially biased, can, when considered in concert with the rest of the data, suggest that there were in fact conditional changes occurring during the first half of the 1st millennium AD – changes which resulted in either population decline or reflect changing historic burial practices and flawed modern excavations.

In order to address the final research question, as to whether the rates of skeletal pathology are associated with any extremes in climate, several aspects of the osteological record were statistically analyzed and plotted chronologically. These steps were taken because certain scenarios of physiological and/or nutritional stress experienced by a struggling agrarian society would likely be evident within the osteological record as skeletal pathologies. Statistical analysis of Öland's osteological data was intended to discern whether a fundamental shift in the health of the population occurred at some point during the Iron Age, and to answer whether or not there is a correlation between the occurrence of evidenced skeletal pathologies and chronology.

The incidences of skeletal pathologies were plotted chronologically against the environmental data provided by the scPDSI in order to visually demonstrate any relationships between skeletal health and climate fluctuations (*Figure 10,* pg. 41). This visualization, like the KDE plot, indicates that there are instances during the chronology of Öland with decreased frequencies of skeletal pathologies. From a generalized standpoint, there is a break in the pathological chronology between the 4th and 9th centuries. This break in the frequency of pathologies coincides with years of dry scPDSI index values. The exception of this pattern occurs in the first half of the 5th century, years with wetter-than-normal conditions, years which also indicate the presence of 5 incidences of pathologies[1]. The break in the chronology, as was true with the KDE model, is possible to attribute to several scenarios: a shift in diet, and perhaps in nutrient intake as suggested by the dietary isotope analyses, may have resulted in a healthier population (although this possibility is contested by a resurgence of pathologies from 800AD); a dearth of complete and successfully dated skeletons from this time would lower the possible

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[1] While the dated pathologies are based on scientific dating techniques, it should be noted that the dates of plotted pathologies represent the median of a date-range. That is to say, while there are incidences of dated pathologies according to *Figure 10,* these dates do not align completely with the chronology of the KDE model in *Figure 12.* The intention of these chronologies is to illustrate trends, and therefore discrepancies between these two plots does not necessarily invalidate them.

frequency of positively identified pathologies; or perhaps due to a shifting social norm regarding the shift from burial to cremation burials from the beginning of the Iron Age.

When considering more than general patterns in the chronology, two periods stand out with higher frequencies of skeletal pathology, occurring around 100 and 950AD. While at this point there is no evidence of famines having been recorded at either of these points in time (Dribe *et al* 2015), the environmental data indicates that both of these periods were preceded by periods of fluctuating climate, from wet-to-dry. While these fluctuations are not evidence in themselves that weather had an effect upon the success of subsistence on Öland (and the resulting health of the population), one cannot disprove that shifting soil-moisture did not have a lasting effect on society.

Droughts and pluvial periods, especially on a longer-term scale, can have drastic effects upon the success of harvests. Even to a lesser degree, disruptions in the normal climate can lead to effects which may be seen within the osteological record. The initial statistical tests indicated that stature, which is considered by some to be a positive indicator of general nutritional health, is not driven by chronology and that any differences according to sex are likely a cause of natural sexual dimorphism (*Figure 9***,** pg. 36). While chronology is not correlated to differences in stature, the analysis of dietary isotopes indicated that a shift in diet occurred at some point during the Iron Age (*Tables 7* and *8*, pg. 39-40). These results indicate that between the Early and Late Iron Ages, a dietary (or at the very least, subsistence) shift occurred.

Dietary development in parallel with an increased reliance on agriculture (as indicated and supported by bio-archaeological assemblages and settlement foundations) may have been a partial cause of this shift. An increase in protein consumption as indicated by $\delta^{15}N$‰ value suggests that the nutritional intake of the Iron Age people increased in quality. This can probably be attributed to the increased sedentary nature and reliance on subsistence agriculture and husbandry that became more prevalent as the Iron Age progressed. Yet even as society continued to exploit the land and established more productive farming and animal husbandry methods, this in itself made people more reliant on a stable or, at the very least, a predictable environment. The scPDSI indicates a typically drier-than-normal climate on Öland as the one in which society was likely to have adapted to in the long term (for example by exploiting the natural island resources, such as the Great Alvar plains). However, when the local environmental conditions shifted the people of the island looked to the ocean for supplementary resources, as indicated by changes in

δ^{13}C‰ isotope values, a sign of a reliance on marine plants and animals for food (*Table 8*, pg. 40).

The incidences of skeletal pathologies (as indicated in *Figure 10*, pg. 41), while providing vital information about the Öland population, does not in its own right provide insight as to whether or not Öland is an outlier pathologically within the Baltic area, or an even greater geographic scale. To draw conclusions based on the pathological frequencies established from the Öland skeletal material one would have to include a comparison to other similar Iron Age settlements from the time, which is a topic for future research. What we may surmise from the frequency data as examined here is that certain pathologies are more common than others, and that the incidences tend to group chronologically.

Indication of potential relationships between the occurrence of pathologies within the skeletal material from Öland was analyzed using Multiple Correspondence Analysis (MCA, see *Figure 14* for Discrimination Measures, pg. 48). While the MCA in its nature does not indicate statistically significant correlation between variables, it does suggest possible relationships between variables according to the responses from the individuals included in the MCA. Three clusters of variables were identified using the MCA, and while relational clusters in terms of MCA output is a distinction made post-analysis by the observer (which therefore may introduce some degree of bias), these relationships perhaps are indicative of some true association between variables.

The first of these clusters (indicated within *Figure 14* within a yellow box, pg. 48) consists of stature and LEH, both of which are manifestations of growth and physiological stress during childhood and adolescence. Stature and LEH, although both indicative of growth patterns during different points of youth, have shown similar relationships in other studies (Clark *et al* 2013; Vercellotti *et al* 2014). Most commonly, this relationship has been explored using LEH to measure early childhood nutritional stress and stature and as an indicator of late childhood stress on a sex-specific basis. In terms of the Öland data set, the relationship between LEH and stature may be an indication of continued physiological stress through the entire period of skeletal maturation. Referring to *Figure 10* (pg. 41), incidences of LEH in the osteological record of Öland occurred most commonly after periods of drier climate, especially when multiple incidences of the disease were recorded from the same time. While it is certainly true that the climate of Öland is one characterized by fluctuation, there may exist associations between the environment and the presence of LEH. As LEH is a condition characterized by abnormal enamel disposition caused by physiological stress (due to, for example, poor or lacking nutrition), the presence of the condition, in relation to stature, indicates that portions of the Iron Age population on Öland experienced stressors during their formative years.

The second of these potential relationships (*Figure 14,* indicated by a blue box, pg. 48) clusters together the two dietary isotopes, $\delta^{13}C‰$ and $\delta^{15}N‰$. As both of these values are reflections on the dietary intake of an individual, it is not unusual that a relationship potentially exists between the two. While the association between these two measurements of diet is indicated by the MCA, the exact relationship between these two variables is not as clear. Within the field of archaeology, ideal scenarios investigating opposing extremes within food webs (carnivore vs. herbivore and marine vs. terrestrial) is the most common approach to investigating variation in dietary isotopes (Wilhelmson 2012). As the MCA indicates a potential relationship between these variables, we may conclude that the reality of life in Öland was one in which people gathered their food resources from across the spectrum of the food web.

The final potential variable cluster indicates a potential relationship between porotic hyperostosis (PH), CO and trauma (indicated within a green box on *Figure 14*, pg. 48). PH and CO are both skeletal conditions characterized by the expansion of spongey bone growth as a result of physiological stress, namely anemia or other vitamin deficiencies. While nutrient deficiencies are often attributed as the underlying cause of these conditions, traumatic injuries can, through the healing process, produce highly vascularized lesions that are easily misinterpreted as CO or PH (Walker *et al* 2009). If this scenario does not explain the relationship between the skeletal defects and trauma, it is possible that the general nutrient deficiency at the root cause of CO and/or PH is reflective of the health of an individual as a whole. An unhealthy individual will be at higher risk for osteological trauma, from, for example, skeletal weakness when suffering accidental or deliberate physical trauma.

While the MCA can provide glimpses of potential relationships between variables within a study, it should be emphasized that the results of an MCA are not statistical and are therefore up to interpretation and bias. The nature of the MCA is to maximize the amount of variance represented within the chosen dimensions, which in this case only represented 51.98% of the variance in the data across two dimensions. The best usage of the MCA is in conjunction with other available data to suggest potential relationships – potential relationships when considered in the grand scheme of things may indicate lines of future research.

Future Research Opportunities

This study is a preliminary examination of previously compiled osteological material in relation to newly published environmental data. While the statistical analyses indicated certain potentially significant relationships between the environment of Öland during the Iron Age and chronic manifestations of physiological stress, the results present several avenues for future study and interpretation. Limitations present in both the environmental and osteological data indicate areas in which future research could intensify the focus in order that stronger conclusions could be made. Specifically, a greater skeletal sample size and a geographical area better represented by the OWDA data would perhaps generate similar results, but with greater statistical significance. Furthermore, more comprehensive dating of the skeletal and archaeological material from Öland would supplement and strengthen any conclusions able to be drawn between the skeletal remains and environmental fluctuations. It is of import to investigate and compare the frequency of the occurrence of pathologies in the Öland osteological record to similar Iron Age skeletal material from other parts of the world.

CONCLUSIONS AND SUMMARY

The shift to agriculture as the main form of subsistence practice allowed past peoples the freedom and potential to exploit their natural and man-made environment for personal and societal gain. While a reliance on farming and animal husbandry drastically lessened the pressures on permanent settlements, local and global climates still governed the success and health of harvests and populations. Droughts and periods of excess precipitation had the potential to ruin entire sources of food, and the fluctuations in available resources can be traced through indicators of physiological stress within the osteological record.

The intention of this thesis was to build upon the already existing pool of research regarding Iron Age Öland and to supplement it with new data, to perhaps shed more light on the life and death of the people and society of the time. While excavations and the resulting archaeological and osteological material provides a wealth of knowledge regarding the lives of the people on Öland, there lacks a greater context to place it all within – a context which is provided by the scPDSI index values detailing the soil-moisture fluctuations over a period of over 1000 years.

The environmental reconstruction presented within this study indicates that, in general, the Swedish island of Öland presents as an outlier when compared to the greater Baltic area – one characterized by a drier climate. For an agrarian society, as was present on Öland during the Iron Age, the ecological factors of a fluctuating (and perhaps unfavorable) climate had direct effects upon the dietary needs of the people, the potential disease environment that was endured, and the food producing potential of the landscape. Whether the environment was the cause of hypothesized crises occurring on the island during the 5th or 6th centuries AD or simply coincidence is a question yet to be answered. However, comparisons between the environmental reconstruction and the available osteological record hint that perhaps increases in pathologies, as a result of nutritional stressors, were in some way related to periods of drought or excess soil moisture levels.

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All we have to decide is what to do with the time that is given us.
– J.R.R. Tolkien, The Fellowship of the Ring

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APPENDICES

Appendix I: OWDA Index Data

Cook, E.R. et al. (2015). ‘Old World Megadroughts and Pluvials During the Common Era’, *Science Advances*, 1. DOI: 10.1126/sciadv.1500561

For easier viewing of the entire OWDA data, please follow the link below:

https://drive.google.com/file/d/1Q7uWqpK0U4ZbQQkV3erJXb4jkN4GKRR8/view?usp=sharing

YEAR	BALTIC	ÖLAND
10	-0.40493	-0.03665
20	0.442676	-0.6884
30	-0.03532	-0.88705
40	-0.58977	0.5311
50	-0.0487	0.8127
60	0.037281	-0.2135
70	0.106919	-0.1498
80	-0.51284	-2.16735
90	0.125896	-1.6468
100	-0.35955	-1.0085
110	-0.55689	-1.5778
120	-0.29043	0.423
130	-0.37941	-1.103
140	-1.14458	-1.54875
150	-1.16041	-2.4323
160	0.039203	-0.77875
170	-0.32504	-0.70585
180	0.041931	0.26715
190	-0.05341	0.53975
200	-0.06857	0.01485
210	0.050289	0.3465
220	-0.60779	-0.9535
230	-0.4104	-2.88355
240	0.609559	-0.1831
250	0.182187	-0.0142
260	0.175677	-1.0832
270	0.431637	0.75
280	0.462944	-0.2349
290	-0.14168	0.98495
300	-0.77299	-0.68075
310	0.027662	-0.96225
320	0.084662	-0.4486
330	0.040776	-0.00745
340	-0.40953	-1.9364
350	0.398087	-0.45235
360	0.070398	-0.61015
370	-0.27091	-0.99905
380	-0.46003	-1.2397
390	-0.05374	-0.08625
400	-0.45955	-0.4894
410	-1.05399	-0.321
420	-0.15345	0.31495
430	0.384012	1.54885
440	0.317554	1.7239
450	0.11769	1.7051
460	-0.71959	-0.41095
470	0.134924	0.19465

480	-0.27767	-2.22695
490	-0.33782	-0.34405
500	-1.26588	-2.0531
510	-0.89245	-1.5411
520	-0.36903	-2.14455
530	0.246679	-0.67375
540	-0.28217	-1.82495
550	1.725116	0.01315
560	0.390304	-1.18925
570	0.379123	-2.1042
580	-1.31472	-1.8622
590	0.426489	-0.22
600	-0.25741	-1.11715
610	-0.02876	-1.4358
620	-1.00567	-0.7491
630	-0.99848	-0.82725
640	-0.34155	0.09855
650	-0.44445	-1.1205
660	-0.44398	-0.72485
670	-0.53707	-0.3732
680	-0.73658	-0.263
690	-1.20647	-0.77165
700	-0.58349	-0.6196
710	-0.93576	-0.64965
720	-0.86094	-0.3907
730	0.772295	0.4832
740	-0.49133	0.44905
750	-0.85147	-0.49145
760	-0.76917	0.498
770	-0.85398	-0.34925
780	-0.65909	-1.21205
790	-0.28925	-0.6701
800	0.419821	-1.3159
810	0.321568	-0.54655
820	1.477012	-0.0538
830	1.009734	-0.4418
840	1.022173	0.47265
850	0.325892	1.1059
860	-0.38118	-0.20695
870	0.673655	0.12085
880	-0.7792	-0.46795
890	-0.27907	-0.0659
900	-0.5852	-0.5978
910	-0.21765	0.08715
920	0.212063	-0.91715
930	-0.43874	-0.7336
940	-1.72178	0.83585
950	-1.64441	-0.5664
960	0.671591	-0.4762

970	0.175584	-1.10955
980	0.099046	-0.99015
990	-0.2697	-0.77295
1000	-0.21634	-1.37595
1010	-0.34909	-0.83135
1020	0.641859	-0.5963
1030	-0.33249	-1.3224
1040	-0.91511	-1.51615
1050	-1.40893	-2.02827

Appendix II: Osteological Material

Wilhelmson, H. (2017). *Perspectives from a Human-Centered Archaeology: Iron Age People and Society on Öland.* Lund: Department of Archaeology and Ancient History, Lund University.

Please note: The osteological material used for this thesis generated a very large data file. It is attached in this appendix in two-page bundles. That is to say, every two pages of the data represents all of the individuals, simply divided into different variables/characteristics.

For easier viewing, please follow this link to the entire data set:

https://drive.google.com/file/d/1x8Wln-4v7Z5mOQKHT0JkSXS_9DVKqHd3/view?usp=sharing

ID#	GraveField	Grave#	Sex	Age	AgeGroup	GroupEst.Age	Staturecm
1002	9754	25	M	35-50?	young-mature	20-59	
1003	31890	8	M	35-45	young-mature	20-59	
1004	31890	11			juvenile-young	13-35	
1005	31890	18	M	60+	old	60+	178.65±4.52
1008	24542	1 under	F	38±10	young-mature	20-59	146.4±4.52
1009	23494	21	M		old	60+	
1011	23280		M	40-45	mature	36-59	169.1±4.52
1012	28549		M	35-45	young-mature	20-59	175.94±4.52
1013	27365	35	M	44-50	mature	36-59	
1014	28364	108 F231 III	M	45-50	mature	36-59	181.1±4.52
1015	25153		F	20-30	young	20-35	161.58±4.52
1016	25096		F	70	old	60+	165.37±4.52
1019	31890	25			young	20-35	
1020	1785/67 Bårby	6	F		mature	36-59	175.4±4.52
1021	26454	3	F		young-mature	20-59	
1022	26454	2?			young-mature	20-59	
1023	26454	1?			young-mature	20+	
1024	25129		F	16	juvenile	13-19	
1025	23981	35b		8?	child	6-12	
1026	19726	1	M	60	old	60+	159.4±4.52
1028	22486		M		mature	36-59	172.4±4.52
1030	25657		M		mature-old	36+	191.33±4.94
1031	27768		M	19-21	juvenile	13-19	
1032	27702	39	F		mature	36-59	
1033	27702	2	M		young-mature	20-59	
1034	25130		M	30-40	young-mature	20-59	168.9±4.52
1035	22348		F	19-27	young	20-35	157±4.52
1036	23267	1	F	20-30	young	20-35	167.5±4.52
1037	27702	1	M	15-17	juvenile	13-19	
1038	28364	6	F	~40?	mature	36-59	
1039	27702	36	F		young	20-35	
1044	27764		M		old	60+	163.5±4.52
1045	29352	24	M	60+	old	60+	158.1±4.52
1046	22291		M	~20	juvenile-young	13-35	165.1±4.52
1047	23981	47	M		young-old	20+	181.57±4.11
1048	23981	35a	M		young-mature	20-59	175.15±4.94
1053	27702	90			mature	36-59	
1054	27702	140		9-10	child	43994	
1055	22231	4			juvenile-young	13-35	
1056	27125			13-15	juvenile	13-19	
1057	29352	13	M		old	60+	173.2±4.52
1058	28364	134	F		mature	36-59	168.6±4.52
1059	23494	20	M	19	juvenile	13-19	181.4±4.52
1060	23494	19		11-12	child	43994	
1061	24543	3	M		mature	36-59	171.9±4.52
1062	19197	2?	F		young-mature	20-59	169.4±4.52

1064	22394		M		mature	36-59	169.2±4.52
1065	6393/75	3	F		mature-old	36+	
1066	6393/75	10		12-15	juvenile	13-19	
1067	6393/75	20	M	72±	old	60+	182.4±4.52
1068	29352	18	M	30-40	young-mature	20-59	169.2±4.52
1071					mature-old	36+	
1072			M	50±14	mature	36-59	
1073			M	55-65	mature-old	36+	
1074			F	~30	young	20-35	
1075	28364	164	M		mature	36-59	162.9±4.52
1076	28364	136	F	50-60	mature	36-59	160.8±4.52
1077	22231	8			juvenile-young	13-35	
1078	21367	A5		12-15	juvenile	13-19	
1079	31890	12	M		young-mature	20-59	
1080	31890	5	F		young-mature	20-59	164.94±4.11
1081	31890	6			young-mature	20-59	165.25±4.52
1082	24543	2	M	45-55	mature	36-59	167.9±4.52
1083	24543	1	M	60	old	60+	186.5±4.52
1085	24866	G	F		young-mature	20-59	162.4±4.52
1086	29352	25	F	38	young	20-35	159.4±4.52
1087	23267	2	F	17-21	juvenile	13-19	
1088	23267	3	M	45-60	mature	36-59	171.6±4.52
1089	23267	4?	M	18-21	juvenile	13-19	
1090	27702	37	M		young-mature	20-59	181.24±4.11
1091	29352	113	M		young-mature	20-59	174.86±4.52
1092	12142	9 over?	M		mature-old	36+	
1093	12142	9 under	M		young	20-35	180.5±4.52
1094	25132		F	60	old	60+	164.5±4.52
1096	24813	2	M		young-mature	20-59	
1097	22763		F		mature	36-59	161.8±4.52
1099	1785/67	5	F	18-19	juvenile	13-19	154±4.52
1100	25021		M	16-18	juvenile	13-19	
1101	21367	24	M	~23	young	20-35	174.9±4.52
1102	23349	3?		7-8	child	43994	
1103	21368	37 under	F		old	60+	
1104	21368	37 over	M		young-mature	20-59	171.9±4.52
1105	28364	108:I:169	M		young	20-35	
1107	19765	13	M	25-30	young	20-35	
1108	Sb	Individual I	M	17-19	juvenile	13-19	171.1±4.52
1109	Sb	Individual II	M	19-22	young	20-35	175.5±4.52
1110			M		adult-mature	20+	
1113	26239	8		15±1	juvenile	13-19	

AdjustedStature	Chronology	AdjustedChronology	IronAgeAdjusted	IronAgePeriod
	0-200	0-200	1	Early Iron Age
	0-400	0-400	1	Early Iron Age
	112±116	-4-228	1	Early Iron Age
178.65	40-150/160	40-160	1	Early Iron Age
146.40	847±65	782-912	2	Late Iron Age
	0-400	0-400	1	Early Iron Age
169.10	200-400	200-400	1	Early Iron Age
175.94	800-1050	800-1050	2	Late Iron Age
	800-1050	800-1050	2	Late Iron Age
181.10	0-200	0-200	1	Early Iron Age
161.58	130±57	73-187	1	Early Iron Age
165.37	800-1050	800-1050	2	Late Iron Age
	40-310/320	40-320	1	Early Iron Age
175.40	40-150/160	40-160	1	Early Iron Age
	800-1050	800-1050	2	Late Iron Age
	800-1050	800-1050	2	Late Iron Age
	800-1050	800-1050	2	Late Iron Age
	1049±58	991-1107	2	Late Iron Age
	100BC-100AD	-100-100	1	Early Iron Age
159.40	986±38	948-1024	2	Late Iron Age
172.40	885±69	816-954	2	Late Iron Age
191.33	800-1050	800-1050	2	Late Iron Age
	250/260-310/320	250-320	1	Early Iron Age
	40-150/160	40-160	1	Early Iron Age
	40-150/160	40-160	1	Early Iron Age
168.90	3±46	-43-49	1	Early Iron Age
157.00	0-200	0-200	1	Early Iron Age
167.50	103±54	49-157	1	Early Iron Age
	0-200	0-200	1	Early Iron Age
	0-200	0-200	1	Early Iron Age
	0-40	0-40	1	Early Iron Age
163.50	0-200	0-200	1	Early Iron Age
158.10	800-1050	800-1050	2	Late Iron Age
165.10	847±65	782-912	2	Late Iron Age
181.57	3±46	-43-49	1	Early Iron Age
175.15	25±47	-22-72	1	Early Iron Age
	0-200	0-200	1	Early Iron Age
	0-200	0-200	1	Early Iron Age
	700-800	700-800	2	Late Iron Age
	22BC±55	-33-77	1	Early Iron Age
173.20	800-1050	800-1050	2	Late Iron Age
168.60	1049±58	991-1107	2	Late Iron Age
181.40	847±65	782-912	2	Late Iron Age
	800-1050	800-1050	2	Late Iron Age
171.90	200-400	200-400	1	Early Iron Age
169.40	88±57	31-145	1	Early Iron Age

169.20	858±68	790-926	2	Late Iron Age
	800-1050	800-1050	2	Late Iron Age
	800-1050	800-1050	2	Late Iron Age
182.40	800-1050	800-1050	2	Late Iron Age
169.20	800-1050	800-1050	2	Late Iron Age
	716±44	672-760	2	Late Iron Age
	119±56	63-175	1	Early Iron Age
	829±57	772-886	2	Late Iron Age
	30±48	-18-78	1	Early Iron Age
162.90	853±67	786-920	2	Late Iron Age
160.80	150/160-260/270	150-270	1	Early Iron Age
	700-800	700-800	2	Late Iron Age
	800-1050	800-1050	2	Late Iron Age
	40-150/160	40-160	1	Early Iron Age
164.94	40-150/160	40-160	1	Early Iron Age
165.25	0-40	0-40	1	Early Iron Age
167.90	67±48	19-115	1	Early Iron Age
186.50	0-400	0-400	1	Early Iron Age
162.40	0-200	0-200	1	Early Iron Age
159.40	799±68	731-867	2	Late Iron Age
	36±49	-13-85	1	Early Iron Age
171.60	858±68	790-926	2	Late Iron Age
	125±57	68-182	1	Early Iron Age
181.24	40-150/160	40-160	1	Early Iron Age
174.86	0-40	0-40	1	Early Iron Age
	40-150/160	40-160	1	Early Iron Age
180.50	40-150/160	40-160	1	Early Iron Age
164.50	125±62	63-187	1	Early Iron Age
	25±47	-22-72	1	Early Iron Age
161.80	1053±60	993-1113	2	Late Iron Age
154.00	200-400	200-400	1	Early Iron Age
	61±54	7-115	1	Early Iron Age
174.90	800-1050	800-1050	2	Late Iron Age
	0-400	0-400	1	Early Iron Age
	70-150/160	70-160	1	Early Iron Age
171.90	0-150/160	0-160	1	Early Iron Age
	853±71	782-924	2	Late Iron Age
	200-400	200-400	1	Early Iron Age
171.10	460-490	460-490	2	Late Iron Age
175.50	460-490	460-490	2	Late Iron Age
	629±18	611-647	2	Late Iron Age
	729±36	693-765	2	Late Iron Age

subperiodallMCA	SubperiodAdjusted	Subperiod	Trauma	LEH	CO	PH	Periostitis	δ13C	δ15N
2.00	1.1	Early Roman	no	no			no	-20.2	12.7
1.00	1.0	.	no	yes			yes	-19.6	12.4
2.00	1.1	Early Roman	no	yes				-19.7	13.4
2.00	1.1	Early Roman	no	no	no		no	-20.3	8.0
4.00	2.0	.	no	no	no	no	yes	-19.1	11.4
1.00	1.0	.	no	no	no	no	yes	-19.5	12.1
3.00	1.2	Late Roman	yes	no	no	no	no	-18.9	10.4
7.00	2.3	Viking	yes	no	no		no	-19.9	12.6
7.00	2.3	Viking	no	no	no	no		-19.4	12.2
2.00	1.1	Early Roman	no	no	no	no	no	-19.8	12.7
2.00	1.1	Early Roman	no	no			yes	-19.6	15.2
7.00	2.3	Viking	no	no	no	no	no	-19.8	13.0
1.00	1.0	.	no	no				-19.9	13.6
2.00	1.1	Early Roman	no	no				-19.7	15.9
7.00	2.3	Viking	no	no	yes			-20.3	13.7
7.00	2.3	Viking		no				-20.0	12.1
7.00	2.3	Viking	no	no			yes	-20.0	12.3
7.00	2.3	Viking	yes	yes	no	no	yes	-19.3	11.1
2.00	1.1	Early Roman	no		no	yes		-19.6	12.1
7.00	2.3	Viking	no	no	no	no	no	-19.7	13.4
7.00	2.3	Viking	yes	no	yes	no	no	-19.3	11.6
7.00	2.3	Viking	yes	no	yes	no	no	-20.5	13.1
6.00	2.2	Late Roman	yes	yes	no	no	no	-20.1	14.2
2.00	1.1	Early Roman	no	no				-20.1	13.1
2.00	1.1	Early Roman		no				-20.0	11.0
2.00	1.1	Early Roman	yes	no	no	no	yes	-19.7	13.2
2.00	1.1	Early Roman	no	yes	yes	no	yes	-19.6	13.2
2.00	1.1	Early Roman	no	no	no	no	no	-19.2	13.9
2.00	1.1	Early Roman	no	no			no	-19.8	14.6
2.00	1.1	Early Roman	no	no				-19.9	13.2
2.00	1.1	Early Roman	no	no	yes	no	no	-19.9	15.2
2.00	1.1	Early Roman	yes	no			no	-19.5	14.2
7.00	2.3	Viking	yes	no	no	no	no	-19.0	11.4
4.00	2.0	.	no	yes	yes	no	no	-19.4	13.4
2.00	1.1	Early Roman	no	no				-19.8	14.4
2.00	1.1	Early Roman		no		no		-19.9	13.9
2.00	1.1	Early Roman	no	no	no	no	no	-20.0	13.9
2.00	1.1	Early Roman	no	no	yes	no	no	-20.3	14.1
6.00	2.2	Vendel		no				-20.1	13.3
2.00	1.1	Early Roman	no	no	yes	no	no	-19.6	13.1
7.00	2.3	Viking	no		no	no	no	-19.2	11.7
7.00	2.3	Viking		no	no	no	no	-19.4	13.3
4.00	2.0	.	no	yes	no	no	yes	-18.6	13.9
7.00	2.3	Viking		no				-20.0	11.4
3.00	1.2	Late Roman	no	no	no	no	yes	-19.7	15.0
2.00	1.1	Early Roman	no	yes	no	no		-19.9	14.3

4.00	2.0	.	no	no	no	no	no	-19.3	12.7
7.00	2.3	Viking	no		no	no	no	-19.4	13.2
7.00	2.3	Viking	no	yes				-20.0	11.9
7.00	2.3	Viking	no	no	no	no	no	-19.1	13.5
7.00	2.3	Viking	yes	no	no	no	no	-19.1	13.2
6.00	2.2	Vendel							
2.00	1.1	Early Roman	yes						
4.00	2.0	.							
2.00	1.1	Early Roman							
4.00	2.0	.	no	no	no		no	-19.1	13.2
1.00	1.0	.	yes	no	no	no	no	-19.9	14.2
6.00	2.2	Vendel	no				yes	-19.8	13.1
7.00	2.3	Viking	no	no	yes	no	no	-19.0	12.0
2.00	1.1	Early Roman	no	no	no		no	-19.8	13.7
2.00	1.1	Early Roman	no	yes				-19.8	13.7
2.00	1.1	Early Roman	no	no				-19.9	15.1
2.00	1.1	Early Roman	no	no	no	no	no	-19.9	15.0
1.00	1.0	.	yes	no	no		yes	-19.7	12.0
2.00	1.1	Early Roman	no	no	yes			-19.6	12.1
4.00	2.0	.	yes	yes	yes	no	no	-19.6	11.9
2.00	1.1	Early Roman	yes	yes	yes	no	no	-19.5	13.8
4.00	2.0	.	no	no	yes	no	no	-19.3	13.2
2.00	1.1	Early Roman	no	no	yes	yes		-19.5	13.5
2.00	1.1	Early Roman	yes	no	yes		yes	-20.0	14.6
2.00	1.1	Early Roman	yes	no	no	no		-19.3	14.2
2.00	1.1	Early Roman	yes	no	no	no	yes	-19.5	14.6
2.00	1.1	Early Roman	yes	no	no	no	no	-20.1	14.9
2.00	1.1	Early Roman	yes	no	yes	no		-19.8	15.9
2.00	1.1	Early Roman	no	no			yes	-19.4	13.4
7.00	2.3	Viking	no	no				-19.5	12.9
3.00	1.2	Late Roman	no	yes	yes	no	no	-19.8	13.7
2.00	1.1	Early Roman	yes	no	yes		no	-19.7	14.1
7.00	2.3	Viking	no	no	no	yes	yes	-19.2	12.4
1.00	1.0	.	no	no		no	yes	-19.8	13.2
2.00	1.1	Early Roman	yes	no	no	no	no	-19.9	13.3
2.00	1.1	Early Roman	no	no	yes		no	-19.8	12.1
4.00	2.0	.		no				-20.0	11.6
3.00	1.2	Late Roman	yes	no	yes	no	no	-19.7	12.8
5.00	2.1	Migration	yes	yes	yes	no	no	-18.9	15.0
5.00	2.1	Migration	yes	no	no		yes	-18.5	15.2
6.00	2.2	Vendel							
6.00	2.2	Vendel		no				-18.8	13.9

malestatureQs	femalestatureQs	maleEIA	maleLIA	femaleEIA	femaleLIA	malestature	femalestature
3		178.65				178.65	
	1				146.40		146.40
2		169.10				169.10	
3			175.94			175.94	
4		181.10				181.10	
	2			161.58			161.58
	3				165.37		165.37
	5			175.40			175.40
1			159.40			159.40	
2			172.40			172.40	
5			191.33			191.33	
1		168.90				168.90	
	1			157.00			157.00
	4			167.50			167.50
1		163.50				163.50	
1			158.10			158.10	
1			165.10			165.10	
4		181.57				181.57	
3		175.15				175.15	
3			173.20			173.20	
	4				168.60		168.60
4			181.40			181.40	
2		171.90				171.90	
	4			169.40			169.40

2			169.20			169.20	
4			182.40			182.40	
2			169.20			169.20	
1			162.90			162.90	
	2			160.80			160.80
	3			164.94			164.94
1							
1		167.90				167.90	
4		186.50				186.50	
	3			162.40			162.40
	2				159.40		159.40
2			171.60			171.60	
4		181.24				181.24	
3		174.86				174.86	
3		180.50				180.50	
	3			164.50			164.50
	2				161.80		161.80
	1			154.00			154.00
3			174.90			174.90	
2		171.90				171.90	
2			171.10			171.10	
3			175.50			175.50	