EFFECT OF TEMPERATURE CHANGE ON IRON AGE CEREAL PRODUCTION AND SETTLEMENT PATTERNS IN MID-NORWAY

ARNE ANDERSON STAMNES
NTNU University Museum
Arne.stamnes@ntnu.no

ABSTRACT

This paper will investigate the relationship between land available for cultivation and settlement patterns, and the potential effect temperature changes had on settlement patterns in the Iron Age of central Norway. Temperature, more specifically the accumulated temperature sum (døgngrader in Norwegian, abbreviated as "ACT"), is an important indicator of the potential for getting ripe crops. By calculating the ACT values at different locations, it is possible to geostatistically model and create maps showing how varying temperature conditions affect arable areas. The results of this can be drawn into a discussion concerning the effect of changing climate conditions on settlement patterns. What is the liminal zone for crop production at a specific time? In which regions would a given temperature change have the greatest effect? Would temperature change have any effect on subsistence strategies? This paper will demonstrate how GIS-systems are a powerful tool for analysing and modelling past climatic conditions, and may possibly reveal important information not previously accessible.

INTRODUCTION

The Migration Period (AD 400-560/570) in Norway is generally considered as a period of settlement expansion and increased wealth. The erection of large burial mounds with rich grave finds indicate that power was centralized, probably in relatively unstable, petty kingdoms or territories with shifting alliances and struggles for power. The society at that time is thought to have been socially stratified, based on alliances arranged through marriages, the exchange of gifts, barter and war. Large boat houses, hillforts and weapons from graves and sacrificial offerings tells us a story of a competitive society where a surplus of resources and raw materials such as iron, hides, craft products and agricultural products could be transformed into power and were necessary to feed workers, craft specialists and warriors. Closer to the 6th century AD, human activity expanded into outlying areas that had few traces of activity in earlier periods. This included fishing along the coasts, iron production, systematic hunting of elk and reindeer, animal husbandry and summer dairying. In some instances, areas were cleared that never have been used for agricultural purposes again. This situation seems to be similar over most parts of Scandinavia (Pedersen and Widgren 1998: 267; Prestvold 1999; Solberg 2000; Myhre 2002: 59-160; Stenvik 2005).

There are a series of changes in the archaeological evidence in the middle of the 6th century. Rich graves disappear, deposition of hoards and sacrificial offerings is discontinued, and a large number of farms seem to have been abandoned (Solberg 2000; Löwenborg 2012). In Trøndelag the extensive iron production seen in the previous centuries disappear completely, and the same technology is never to be seen again (Stenvik 1994; Stenvik 2005; Prestvold 1999). Boat houses also disappear from the archaeological record. Such boat houses are assumed to be indicators of trade or military activities, and connected to the social and political organisation of the area. If they disappear, then there is reason to believe that the organisation behind them also disappeared (Myhre 1987; Johansen 2007; Grønnesby and Ellingsen 2012: 137). While all these aspects might point towards a crisis, some scholars have indicated that this transition might not have been so dramatic in Trøndelag as in other regions of Norway (Myhre 2002: 173).

Several suggestions have been put forward to explain these events, and these can generally be organised as either internal or external explanations. Internal explanations are, for instance, that due to an increased population, technological changes and wider contact networks in the 6th century (Myhre 2002: 159-170), society reached the limit of land available for settlement and exploitation. Another internal explanation is that an increased consolidation of power could allow wealthy chieftains and their families to restructure the settlements in the landscape (Prestvold 1999: 99 and Myhre 2002: 159-170 and 198).

This is a notion that contrasts with observations made by Grønnesby and Ellingsen (2012: 137) concerning the disappearance of the boat houses in the archaeological record. This could be explained as a downfall in trade with the Roman Empire (Solberg 2000: 210), or other external factors such as the Justinian Plague. A plague could have altered the power balance in the societies, but could also have led to technological innovation to counter the fall in labour or inspired a change of focus from cereals to animal husbandry (Solberg 2000: 176-182; Myhre 2002: 172-173, see Löwenborg 2012 for a more general discussion on the effect of disasters).

Another suggested external explanation is the effect of climatic changes on population size, settlement size and the way societal organisation. Issues related to the "AD 536 event", a proposed drastic climatic shift ca. AD 536-37, have been particularly heavily debated. This event is described as a drastic climatic catastrophe, which has been observed through low growth in tree rings and layers of sulphate in glacial ice sheets. Such an event is well documented, and is assumed to be caused by one or several large volcanic eruptions. The effect of this catastrophe would have been lower summer temperatures, with a temperature fall of up to 3-4 degrees Celsius (Gräslund 2007; Gräslund and Price 2012, both with references to Briffa et al. 1990, Scuderi 1990 and Grudd *et al* 2002). Classical written sources from Europe, the Middle-East and China also mentions years of cold summers, and this dramatic fall of temperatures is by Gräslund connected to the Nordic tradition of the "Fimbulvinter" (Gräslund 2007; Gräslund and Price 2012; Löwenborg 2012).

The regional effect of such a dramatic fall in temperature can be modelled through the notion of growing degree days (abbreviated to "GDD", or "døgngrader" in Norwegian), which will indicate whether or not it is possible to cultivate cereals that reach maturity. The GDD can be calculated for every meteorological measurement station, and effects of climatic variation on available land can be visualised through a geostatistical analysis and visualisation. These maps will tell us the effect of such temperature variation on available land for cultivation of grain. The aim of this paper is to model the effect of climate variations, and use the results of such models in a discussion of the potential effect this might have on settlement patterns, agricultural practices and social structures in an Iron Age society in the region of Trøndelag, Norway. Various available archaeological sources, as well as natural-historical and archaeobotanical evidence will also be investigated.

CLIMATE, CEREALS AND SETTLEMENT STRUCTURES

Climate changes can have detrimental effects on growing conditions for cereals. Different cereal-species have varying requirements for soil conditions, pH and growing degree days (GDD). A nutritional soil is dependent on the local geology. Various minerals such as silicate, aluminium, iron and magnesium in combination with nutrients such as oxygen, hydrogen and carbon, are components that contribute to the health of plants and agricultural cereals (Strahler and Strahler 2005: 610-611, 641). Soils of a higher pH will also be more fertile than acidic soils, as long as the pH is not too high. Chalk-rich soils can also be beneficial. Modern barley requires a pH of at least 5.8 on sandy and silty soils. However, a moist climate with increased rainfall will wash nutrients and alkaline ions out of the reach of plants, potentially creating a non-ideal situation for further cultivation (Welinder 1998: 42; Frøseth 2004: 175). In the early stages of the cultivation season, it is important that nitrogen is available for the plants, which happens in "warm" soils, typically when exposed to sun or on more stony, moraine soil types. At the same time, a low temperature early in the season will make the plants grow slowly and give them time to develop properly (Stamnes 2008: 38 with personal reference to Randi Berland Frøseth).

As mentioned earlier, different types of cereals have different temperature requirements during the growing season, typically referred to as "Growing Degree Days" (GDD). For the cultivation of grain, this is the accumulated temperature from the day the average temperature goes above 6˚ C in spring until it falls below 10 ˚C in the autumn. 10 ˚C is necessary for the grains to reach maturity. The GDD increases by 20 points per latitude degree above approximately 60˚, due to longer and sunnier days during the summer season at higher latitudes. At the same time, a rainfall above 250mm during the growing season will decrease the GDD by 60-80 for barley and 100-110 for wheats (Frøseth 2004: Stamnes 2008: 36-41).

Table one presents the GDDs required for various modern cereal types. These numbers are based on modern cereal types:

The numbers presented in table 1 are based on modern cereal types, and will vary with the amount of rainfall. It is possible that locally adapted species, developed through careful selection of the best seeds

Cereal type	Growing Degree Days	Average Corrected GDDs for cereals in Nord-Trøndelag
Early Barley	1250	1200
Late Barley	1330	1280
Early Oats	1300	1258
Late Oats	1380	1338
Spring Wheat	1460	1423

Table 1: GDD requirements for the various modern cereal types (source Frøseth 2004– corrections calculated depending on average latitude and rainfall in Nord-Trøndelag by the author)

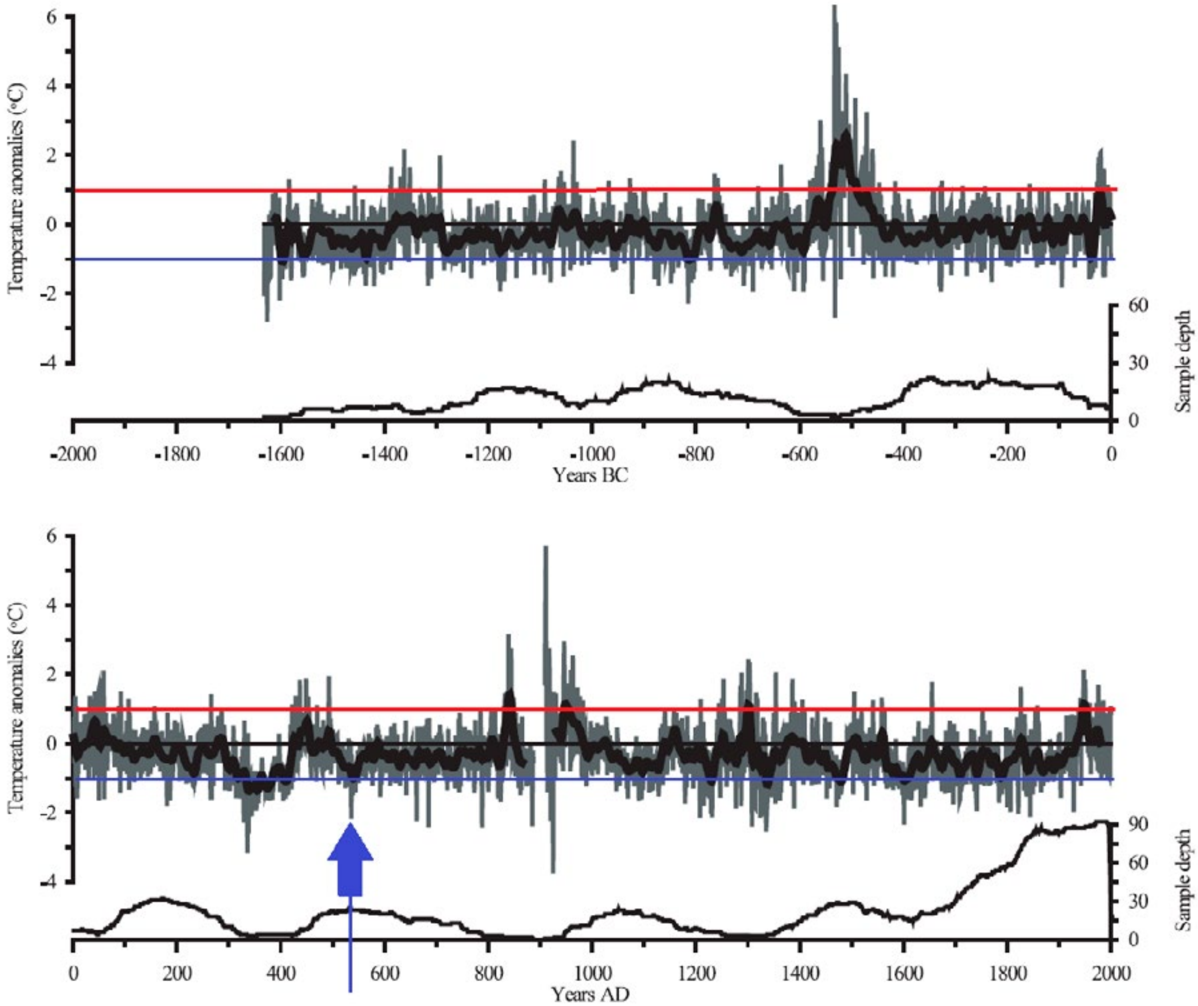

Figure 1. The reconstructed summer temperatures (June to August) from Jämtland as presented by Linderholm and Gunnarson 2005: 237. The upper part of the figure is for the years BC, and the bottom part is for the years AD. The lines and arrow have been inserted by the author, and indicate + 1 degree C in red and -1 degree C in blue. The blue arrow indicate the time of the potential "fimbulvinter"-event. Used with permission.

Period	Effect	Approximate temperature change compared to the 1961–1990 mean
450-550 BC	Warm	+ 1-2,4 degrees
AD 300-400	Cold	1 degree
AD 900-1000	Warm	+ 0,5-1 degrees
AD 1550-1900	Cold	0,5 degree

Table 2: Climatic periods highlighted by Liderholm and Gunnarson (2005).

from each cereal, could have had a lower GDD than the current available cereal types. Of cereal types found in archaeological contexts in North-Trøndelag up to 2006, barley was found at 11 out of 15 sites where cereals was discovered; 10 of these finds are covered barley. Barley is known to have been cultivated from the Early Bronze Age and throughout through the Iron Age. The other cereal types found are wheat (2), oats (1) and rye (1) (Stamnes 2008: 42). Pollen analysis conducted in mid- and northern Norway also show that farming activities expanded in the Late Roman Iron Age (especially in the period AD 200-375), and that the cultivation of barley increased in particular (Vorren *et al.* 1990).

When it comes to temperature variations during the Scandinavian Iron Age, Berglund (2003) compiled and compared several sources looking at solar variability, ice rafted debris, lake levels, lake catchment erosion, peat growth, tree-ring records, glacier advances, sea-level changes and paleosols correlated with dry periods. He emphasises a rapid cooling period based on tree ring data, sea surface temperatures and rising lake levels in the period AD 480-540. This probably led to a wet climate. He also suggests a shift during the Viking Period which led to a warm and dry climate, with high tree lines, glacier retreat and reduced lake catchment erosion. This lasted until around AD 1200, when a gradual change to a more cool and moist climate occurred (Berglund 2003: 9-10). Linderholm and Gunnarson (2005) also emphasise a series of climatic variations based on tree ring samples taken from bogs and lakes in the Jämtland area, which is more inland but geographically close to Trøndelag (Table 2).

The Linderholm and Gunnarson (2005) sequence does not seem to indicate a dramatic temperature decline around AD 500-550, but a small low peak deviating from the 30 year moving average at around AD 530-540 might be exactly the "fimbulvinter"-event at AD 536-37 suggested by Gräslund (2007) (indicated by the blue arrow in figure 1) and Gräslund and Price (2012). There are other outlying events during this time period, but the sequence and the article by Linderholm and Gunnarson (2005) focus on general trends rather than dramatic events.

METHOD

The Norwegian Meteorological Institute has a database of historical climate data called "eKlima"[1] which contains historical data of rainfall and temperatures recorded by their meteorological measurement stations all over Norway. Exported data from this database will be used in this investigation. Points with recorded coordinates and data properties can be used to generate maps, models and visualisations of the inherent properties at these locations. The geographical location of each meteorological measurement stations, as well as the recorded rainfall and temperatures at these locations have been used as data. By using an interpolation technique called cokriging, coverage maps of the GDD can be generated in the software ArcMap10.1 with the Geostatistical Analyst-extension. Kriging is considered an exact interpolation method, and is based on spatially modelling variables under the assumption that natural occurring properties will be more similar the closer they are to each other. The statistical relationship between spatial distance and the correlation between measurements can be statistically modelled through what is called a variogram, which describes the spatial variability of a variable in terms of its magnitude, scale form and contribution of random noise. The variation of the measurements or parameters, as well as the distance between measurement points, are used to perform the most ideal interpolation – increasing the accuracy of the models. Cokriging is a variant of kriging used to model a property in instances where few measurements of the primary variable

1 www.eklima.no

exist, while measurement of a secondary variable is more abundant. The correlation between the property one wishes to model and a secondary property can be utilized to model the primary variable based on the secondary one. In essence, this means that we can use the abundant information of height above sea level as a secondary variable to model the GDD over a chosen area, as long as there is a strong statistical relationship between GDD calculations at the known sample points and the height above sea level. The mathematics behind these methods is quite advanced and thoroughly explained in, for instance, Isaaks and Srivastava (1989).

The use of geostatistical modelling to model past climatic conditions has not previously been undertaken for this part of Norway. While a map of the GDD of Sweden have been presented in Welinder (1998: 252), it is unclear how the map was produced as there are no references related to it in the publication. This project will also be considered as a test of the applicability of this methodology for this type of modelling. Some notes on the methodological drawbacks and advantages will therefore be discussed later.

To investigate the potential effect of climate change on settlement patterns, agricultural practises and social structures in the Iron Age mid-Norway, it is possible to use publicly available climatic data. A database of such data was compiled, and temperature variations for the various meteorological measurements stations within the geographical area of interest were calculated. Information on the average temperatures from all meteorological stations that had recorded data from the climatic standard period between AD 1961-1990 in the county of Nord-Trøndelag were exported. Based on the geographical location and mean average height above sea level for each station, this information was entered and processed in a Geographical Information System using geostatistical programme extensions (ArcMap 10.1 with the Geostatistical Analyst plugin). There are 49 stations spread out over the county, and additional measurements were exported from neighbouring municipalities in the counties of Nordland and Sør-Trøndelag, making it a database of 64 stations in total, with 365 measurements for every year. For each station the average temperature for each daily measurement was increased by 1 °C, 0.5 °C, as well as reduced by 0.5 °C, -1 °C and -3.5 °C, creating a sequence of temperature calculations for each meteorological station. The GDD was then recalculated for each average temperature at each station, making it a total of 384 calculations. The height above sea level is available for each station. The Pearson correlation coefficient (*r*) between the GDD and the recorded height is -0.93, showing a close relation between the decrease of temperature with an increased height above mean sea level. In essence, this means that using mean height above sea level as a secondary variable is highly applicable in a cokriging procedure as described above is, and increases the confidence in the final results of the model. 13604 height measurement points, including those at the meteorological stations, have been used as a secondary variable. These height measurements were also compared with the calculated GDDs for each station, to identify approximately the highest station with a GDD equal to the average for early barley in the region, and for the purpose of comparison with to the geostatistical models.

RESULTS

The result of these cokriging operations is a series of raster datasets. Below are visualisations of the results for the GDD of the average period 1961-1990 (Fig. 2), the effect of a temperature rise of 1 °C (Fig. 3), a temperature decline of 1 °C (Fig. 4) and a temperature decline of 3.5 °C (Fig. 5).

All these maps (Figs. 2-5) shows how temperature variation affects GDD. It is important to be

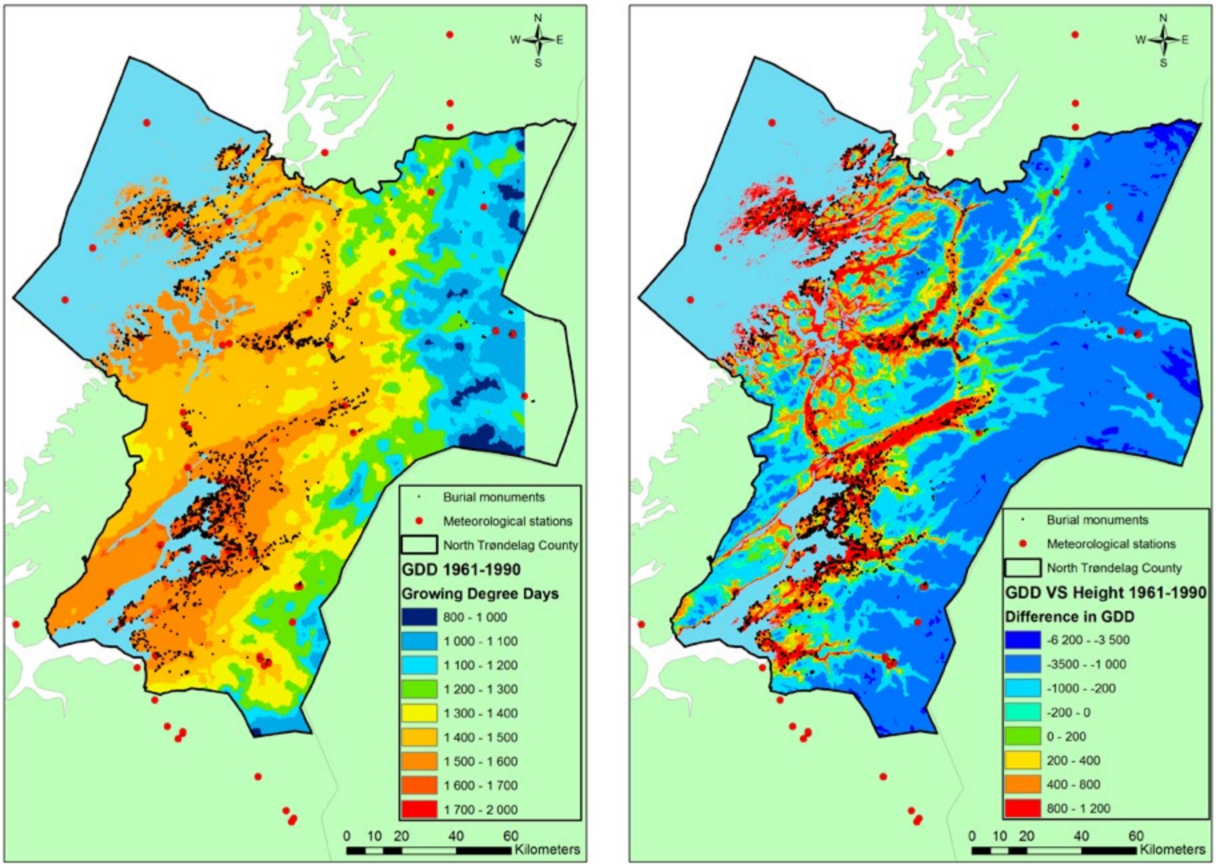

Figure 2. Left: The cokriged model for GDD based on the average temperature between 1961-1991. Right: The calculated maximum height above sea level based on the calculated GDD.

aware of the fact that an increasingly wet climate might increase or decrease the GDDs, and potential changes in rainfall have not been taken into account in this modeling. As mentioned earlier, a rainfall above 250 mm during the growing season decreases the GDD by 60-80 for barley and 100-110 for wheats. Still, it can be demonstrated how a small change in temperature might have a large effect on the potential for a ripe cereal harvest, and how the potential cultivatable areas are highly affected by these changes. A lowering of the average temperature from the 1961-1990 period by 1 ˚C moved the maximum extent for agriculture on average 15-32 kilometers closer to the sea or fjord. Still, the number of possible settlement sites within the affected areas can be roughly estimated using the distribution of known monuments. These calculations are presented in table 3.

This table does not take into account chronological differences in the construction of the monuments, but it is believed that the sheer number of mapped monuments, 7996 – 4348 with their diameter recorded, still have some cultural historical analytical significance when analysed in this manner. It is also believed that

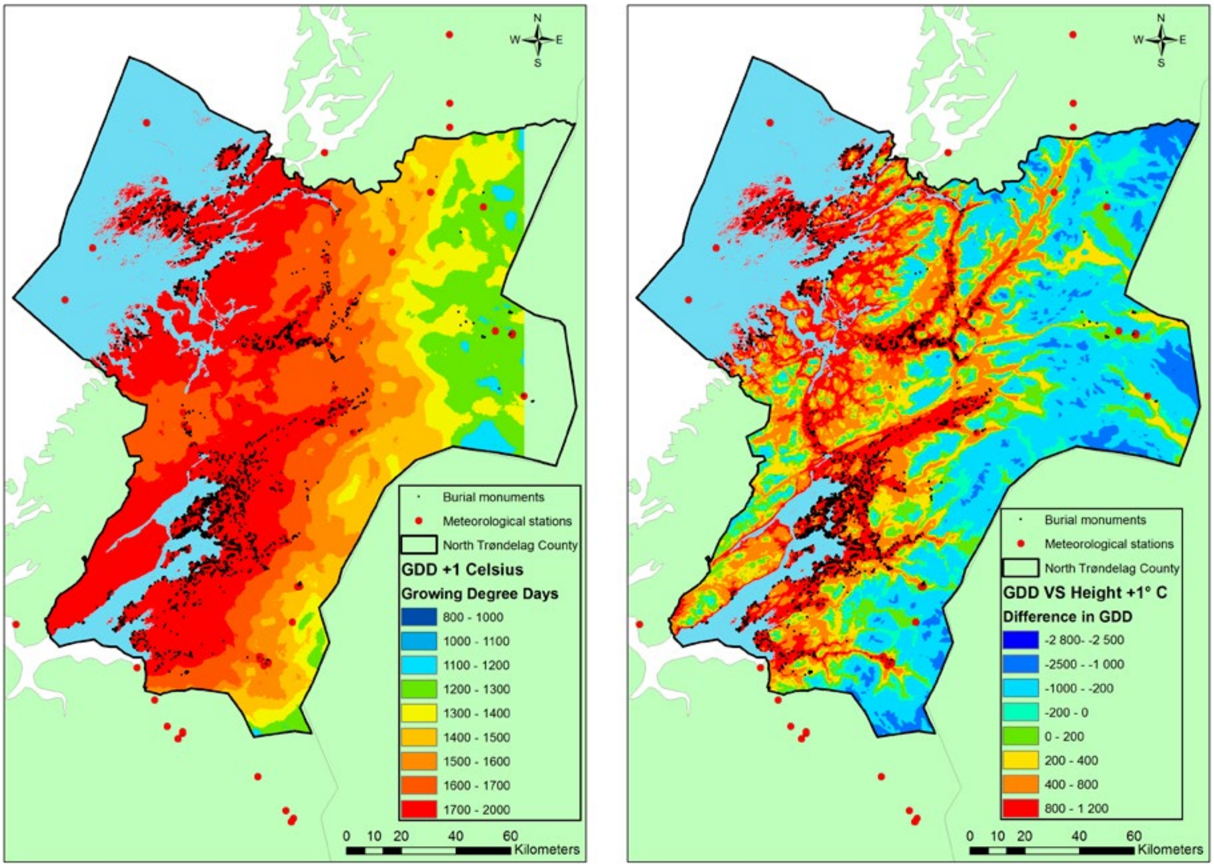

Figure 3. Left: The cokriged model for GDD based on an increased average temperature by 1 ˚ C compared with the standard period between 1961-1990. Right: The calculated maximum height above sea level based on the calculated GDD.

Temperature	Percentage of burial monuments within 1200/1400 GDD	Average GDD for burial monuments with measured dm.[2]	Average GDD for burial monuments above 15m in dm. (highest quartile)	Average GDD for burial monuments above 20m in dm. (highest 7th quantile)
Average 1961-1991	99,59/99,25 %	1555,7 (1562,5)	1565,3	1573,5
+ 1 ˚ C	99,99/99,91 %	1787,7 (1798,1)	1798,3	1807,6
- 1 ˚ C	98,5/14,22 %	1325,8 (1337,7)	1338,3	1345,6
- 3,5 ˚ C	0/0 %	794,1 (796,7)	809,1	816,7

Table 3: GDD calculations for burial monuments of various sizes at different average temperatures. The GDD values indicate whether or not the burial mounds are situated in an area of ideal climatic conditions for the cultivation of crops. An increased GDD for burial monuments of higher diameter, i.e. more monumental and potential indications of farms and families of increased power and wealth (c.f. Myhre 1987, Presvold 1999, Solberg 2000 and Stenvik 2005) can indicate a relation between farming conditions and increased power/wealth. This could be related to other factors such as strategic locations in the lower regions above sea level – i.e. closer to the fjord.

2 Data in brackets are for all monuments including those without diameter information

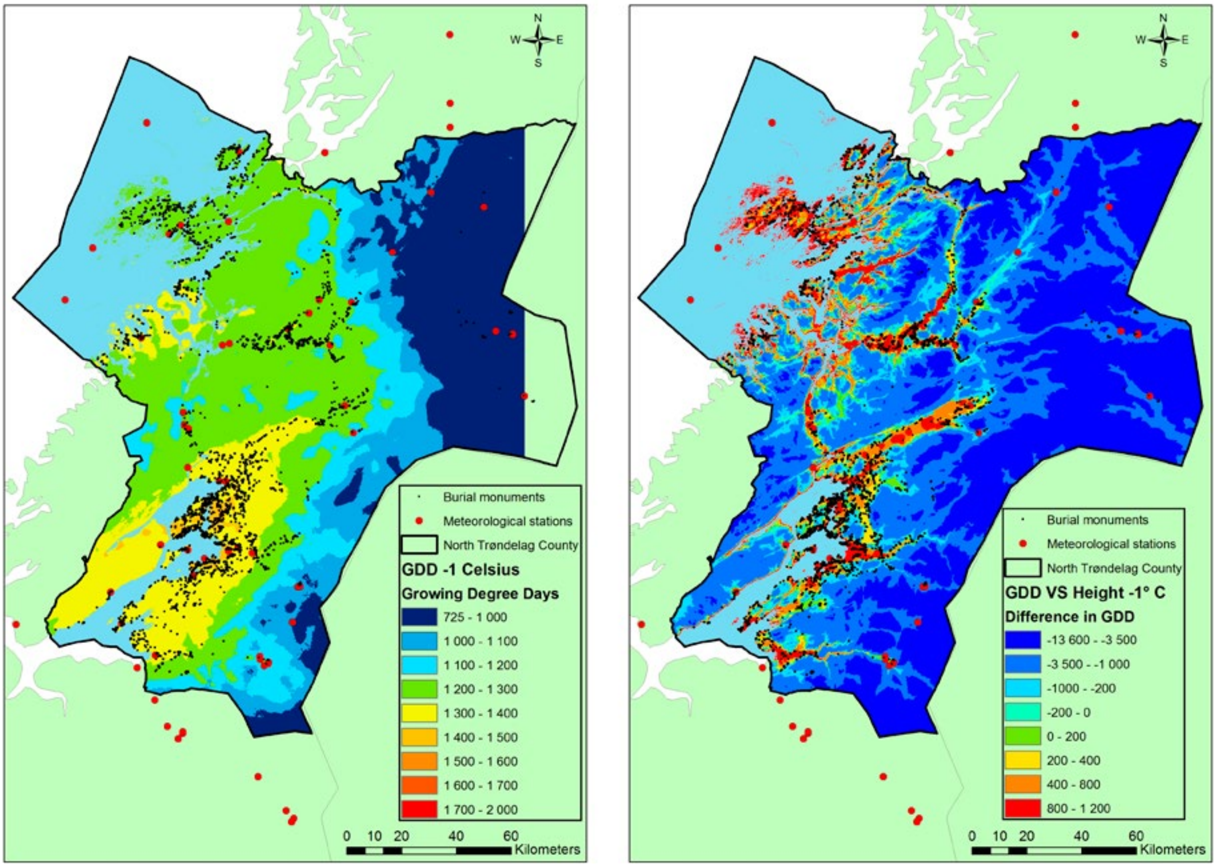

Figure 4. Left: The cokriged model for GDD for a decreased average temperature by 1 ° C compared with the standard period between 1961-1990. Right: The calculated maximum height above sea level based on the calculated GDD.

this way of using these results could help identify monuments that might belong to a certain period of time or areas that are anomalous for some reason.

There are some differences in the two model types presented, which shows that while the cokriging creates a good general idea of the GDD values and to some extent uses the height values purposefully, it still lacks some detail that the maximum height above sea level might contain. The latter on the other hand does not take into account potential regional variance. Due to the apparent lack of resolution in the GDD calculation, it is therefore important that the accuracy of this model can be investigated further. The principles of cokriging make it possible to model the spatial accuracy of such a model. This is called a prediction standard error, and shows the predicted accuracy of the interpolated values.

A visual inspection of this map (Fig. 6) tells us that most of the known burial monuments are within an area of higher accuracy. This means that the analysis in table 3 is more likely to present adequately correct information. The Prediction Standard Error

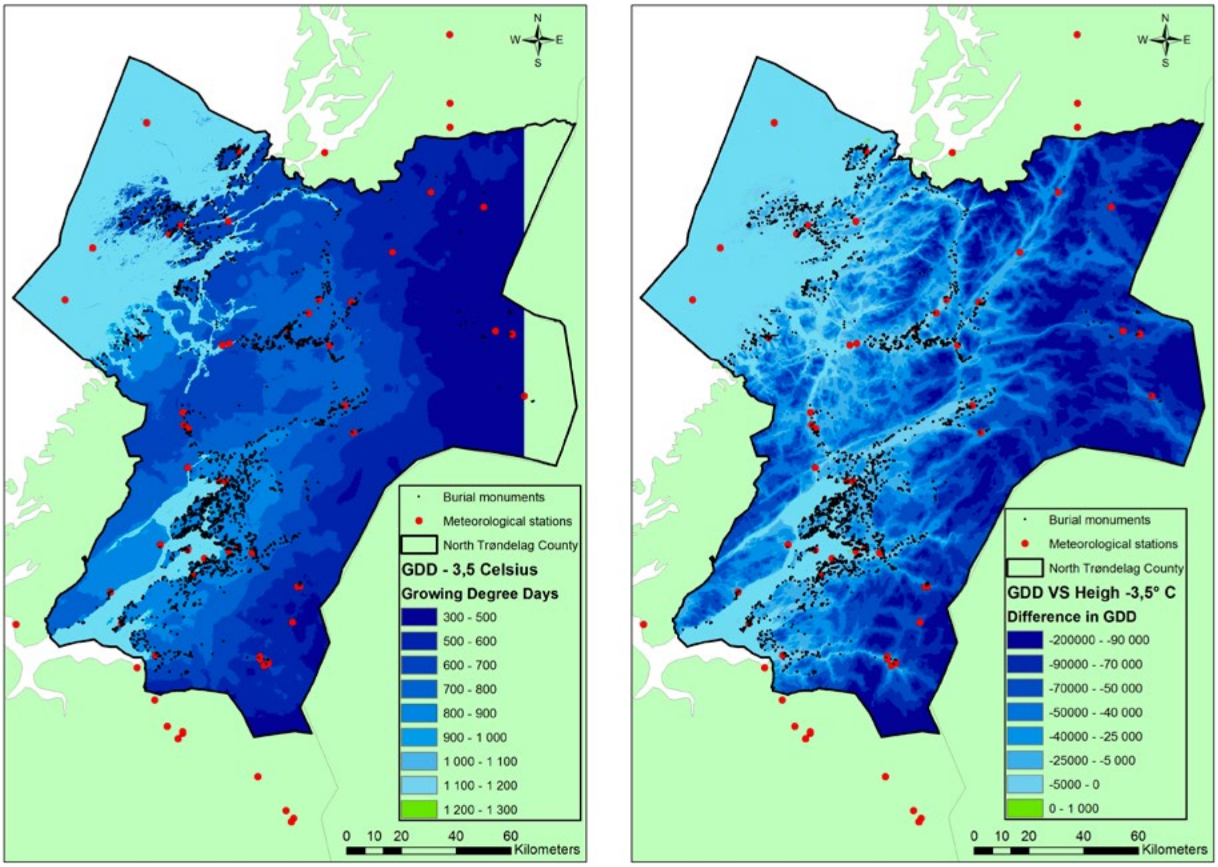

Figure 5. Left: The cokriged model for GDD based on a decreased average temperature by 3,5 ° C compared with the standard period between 1961-1990. Right: The calculated maximum height above sealevel based on the calculated GDD.

also tells us that the interpolated values are less accurate in areas far between each meteorological measurement point, especially in the mountainous areas to the east.

DISCUSSION

These geostatistical and GIS models show the effect of climatic change on the potential for growing cereals in varying temperature conditions. Their results are quite convincing in demonstrating that even small changes in the average temperature in the past might have a large effect on agriculture in liminal areas. While the maximum limit, i.e. the potential area to cultivate, increase and decrease with as much as 15-32 kilometres with a change of ±1 °C, the GDD numbers for each digitally mapped burial monument in the area also tells us a story.

In table 3 it is demonstrated how the average GDD for the location of each burial monument can be extracted from the models. As the burial monuments are assumed to be associated with prehistoric settlements in one way or another, the

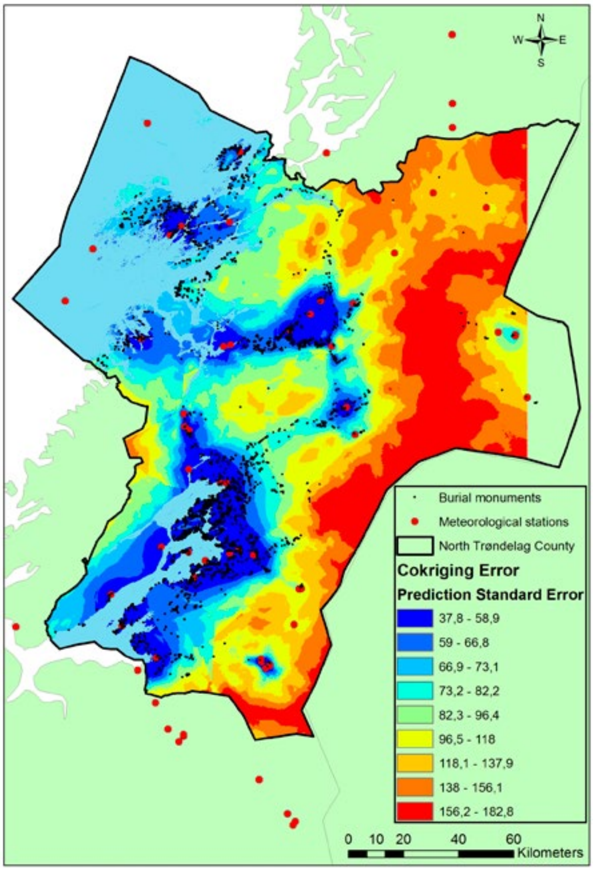

Figure 6. The Prediction Standard Error for the cokriging model. This figure shows an estimation of the quality of the interpolations that are included in the models.

distribution of the surviving monuments can give a rough indication of past land use. It is interesting to note how the burial monuments larger than 15-20 meters in diameter are situated within areas with a higher GDD. Additional investigations are needed to assess if this could be related to agricultural surplus, or might be connected to other factors such as strategic locations in the lower regions above sea level. Still, this could be an indication that the farms assumed to be wealthier were more beneficially situated for increased agricultural yields.

For a more general overview, 99.25 % of the burial monuments are within a GDD of 1400 calculated for the present day temperatures. This means that almost every location is within a larger margin of barley cultivation today. If the temperature dropped by 1 ˚C, this changes to only 14.22 %. 98.5 % will still be somewhere between 1200-1400 GDD, but there is reason to assume that this is relatively marginal. The yields would be lower, and the general possibilities for a production surplus and access to cereals as food would be lower. The same accounts for the possibilities for brewing beer or providing feasts, which is generally assumed to be an important part of social networking and the demonstration of wealth and power. We also know from medieval sources that about 60 % of the diet can be assumed to be from cereals (Øye 2002: 323-25). Figure 5 and table 3 also demonstrates a complete collapse of cereal production in the event of a temperature fall of 3.5˚C, as suggested by Gräslund (2007) and Gräslund and Price (2012). The models therefore yield additional support for the theory of an agricultural collapse in case of such an event. The question is then what the consequences would be for agriculture and subsistence.

It is not unlikely that this could result in a shift towards outfield hunting and gathering, and the potential increase in animal husbandry. In Jämtland a series of C14 dated hunting pits shows a steady increase in the amount of pits from approximately AD 400 to AD 800 (Bengtsson 1997: 23). It is rather hard to say if this is directly related, but at least it shows that the potential of getting access to elk- or reindeer meat should have increased in the centuries after the AD 536-37 event.

In the pollen diagrams of the seven farms investigated by Vorren *et al.* (1990), two were probably not settled in this period, three farms had a decrease in the levels of particulate carbonate (or charcoal dust) around AD 530-60, one farm might have had a small hiatus around AD 580, and the Strugstad farm had a small increase in the charcoal levels. The latter is generally not considered one of the major farms in the area. A pollen diagram from the higher altitude farm of Neset in Lierne, about 400 masl, also shows a fall in charcoal dust around this time. The cultivation of cereals does not appear in the diagram before around AD 750-1150, while charcoal dust observed in the pollen diagram indicates an increased activity in the Roman Iron Age for then to almost disappear from around AD 200 (Selvik and Stenvik 1983). This farm can generally be considered to be liminal for agriculture. One of the meteorological stations happens to be only five kilometres away on the shores of the same lake- Laksjøen. This station has a GDD value of 1002 for the 1961-1990 period, a GDD of 1202 with an increase of 1 °C, 1102 GDD with the increase of 0.5 °C, 908 with the decrease of 0.5 °C and 807 with the decrease of 1 °C. The appearance of cereal production in this landscape should in theory either be short-lived in better years, but might also indicate that the prehistoric cereals cultivated might have a lower GDD requirement than modern ecological types.

A more thorough study of natural historical and palaeobotanical sources is necessary to understand changes in agricultural practices from cereals to pastoralism. The effect this had on architectural practices and settlement structure could also be investigated further. Settlements sites from the Late Iron Age, and especially the Merovingian period, are absent in the material (Solberg 2000; Myhre 2002; Stamnes 2008).

CONCLUSION

The transition between the Early and Late and younger Iron Age in Scandinavia is a much discussed period, with huge transitions in the material culture and types of archaeological features present. Many explanations for this change have been suggested, including the Justinian plague, restructuring of the landscape and consolidation of the power, as well as climatic changes. The purpose of this paper has been to model the potential effect of climatic changes through geostatistical modelling of temperature conditions. The results showed how a change in mean temperature throughout the year might push the limits for cultivating cereals, in this instance barley, with as much as 15-32 kilometres with just an average change of ±1 °C. The results also showed that the distribution of settlement sites in the period in general, with burial monuments as a proxy for settlements, are generally found within the limits for the cultivation of barley. These locations become more liminal without much margin for getting ripe crops in colder years. A change of -3.5 °C in average temperature would have been detrimental to cereal production in Nord-Trøndelag. The models presented demonstrate how climatic change can have a large effect on agricultural potential. It is not unlikely that climatic change, paired with already changing currents in the power structure and fixation of power towards controlling larger areas and more people, created a situation where the leading families and dynasties could benefit by controlling and reorganizing the settlement structure to suit their needs as suggested, by Myhre (2002: 159-170). The fact that the larger burial mounds are placed in areas with a higher GDD, even though the increase is not enormous, might be an indication of a situation where richer farms are placed in areas that are more suited for larger agricultural production.

REFERENCES

Bengtsson, PG 1997. *Fangstgroparnas konstruksjon.* CD-Uppsats, Instituten for humaniora. Mitthögskolan.

Berglund, Björn E. 2003. "Human impact and climate changes – synchronous events and a causal link?" *Quarternary International* 105, 7-12.

Briffa, Keith R., Phillip D. Jones, Thomas Bartholin, Dieter Eckstein, Phillip D.Jones, Widbörn Karlén, Fritz Schweingruber and Pentti Zetterberg 1990. "A 1400-hundred tree-ring record of summer temperatures in Fennoscandia". *Nature* 346, 434-439.

Frøseth. Randi Berland 2004. "Korn". G. L. Serikstad (ed.) 2004. *NORSØK Økologisk handbook. Matveksted.* Kapittel 20, 167-187. Oslo: GAN forlag AS.

Grudd, Håkan, Keith R Briffa, Widbjörn Karlén, Thomas Bartholin, Philip D. Jones and Bernd Kromer 2002. "A 7400-year tree-ring chronology in northern Swedish Lapland: natural climatic variability expressed on annual to millennial timescales". *The Holocene* 12: 6, 657-665.

Gräslund, Bo 2007. "Fimbulvintern, Ragnarök och klimatkrisen år 536-37 e.kr.". *Saga och Sed* 2007, 93-123. Stockholm: Kungliga Gustav Adolfs Akademien för svensk folkkultur

Gräslund, Bo and Neil Price 2012. "Twiligh of the gods? The 'dust veil event' of AD 536 in critical perspective". *Antiquity* 86, 428-443.

Grønnesby, Geir and Ellen Grav Ellingsen 2012. "Naustene på Lænn og Lø – en manifestasjon av krigerfølgets status". Geir Grønnesby (ed.). *Graver i veien. Arkeologiske undersøkelser E6 Steinkjer*, 122-139. Vitark 8. Trondheim: Akademika forlag.

Isaaks, Edward H. and R. Mohan Srivastava 1989. *An Introduction to applied geostatistics.* New York: Oxford University Press.

Johansen, Hans Marius 2007. *Nausttufter i Midt-Norge. Utbredelse, konstruksjon og datering. Naust og samfunn belyst ved eksempler fra Nord-Trøndelag.* Hovedfags-thesis in archaeology. The NTNU Museum of Natural History and Archaeology. Trondheim.

Linderholm, Hans W. and Björn E. Gunnarson 2005. "Summer temperature variability in central Scandinavia in the last 3600 years". *Geografiska annaler, serie A. Physical Geography* 87: 1, 231-241. Blackwell publishing.

Löwenborg, Daniel 2012. "An Iron Age Shock Doctrine – Did the AD 536-37 event trigger large-scale social changes in the Mälaren valley area?". *Journal of Archaeology and Ancient History.* 2012: 4, 3-29.

Madsen, Birger 2011. *Statistics for Non-Statisticians.* Heidelberg, Berling: Springer-Verlag.

Myhre, Bjørn 1987. Chieftains' graves and chiefdom territories in South Norway in the Migration period. *Studien zur Sachsenforschung 6,* 169-187. Hildesheim, Germany.

Myhre, Bjørn 2002. "Landbruk, landskap og samfunn 4000 f.kr. -800 e.kr.". Bjørn Myhre and Ingvild Øye. *Norges landbrukshistorie 1. 4000 f.kr. – 1350 e.Kr. Jorda blir levevei,* 11-203. Oslo: Det norske samlaget.

Pedersen, Ellen Anne and Mats Widgren 1998. "Järnalderen 500 f.kr. – 100. e.kr.". Stig Welinder, Ellen Anne Pedersen and Mats Widgren 1998. *Jordbrukets första femtusen år. 4000 f.kr. – 1000 e.kr. Det Svenska Jordbrukets historia,* 237-459. Borås: Natur och Kultur/LTs förlag.

Prestvold, Kristin 1999. *Trøndelag i støpeskjeen: jernproduksjon og sosial organisasjon I Nord-Trøndelag mellom 350 f.kr og 500 e.kr.* Gunneria 75. Trondheim.

Scuderi, Louis A. 1990. "Tree-ring Evidence for Climatically Effective Volcanic Eruptions". *Quarternary Research* 34, 7-85.

Selvik, Synøve Fjeldstad and Stenvik, Lars F. 1983. "Arkeologiske registreringer og pollenanalytiske undersøkelser i Sanddøla-vassdraget, Nord-Trøndelag". *D.K.N.V.S. Mus. Rapport arkeologisk serie 1983: 2*

Solberg, Bergljot 2000. *Jernalderen i Norge 500 før kristus til 1030 etter Kristus. Oslo:* Cappelen akademisk forlag.

Stamnes, Arne Anderson 2008. *Jernalderens jordbruksbosetning i Nord-Trøndelag. Utvikling og testing av en prediktiv modell.* Masterthesis in Archaeology. The NTNU Museum of Natural History and Archaeology.

Stenvik, Lars 1994. "Jern og samfunn – verkstedsplasser for jernframstilling i Trøndelag". *Spor* 1 1994.

Stenvik, Lars 2005. "Jernalderen". Ida Bull (ed.). *Trøndelags historie bind 1. Landskapet blir landsdel. Fram til 1350,* 107-170. Trondheim: Tapir akademisk forlag.

Strahler, Alan and Arthur Strahler 2005. *Physical geography. Science and Systems of the Human Environment.* Third Edition. Hoboken, USA: John Wiley & Sons. Inc.

Vorren, Karl-Dag, Eilif Nilssen and Brynhild Mørkved 1990. "Age and agricultural history of the "-stadir"- farms of north and Central Norway". *Norsk Geografisk Tidsskrift – Norwegian Journal of Geography,* 44: 2, 79-102.

Welinder, Stig 1998. "Jordbrukets ekologi". Stig Welinder, Ellen Anne Pedersen and Mats Widgren (eds.). *Jordbrukets första femtusen år. 4000 f.kr. – 1000 e.kr. Det Svenska Jordbrukets historia,* 21-43. Borås: Natur och Kultur/LTs förlag.

Øye, Ingvild 2002. "Lanbruket under press 800-1350". Bjørn Myhre, Bjørn and Ingvild Øye. *Norges landbrukshistorie 1. 4000 f.kr. – 1350 e.Kr. Jorda blir levevei,* 214-414. Oslo: Det norske samlaget.

(Footnotes)

1 Data in brackets are for all monuments including those without diameter information