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Human responses to early Holocene climate variability in eastern Fennoscandia

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Abstract :

In eastern Fennoscandia numerous biological and physical proxy records provide ample evidence of Holocene climate-environment dynamics. The region therefore has great promise for studies concentrating on the impacts of past climate change on human populations in the early Holocene, that is, in the period that saw the beginning of postglacial human dispersal into the area.

Here we provide a brief overview of the high and low frequency climate changes indicated by different proxy records in Finland and nearby areas in eastern Fennoscandia, and discuss the archaeological evidence for human responses to abrupt climate-related environmental change and low-frequency climate trends. The clearest archaeologically visible event-like responses seem to derive from ecotonal regions, i.e., the forestetundra or coastal regions and suggest a correlation between ecological "hinge-regions" and the archaeologically clearest signs of hunter-gatherer responses to climate stress. However, the evidence of the abrupt climate events is often ambiguous and their influence on early Holocene human populations remains equivocal.

1. Introduction

Despite a wealth of palaeo climatic proxies and a strong tradition of palaeoecological research in eastern Fennoscandia (defined here as the area covering Finland, Karelia, Kola Peninsula, and northeastern Norway, see Fig. 1), corresponding research into human responses to past climatic change has only recently started to gain ground in the area (e.g., Solantie, 2005; Hayward et al., 2012; Tallavaara and Seppa, 2012; Helama et al., 2013; Honkola et al., 2013; Manninen, 2014).

Prehistoric population size and its relation to climate in eastern Fennoscandia has been studied using temporal distribution of archaeological radiocarbon dates as a proxy of relative human population size and by comparing the results to palaeoclimate proxy records (Tallavaara et al., 2010, 2014a; Tallavaara and Sepp € a, 2012). This "dates-as-data" approach is based on the assumption that the amount of archaeological material deriving from any particular time point is correlated with the human population size at that time point: Large populations produced more archaeological remains for archaeologists to find and date than smaller populations (e.g., Rick, 1987; Gamble et al., 2005; Shennan and Edinborough, 2007; Williams, 2012; Kelly et al., 2013). Here, our population proxy for eastern Fennoscandia is based on a subset of a larger radiocarbon date dataset that has been previously analyzed in several publications that show the entire distribution of the data (Oinonen et al., 2010; Tallavaara, 2015; Tallavaara and Sepp € a, 2012; Tallavaara et al., 2010, 2014a; 2014b). In addition, extensive evaluations of the data have shown that all available population proxies, some of which are totally independent of the archaeological data and methods (e.g., genetics), support the pattern revealed by the radiocarbon date-based proxy and its demographic interpretation (Oinonen et al., 2010; Tallavaara et al., 2010, 2014b). There is an ongoing plan to make the whole dataset publicly available in open databases maintained by Laboratory of Chronology at the Finnish Museum of Natural History (http://www.oasisnorth.org/).

Possible climate-induced changes in hunter-gatherer socioeconomic systems, suggested by temporal co-variance between climate events and behavioural change, on the other hand, have been discussed within what can be called “the socio-economic change approach” (Grydeland, 2005; Hagen, 2011; Manninen and Tallavaara, 2011; Manninen, 2014). As has been noted before (e.g., Wossink, 2009; Eren, 2012; Robinson et al., 2013), such interpretations of climate-induced culture change require clear temporal co-variance between climate change and behavioural change to be shown, while causality between the changes needs also be satisfactorily explained.

These approaches in archaeology are based on the premise that gradual or abrupt change in any key variable in an ecosystem is likely to lead to change in human population due to the changes in nutrition, fertility and mortality, as well as to various behavioural responses, such as migration, conflict, and technological and societal change (see, e.g., Riede, 2009; Hayward et al., 2012; Kuhn, 2012; Schmidt et al., 2012; Kelly, 2013). This is especially true with hunter-gatherer communities that live directly off the natural environment and respond on a local level to both non-human and human factors (e.g., Pfister and Brazdil, 2006; Gronenborn, 2009; Tallavaara and Seppa, 2012). Furthermore, behavioural changes are often mediated through demographic changes so that the immediate cause of behavioural change is change inpopulation size or density (e.g., Henrich, 2004; Kennett et al., 2009; Powell et al., 2009; Kline and Boyd, 2010). But how well do climate data correspond with the changes observed in the archaeological record in eastern Fennoscandia and what kind of problems should be taken into account when selecting climate proxies to compare with the archaeological record?

In this paper, we discuss recent research on early Holocene human responses toclimate change in the area. We present cases in which archaeological proxies reflect change in human population size and/or behaviour that can be linked to climatic and environmental change. As most of eastern Fennoscandia was covered by the Scandinavian Ice Sheet (SIS) until the Late Glacial (Winsborrow et al., 2010; Hughes et al., 2015; Stroeven et al., 2015) and because there is no unequivocal evidence of human occupation predating the early Holocene (Blankholm, 2004; Bjerck, 2008; Rankama and Kankaanpaa, 2011), we focus on the early and mid-Holocene. We stress that climate proxies are not without their differences and suggest that archaeological evidence of climate-induced changes in prehistoric human populations is easiest to find in ecotonal regions and other ecologically sensitive zones while they may be more difficult to detect in other areas.

2. Climate trends and abrupt cold events in early Holocene eastern Fennoscandia

Myriads of lakes, ponds, and peat bogs in our target area yield a rich variety of palaeoclimatic and palaeoecological records such as pollen, aquatic invertebrates, plant macrofossils, oxygen isotopes, glaciers, and lake varves (Fig. 1). Alongside alkenone-derived estimates of sea surface temperature and marine freshwater influence, and a high number of proxy records especially from areas west and south of the area, these sources enable high-resolution reconstructions of climate and environmental development for most of the postglacial period in and around eastern Fennoscandia (e.g., Eronen et al., 2002; Korhola et al., 2002; Seppa et al., 2002, 2007; 2009, 2010; Kultti et al., 2006; Ojala et al., 2008; Chistyakova et al., 2010; Risebrobakken et al., 2010; Weckstrom et al., 2010; Erasto et al., 2013; Sejrup et al., 2016). Here (Fig. 2) we present a sample of proxy curves selected to show both the general trends and the high variability with regards to detecting climate events in and around the target area.

Human influence is generally recognized as a potential source of bias in pollen-based climate reconstructions (Li et al., 2014), especially in regions with long-lasting and intense agricultural history. In northern and central Fennoscandia agriculture is less intensive than in Central Europe and the proportion of introduced tree species is small. It is thus likely that the main vegetation changes, such as the longitudinal shifts of the arctic treeline in northern Fennoscandia, mostly reflect the long-term climatic changes during the Holocene (Seppa et al., 2004).

Forest fires are also known to potentially influence forest composition, and hence could influence pollen-based climate reconstructions. The past fire frequency can be investigated using microscopic and macroscopic charcoal preserved in lake sediments. In Fennoscandia, the general Holocene forest fire frequency reconstructions by Clear et al. (2014) and Molinari et al. (2013) reveal general trends but also show the substantial local variability of the firerecords. As stated by Kuosmanen et al. (2016), it is probable that fire frequency has been to great extent related to the general climatic trends, with warmer and drier climate favouring higher fire frequency. During the increasing human influence over the last two millennia, the fire frequency has undoubtedly risen because of human-induced fires. However, even during the last few centuries the climatic conditions have remained the most important driver of fire frequency in the boreal forest of Fennoscandia (Aakala et al. 2017)

The accuracy and reliability of chronologies used in the palaeoclimate records used in our study vary substantially. Most of the sediment cores have been dated with AMS radiocarbon dating. In such records, the accuracy will depend on the number of AMS dates, but also on the suitability and reliability of the dated material. In general, it can be assumed that the error estimates with typical radiocarbon-dated Holocene sequences are in the order of few hundreds of years (Bronk Ramsey, 2008). This should not have an influence on observed trends, but may make it impossible to identify and date short-term events in individual records. On the other hand, it can be assumed that detecting Holocene climate events is possible when many records have been analyzed and compared, as has been done in this study.

2.1. Trends

From ca. 11,000e8000 cal BP many climate reconstructions showa trend of steadily rising summer temperature in the whole of eastern Fennoscandia (e.g., Seppa et al., 2002, 2009; Lilleøren et al., 2012; Tallavaara and Seppa, 2012; Erasto et al., 2013; Ilyashuk et al., 2013) which is in good agreement with the Greenland ice core data (e.g., Rasmussen et al., 2006, 2007). Regional differences become more pronounced only later when, for example, the pollen-based reconstructions from southern and northern Finland show deviations from the Greenland ice core data (Seppa et al., 2009; Tallavaara and Seppa, 2012; Sejrup et al., 2016). In the south, summer temperatures keep rising until ca. 6000 cal BP, thus the peak Holocene thermal maximum (HTM) occurs 2000 years later in the local data than in the Greenland ice core data (Heikkila, 2010). After 6000 cal BP temperatures start to decline. In the north, however, the peak HTM occurs earlier, according to pollen data between 8000 and 7000 cal BP (Seppa and Birks, 2002). This is roughly 1000 years later than the Holocene maximum in the Greenland ice core d 18 O records but concurrent with the highest Holocene values in direct borehole temperature data from Greenland (Dahl-Jensen et al., 1998). Similar differences in temperature trends between south and north are visible also in the Norwegian data (Eldevik et al., 2014).

2.2. Climate events

Archaeological finds and the deglaciation pattern of the SIS suggest that the pioneer human colonisation of eastern Fennoscandia took place via two general directions during the late glacial (roughly 13,000 - 11,000 cal BP). One colonisation front moved into the area following the deglaciated strip of Norwegian Atlantic coast (e.g. Bjerck, 2008) while a second front entered the deglaciated areas from the east and southeast (Tallavaara et al., 2014a).

Archaeological proxies indicate that the long-term trend in human population size in the area correlates generally well with temperature: steady population growth starts after ca. 8500 cal BP, population peaks just after 6000 cal BP in tandem with the highest temperatures and environmental productivity in the south, and starts to decline with declining temperatures and the rise of a less productive boreal ecosystem (Tallavaara and Seppa, 2012). This link between climate and human population seems to disappear when agriculture starts to gain more ground after 4000 cal BP (Tallavaara and Seppa, 2012).

3.1. The 10.3 ka event

Following the period of initial human colonisation of the recently deglaciated areas in south-eastern Fennoscandia (ca. 10,900-10,300 cal BP) the radiocarbon date record shows a ca. 200 years long gap suggesting an abrupt and possibly severe decline in local population, but it is also possible that the gap represents an artefact of the radiocarbon calibration procedure and does not reflect true demographic signal (Tallavaara, 2015). However, a recolonisation of the area from the east/southeast after 10,100 cal BP is suggested, not only by radiocarbon date distribution, but also by changes in lithic technology, and raw material import (Fig. 3; Tallavaara et al., 2014a).

The stone tool production technology related to the eastern/ south-eastern colonisation front appeared at the Barents Sea coast after ca. 10,100 cal BP, starting from the Varangerfjord area farthest to the east (Rankama and Kankaanp € a € a, 2011; Sørensen et al., 2013). This can indicate socio-economic changes and possibly a re-colonisation of the North Atlantic coastal area after the 10.3 ka event (see, e.g., Damlien, 2016: 438-441). The response of the earliest coastal pioneer population to the climate event and the possible depopulation of the area in relation to the event, however, remain to be studied.

3.2. The 9.2 ka event

In the Varangerfjord area, a link between synchronous changes in lithic technology and settlement organisation and the 9.2 ka event has been suggested (Grydeland, 2005; Hagen, 2011; but see Manninen, 2014:32-33). However, as palaeoclimatic evidence for this event is equivocal, a causal linkage between the possible climate event, its impacts on the local environment, and the changes observed in the archaeological record, remain to be demonstrated. In more southerlyparts of eastern Fennoscandia, the event does not seem to have a signal in the archaeological population proxy that reflects changes in the relative population size.

3.3. The 8.2 ka event

In eastern Fennoscandia, the archaeological population proxy shows relatively low population sizes between 9000 and 8400 cal BP, but no clear link to the 8.2 event, neither in the southern nor in the northern part of the area (Tallavaara et al., 2010). Nevertheless, with respect to climate-induced changes in hunter-gatherer socio economic systems in eastern Fennoscandia, the most robust case is that of behavioural and organisational change in the north-east following the 8.2 ka cold event (Fig. 3B).

Starting from ca. 8300 cal BP, marked changes are detected in both material culture and larger-scale behavioural patterns, that is, in technological organisation, settlement configuration, and land use, in northernmost Fennoscandia, which in this particular case can be considered direct consequences of reduced marine productivity following the increased freshwater influence connected to the 8.2 ka event (Manninen, 2014; see also Hagen, 2011; Manninen and Tallavaara, 2011). The clearest socio-economic changes, such as the disappearance of coastal pit-houses and the development of a new lithic technology well suited for high residential mobility on land (Manninen, 2014; Manninen and Knutsson, 2014), can be observed through the marine cold period suggested by some proxies at ca.

8400-7500 cal BP.

In south-eastern Fennoscandia, there are roughly contemporaneous changes in coastal stone-tool technology (Fig. 3C; Matiskainen, 1989) which appear to be linked to the 8.2 ka event (Manninen and Tallavaara, 2011). A temporal and causal relation ship exists between the beginning of the ancestral Litorina Sea stage of the Baltic Sea, environmental changes caused by the influx of salty Atlantic water into the Baltic Sea basin, and the 8.2 ka climate event. The Litorina transgression that started the saline phase of the basin (Miettinen, 2004; Grigoriev et al., 2011) was connected to the drainage of Lake Agassiz into the North Atlantic, i.e., the same freshwater release that triggered the 8.2 ka event (Alley and Agústsdottir, 2005; Tornqvist and Hijma, 2012). Although the mechanism behind the change in stone-tool types in south-eastern Fennoscandia is unclear and needs further study, the synchronicity of the environmental changes and the sudden change in stone-tool types strongly suggests a link between culture change on the Baltic Sea coast and global environmental change related to the 8.2 ka event.

4. Discussion

The fact that the early Holocene climate reconstructions differ in different parts of eastern Fennoscandia, highlights the need to use local palaeoclimatic data in studies of human-environment interaction. In southern and central Finland there is currently no clear evidence in the archaeological record, nor in the palaeoclimatic proxies, of changes induced by the 9.2 ka event. This suggests that the climatic cooling felt elsewhere especially in north-western Europe at this time (for a case with detected human responses see Robinson et al., 2013) may not have been adequately strong to affect the ecosystems in our study area to any large degree.

However, the fact that the climate events are not detected in all the available proxy records may be related also to the sensitivity of the species/taxa used as biological climate proxies to change in differing ecotonal regions. For example, pollen proxies in southern and central Finland register the 8.2 event as a decline in the pollen values of such trees as Corylus and Ulmus (Seppa et al., 2007), i.e., in species close to their geographical range limit, while climate reconstructions based on Pinus and Betula pollen in north-eastern Fennoscandia do not show any clear evidence of cooling connected with the event (Allen et al., 2007; Seppa et al., 2007).

At the same time, in eastern Fennoscandia some chironomidbased records reflect cooling during the 8.2 ka event and in certain records in northernmost Fennoscandia also during the 9.2 ka event (Korhola et al., 2002; Ilyashuk et al., 2013; but see Velle et al., 2010 for a critique of this evidence). Although the method has limitations (Velle et al., 2010, 2012), the records may suggest that chironomid assemblages in the area, and especially in northeastern Fennoscandia, could be more sensitive to alterations in ambient temperature than pollen records. Nevertheless, chironomid records can only provide reliable temperature estimates if temperature is the dominating gradient of change at the time of interest (Birks et al., 2010; Velle et al., 2012) and consequently some taxa are best suited for temperature reconstructions when they are found close to their temperature-controlled range limit (see Reed et al., 2011; Nevalainen et al., 2013).

The variation in the proxy records highlights the need of joint projects involving archaeologists and palaeoecologists in finding and acquiring the best target records for studying the relationship between climate and humans in the past. Small-scale human societies that live directly off the natural environment often do not have much leeway in their adaptations (e.g., Binford, 2001; Kelly, 2013). Therefore it is clear that prehistoric hunter-gatherers were always affected bychanges in their respective ecosystems and what remains to be studied is the nature and scale of the response. However, the eastern Fennoscandian evidence suggests that especially when it comes to studying the impact of climate events on past societies, regionally specific, high resolution, and carefully selected proxy types become increasingly important in order to detect short-term fluctuations. For the archaeologist, it is also necessary to keep in mind that the climatic records are inherently noisy or, especially on a regional level, may contain climate events, both cold and warm, that did affect human socio-economic systems but are not discussed in research papers concentrating on other events or climatic trends.

As shown here, studies on human-environment interactions in different parts of eastern Fennoscandia show long-term responses to the early and mid-Holocene climatic trends but also suggest responses to abrupt climate-induced ecosystem changes caused by the 10.3 and 8.2 ka events. The two general approaches used to study climate-induced change in prehistoric eastern Fennoscandia, i.e., the dates-as-data approach on human population dynamics and what can be called the socio-economic change approach, both have their advantages and disadvantages. When temporal frequency distributions of radiocarbon dates are used as population proxies, possible biases due to taphonomic factors and past research foci have to be taken into account in order to avoid detecting spurious correlations between climate and human population (e.g., Surovell et al., 2009; Oinonen et al., 2010; Tallavaara et al., 2010, 2014a; 2014b; Williams, 2012). Regarding the detection of impacts of abrupt climate events, radiocarbon date calibration creates the biggest challenge (Tallavaara, 2015): Due to the non-linearities in calibration curve, calibration can create artificial peaks and valleys inpopulationproxyevenwhen true demographic responses are absent (e.g. McFadgen et al., 2006; Bamforth and Grund, 2012; Brown, 2015). If a valley exists in the population proxy, e.g., around the time of a cold climate event, one may easily interpret the valley as a response to the cold event, even when it is primarily a calibration artefact. New Monte Carlo simulation tests provide necessary tools that make it possible to differentiate calibration-induced features in the population proxy from the features that are not calibration artefacts (Shennan et al., 2013; Timpson et al., 2014; Brown, 2015; Crema et al., 2016). However, this approach will not help when an abrupt climate event, a true population response to the event, and artificial fluctuations in the archaeological population proxy created by the shape of the calibration curve coincide. In these cases we cannot detect the true response, as it is masked byan analogous but artificial feature in the observed population proxy. This is because the feature in the proxy is deemed non-significant by the Monte Carlotest. Thus, we have to very cautious when making inferences about short-lived population responses from the temporal distributions of radiocarbon dates.

In the socio-economic change approach, the causal relationships between climate-induced environmental change and changes in human adaptations and material culture can be tracked but they are often clearest in cases of rapid and severe climate events that do not give time for hunter-gatherers to adapt gradually. Gradual behavioural change, on the other hand, is well represented in the archaeological record but the underlying reasons for it are often difficult to pinpoint (e.g., Barton and Clark, 1997; Dincauze, 2000). The two approaches are not mutually exclusive, however. For instance, the response to the 10.3 ka event by the pioneer colonisers of south-eastern Fennoscandia is detected in both the radiocarbon date record and independently as patterned technological changes in the stone tools used by the colonising groups (Tallavaara et al., 2014a).

The fact that the socio-economic changes observable in the archaeological record in the coastal regions of eastern Fennoscandia following the 8.2 ka event are not detected in the temporal radiocarbon date frequency distributions, may be due to several reasons. The eastern Fennoscandian population proxy has thus far excluded northernmost Norway and there is still a relatively small number of radiocarbon dates deriving specifically from the Baltic Sea coastal sites (Tallavaara et al., 2010; Tallavaara and Seppa, 2012). We suspect that these factors may contribute to the discrepancy and hope that future studies will clarify whether this is indeed the case. For example, the radiocarbon date proxy record derived from 211 sites in Scotland did not show any marked change in population density during the 8.2 ka event (Woodbridge et al., 2014) while a clear decrease in activity was detected in the more restricted dataset deriving from 32 sites in western Scotland where the environmental impact during the event is likely to have been the most severe (Wicks and Mithen, 2014).

In both discussed archaeological approaches the impacts of climatic cooling on ecosystems, and consequently also humans, can be expected to be most pronounced in environmentally sensitive areas, i.e., in marginal habitats (Batterbury and Forsyth, 1999; Kawecki, 2008), but also in those ecotones (see Risser, 1993; Cannone et al., 2007; Shen et al., 2008) where ecological threshold values are easily exceeded, i.e., in what Birks et al. (2015) call “hinge regions”. Considering the postglacial environmental development in eastern Fennoscandia, it can be suggested that ecologically sensitive habitats existed throughout the early and mid-Holocene and that they affect both the representativity of biological climate proxies and the archaeological record.

The earliest pioneer colonisation of eastern Finland, discussed in Tallavaara et al. (2014a), took place in a rapidly changing foresttundra ecotone in an area that had only recently become ice free from under the retreating SIS. This type of habitat is risky to toplevel predators such as humans, especially if dispersal is too low to sustain the colonising population demographically in case of local extinctions (see, e.g., Svoboda and Henry, 1987; Kawecki, 2008). A clear decrease in human activity, as suggested by the archaeological record in this area, fits well in a scenario of human response to cooling during the 10.3 ka event, especially considering the marginal and fragmented early postglacial environment surrounding the melting ice sheet.

Similarly, onthe Fennoscandian BarentsSea coast the conditions of the land-sea and forest-tundra ecotones are stronglyconditioned by the inflow of Atlantic waters through the Norwegian Atlantic Current (Loeng, 1991; Loeng and Drinkwater, 2007; Schmittner et al., 2007). The warm and salty Atlantic water masses, when they reach the Barents Sea, have a warming influence on the climate of northeastern Fennoscandia (Førland, 2009) but they are also critical for the marine productivity of the sea. Put simply, when salinity and warmth decrease, so does the productivity of the Barents Sea (Sakshaug and Slagstad, 1992; Sakshaug 1997; Hjermann et al., 2004; Cochrane et al., 2009; Manninen, 2014).

The part of the Norwegian Barents Sea coast which is most sensitive to changes in the amount of warm salty water brought in by the Norwegian Atlantic Current is the coast of eastern Finnmark, including the Varangerfjord area, where the influence of Atlantic waters is the weakest (Loeng, 1991). This is also the area where temporal links exist between changes in the archaeological record and the 10.3 and 8.2 ka (and possibly also 9.2 ka) events. The observed pattern is a logical consequence of situations where glacial meltwater outbursts into the North Atlantic caused a rapid decrease in the influx of warm salty water into the Barents Sea (Fig. 2D) and was followed by a drop in primary production in the land-sea ecotone.

In the coastal regions that are directly influenced by changes in the North Atlantic water masses, the Barents Sea and the earliest post-glacial stages of the Baltic Sea in the eastern Fennoscandian case, changes in water temperature, salinity, and ice cover (Voronina et al., 2001; Gustafsson and Westman, 2002; Risebrobakken et al., 2010), sea-level changes (Miettinen et al., 2007; Tornqvist and Hijma, 2012), and abrupt climate change, were all interconnected parts of the same rapid large-scale Early Holocene environmental change. It is therefore in line with expectations that in eastern Fennoscandia these areas show pronounced changes in human adaptations following the meltwater outbursts from North America which caused multiple changes affecting the ecosystems of these land-sea ecotones.

5. Conclusion

We show that in eastern Fennoscandia there is evidence of both gradual and abrupt changes in human socio-ecological systems that can be linked with changes in climate. However, it is also clear that although the area has a wide variety of proxy records of Holocene climate, there is still a need to develop and improve the ways archaeological data and climatic proxies are combined in order to get the best results especially when attempting to tackle the effects of climate events on past human populations. It is evident from the eastern Fennoscandian records that regional differences and the temperature sensitivity of proxies play a major role in such studies. Our results also suggest that human responses to short-term climatic fluctuations are best detected in ecologically vulnerable areas, whereas gradual and more robust and lasting ecosystem changes are reflected also in the archaeological records of less sensitive areas.

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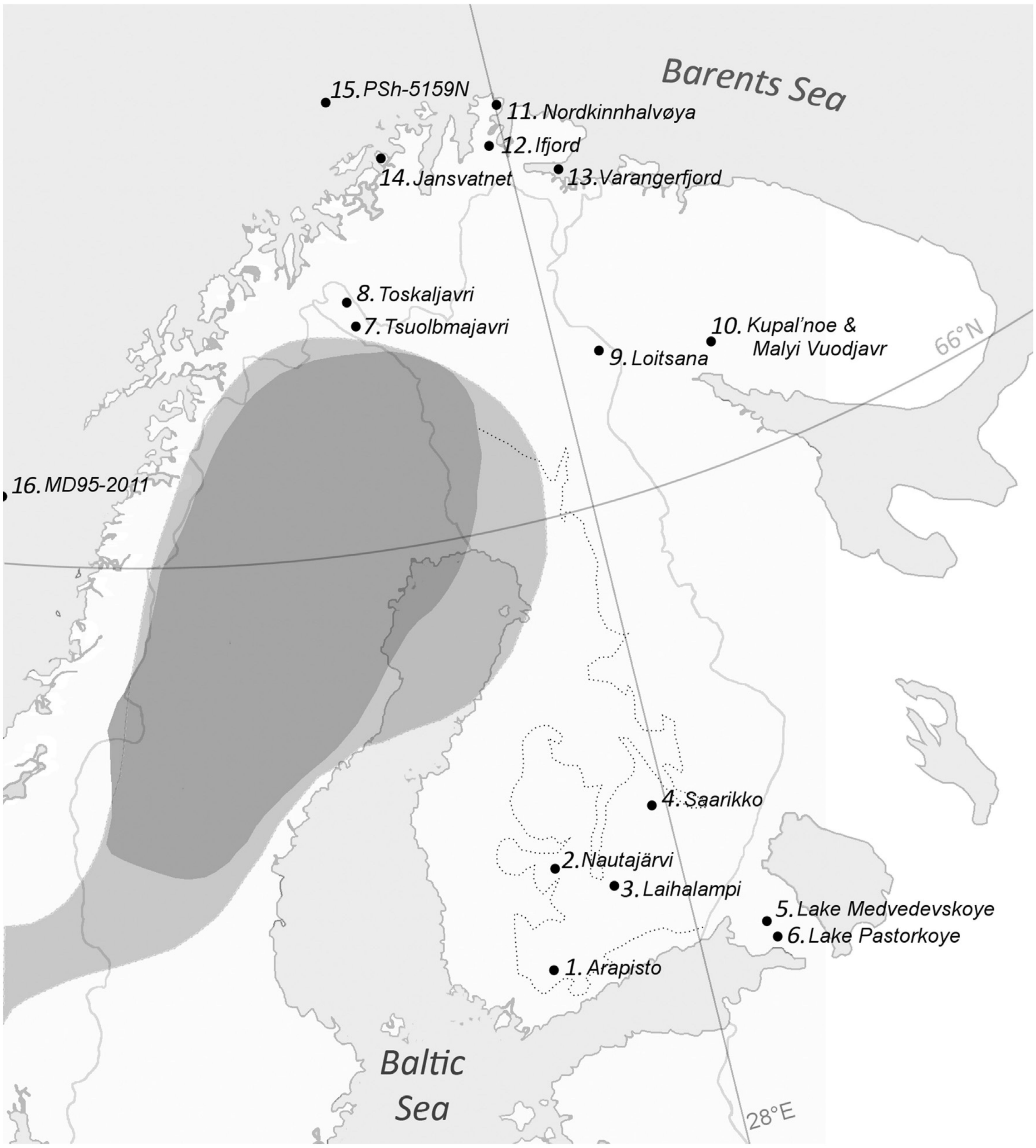

Fig. 1. Eastern Fennoscandia (Finland, Karelia, northernmost Norway, Kola Peninsula) and nearby areas. Marked is the area covered by the Scandinavian Ice Sheet at 10.3 ka cal BP (after Daniels, 2010: unpublished digital atlas; Påsse and Daniels, 2011; dark grey area, and after Stroeven et al., 2015; light grey area) and part of the reconstructed Baltic Sea shoreline at 10.3 ka cal BP (dashed line, after Daniels, 2010: unpublished digital atlas; Påsse and Daniels, 2011). Black dots mark the sites and areas discussed in the text: 1.) Lake Arapisto (Sarmaja-Korjonen and Seppa, 2007); 2.) Lake Nautajarvi (Ojala et al., 2008); 3.) Lake Laihalampi (Heikkila and Seppa, 2003); 4.) Lake Saarikko (Heikkila et al., 2010); 5.) Lake Medvedevskoye (Subetto et al., 2002); 6.) Lake Pastorkoye (Subetto et al., 2002); 7.) Lake Tsuolbmajavri (e.g., Korhola et al., 2002; Erasto et al., 2013); 8.) Lake Toskaljavri (e.g., Seppa et al., 2009); 9.) Lake Loitsana (Shala, 2014); 10.) Lakes Kupal'noe and Malyi Vuodjavr (Ilyashuk et al., 2013); 11.) Nordkinnhalvøya (Allen et al., 2007); 12.) Lake Ifjord (Seppa et al., 2002); 13.) Varangerfjord; 14.) Lake Jansvatnet (e.g., Birks et al., 2012; Birks, 2015); 15.) PSh-5159N (SW Barents Sea; Chistyakova et al., 2010; Risebrobakken et al., 2010); 16.) MD95-2011 (Norwegian Sea, Calvo et al., 2002; Andersson et al., 2010). Note that the map is not comprehensive in terms of important sites with proxy data on Holocene climate in the area.

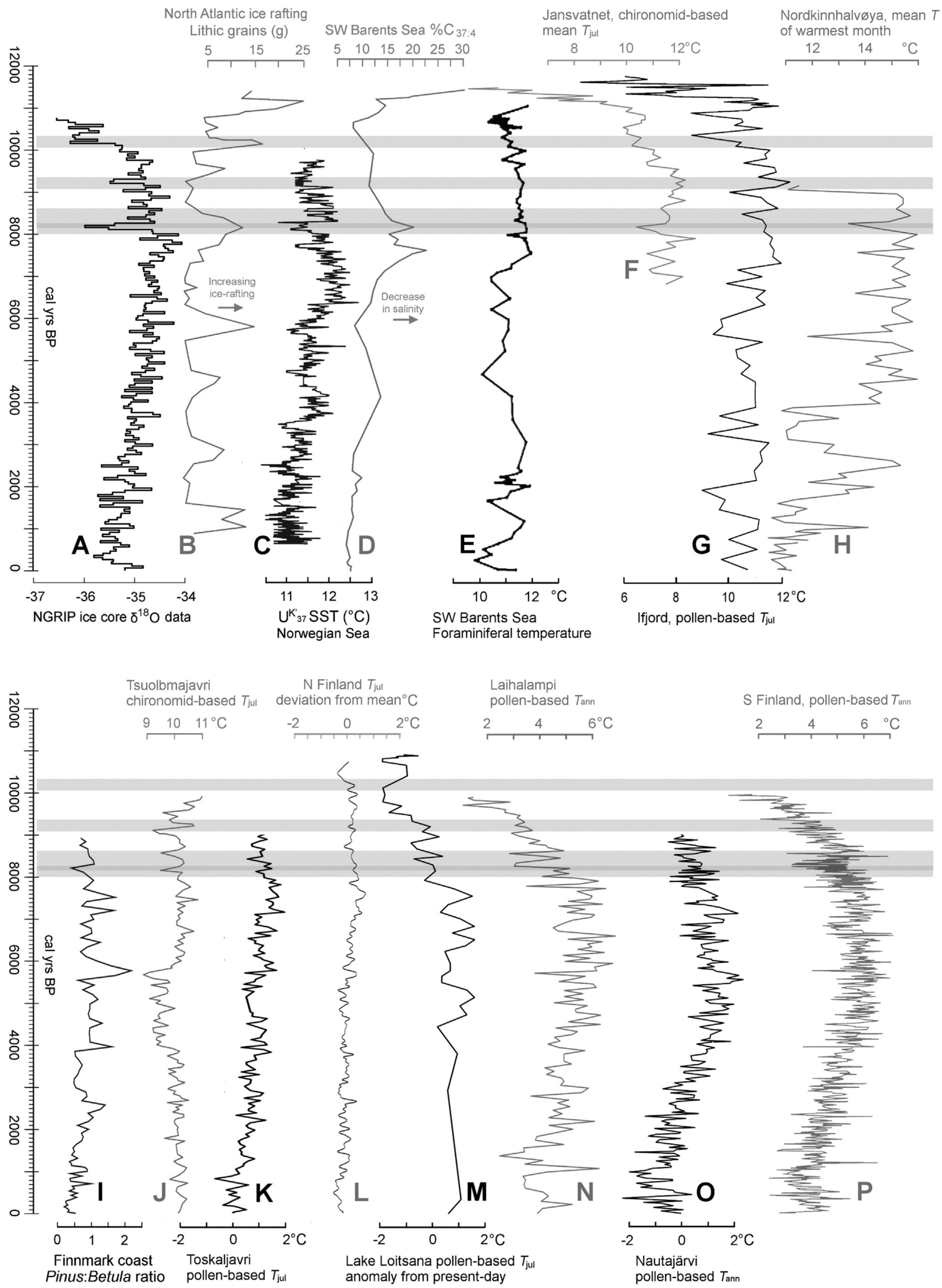

Fig. 2. The North Greenland Ice Core Project Oxygen Isotope Data (NGRIP, 2004) and fifteen proxy curves from Eastern Fennoscandia and nearby marine core sites. Curves have beenselected to show the high variability in the visibility of the 10.3 ka, 9.2 ka, and 8.2 ka cold events and represent only a small part of the available curves. A) NGRIP 2004; B) Amount ofdebris-bearing drift ice in the North Atlantic (Bond et al., 1997); C) Alkenone derived Sea surface temperature reconstruction for the Norwegian Sea (Andersson et al., 2010; Calvoet al., 2002); D) Freshwater influence in south-western Barents Sea (Risebrobakken et al., 2010); E)) South-western Barents Sea foraminiferal temperature reconstruction(Risebrobakken et al., 2010); F) Chironomid-based mean

July temperature from Lake Jansvatnet (Birks, 2015); G) Pollen based July mean temperature reconstruction from LakeIfjord, Barents Sea coast (Seppa et al., 2002); H) Pollen-based reconstruction of mean warmest month temperature from Nordkinnhalvøya, Finnmark (Allen et al., 2007); I) Holoceneecotonal changes as indicated by the Pinus:Betula pollen ratio in Nordkinnhalvøya, Finnmark (Allen et al., 2007); J) Chironomid-based July mean temperature reconstruction fromLake Tsuolbmajavri (Korhola et al., 2002); K) Consensus of six temperature reconstructions (chironomid, diatom, and pollen) from Lakes Toskaljavri and Tsuolbmajavri (Erasto et al., 2013); L) Pollen-based mean July temperature reconstruction from Lake Toskaljavri (Seppa et al., 2009); M) Pollen-based July mean temperature reconstruction from Lake Loitsana(Shala, 2014); N) Pollen-based annual mean temperature reconstruction from Lake Laihalampi (Heikkila and Seppa, 2003; Seppa et al., 2009); O) Pollen-based annual meantemperature reconstruction from Lake Nautajarvi (Ojala et al., 2008); P) Mean annual temperature in southern Finland. Combined reconstructions from Lake Laihalampi, LakeNautajarvi, Lake Arapisto, and Lake Saarikko with LOWESS smoother of a span of 0.05 (Tallavaara and Sepp€a, 2012). See Fig. 1 for site locations. Grey vertical bars mark the earlyHolocene cold events discussed in the paper.

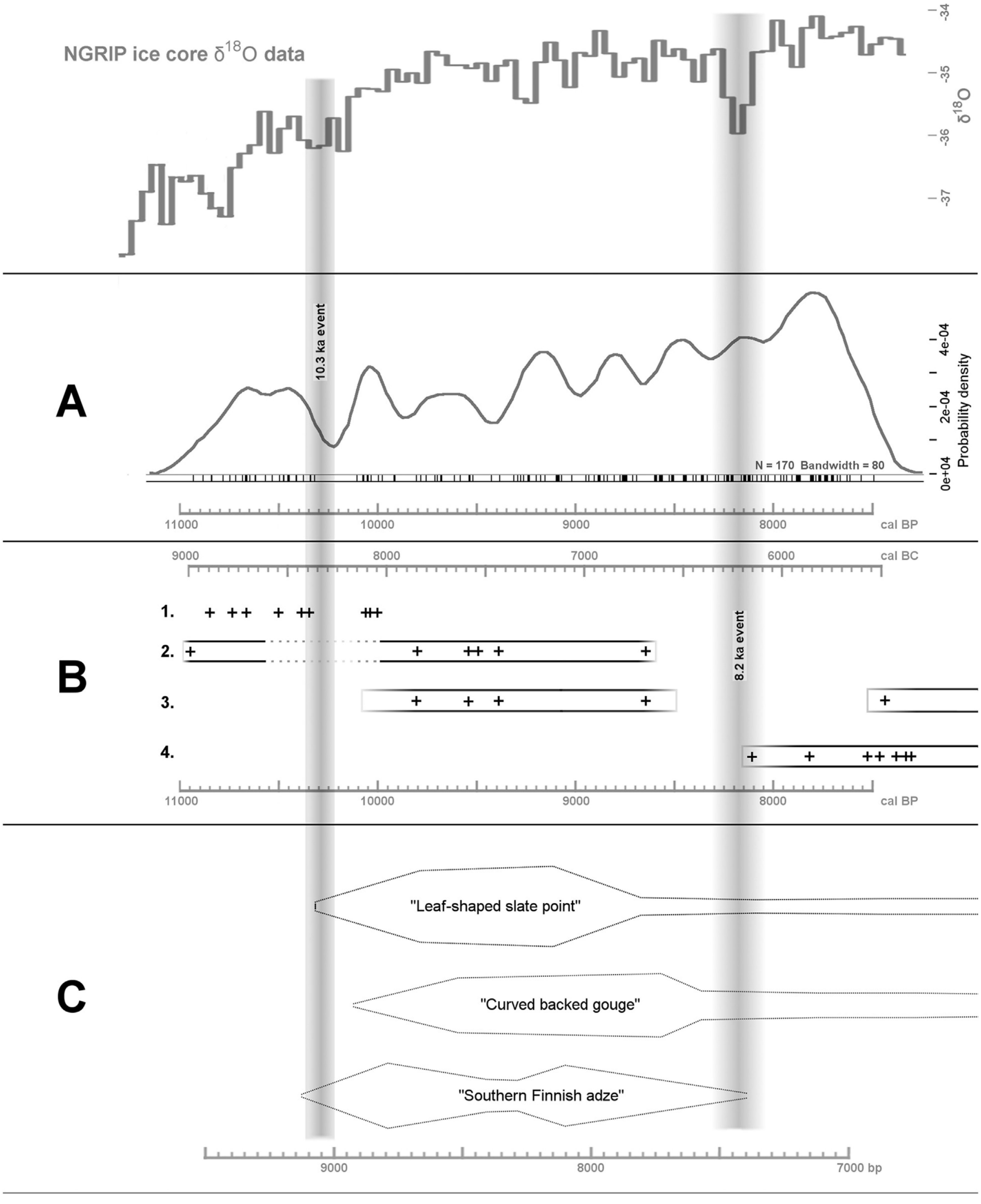

Fig. 3. Indications of climate-related socio-economical change and change in population size in the eastern Fennoscandian archaeological record. A) Archaeological radiocarbondate distribution (Finland and Russian Karelia; B) Temporal distributions of stone tool types and other technological markers at the Norwegian Barents Sea coast and in Finland. Crosses mark radiocarbon date median values and boxes shoreline dates: 1. Prismatic (post-Swiderian) blades of imported raw materials in Finland, 2. Prismatic blades at the Norwegian Barents Sea coast, 3. Pit-houses at the Norwegian Barents Sea coast, 4. Microlithic transverse/oblique arrowheads in southern Finland; C) Examples of shoreline-dated distributions of stone tool types on the Finnish Baltic Sea coast according to Matiskainen (1989). Note that shoreline dates in Matiskainen's study are based on uncalibrated radiocarbon dates.

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