Technological transitions and human-environment interactions in Mesolithic Southeastern Norway, 11 500 – 6000 cal. BP

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Abstract: In Northern Europe, the Holocene is characterized by great climatic and environmental variations. A central question is how hunter-gatherer in different regions coped with these changes. In this article, we explore the temporal co-variance between environmental change and transitions in lithic technology during the Mesolithic of southeastern Norway. The empirical starting point comprises technological analysis of lithic assemblages from sites dated between 11 500 and 6000 cal. BP. We focus on two major transitions identified in the lithic assemblages: 1) the introduction of the conical core pressure blade technology and ground macro tool technology, c. 10 300-10 100 cal. BP, and 2) the introduction of microblade production on handle cores and changes in the macro tool assemblage, c. 7700-7500 cal. BP. The main objective is to investigate the factors influencing transitions in material culture, and contribute to the discussion of the complexity and diversity of human-environment interactions during the Mesolithic of Northern Europe. The results from this study contribute to an increasing knowledge on the diversity and complexity of hunter-gatherers relation with environmental and climatic variation, and add more insight to the vital question of how we can understand culture change among past populations.

Keywords: Archaeology, Holocene, Scandinavia, Mesolithic, Lithic technology, Human-environment interaction,

1. Introduction

The effect of climatic and environmental variability is a major factor in fluctuations in hunter-gatherer populations (e.g. Kelly et al., 2013; Robinson and Riede, 2018; Tallavaara et al., 2015). Impact of environmental events on human society is not conditioned solely by geological aspects, but also by social factors determining the vulnerability of the affected communities. This implies that climate change is not simply natural in their causes and effects (Riede, 2018: 2). The success of the human species is closely related to its flexibility in adapting to different environments. Not only do humans adapt to various environments through different technologies (Binford, 1962; Kelly, 2016: 114-136), but also by actively shaping and modifying environments (Laland and Brown, 2006; Odling-Smee et al., 2003). These important factors need to be considered when studying human–nature relations. Adaptation to environmental or climatic change by shifting or modifying technology can be a successful strategy but there are limits to adaptive behavior (Laland and Brown, 2006: 98). What is successful on the short-term scale might be maladaptive in the long run. Moreover, in times of crises or rapid changes in the natural environment, the choice of keeping to established practice could also serve as the preferred strategy.

High-resolution climate and environmental records have made it evident that the hunter-gatherers of Northern Europe experienced great climatic and environmental variations during the Early and Mid-Holocene (e.g. Burroughs, 2005; Groß et al., 2018; Jørgensen and Riede, 2019). Intensified archaeological research and the accumulation of climate proxy data has highlighted the complexity of ecosystems' and human's responses to climate change in the past, and given new insight into how we understand the pace of climate change (Fitzhugh et al., 2018).

The Holocene is a period of relatively climatic stability, but also characterized by several climatic and environmental oscillations in most parts of Northern Europe (Burroughs, 2005). In southern Norway, which is the geographical scope of this paper, the palaeoenvironmental data demonstrate fluctuations in temperatures, glacier dynamics, and isostatic and eustatic rebound after the retreat of the Scandinavian Ice Shield, as well as changes in vegetation, fauna and marine conditions (e.g. Lilleøren et al., 2012; Nesje et al., 2005; Sørensen et al., 2014; Wieckowska-Lüth et al., 2017). Here we ask how the hunter-gatherers that populated the present Norwegian landmass in Early and Mid-Holocene coped with environmental changes.

In the course of several thousand years' of environmental change, the archaeological record tells a story of shifts in population, settlement patterns and material culture. A central question here is if the cultural and environmental trajectories are related. The effect of climate events on human society is recognized in different areas, but shifts identified at a global scale do not necessitate a severe impact on the local ecosystem. When working with global climate records there is a risk of correlating chronologically imprecise events with the expectation of environmental change and human responses that is not detectable at a local scale (Griffiths and Robinson, 2018: 6). Ecosystems will change in accordance with its characteristics as well as the ecosystem's resilience (Birks et al., 2015) and, depending on the scope of the study we need to apply local or regional proxy data that can inform us of the environmental development in the study area.

The effect of environmental and climate change on the human groups populating the landmasses of southern Norway during the Early and Mid-Holocene have, with a few exceptions, been less explored by archaeologists (Breivik, 2014; Breivik et al., 2018; Fossum 2020; Glørstad, 2016; Wieckowska-Lüth et al., 2018). Through focused case studies we can gain insight in the diversity of hunter-gatherers' adaptive response to climate change (Eren, 2012: 12; Jørgensen et al. 2020). Thus, it is necessary to consider if and how environmental factors affected the cultural development in southern Norway at a short and long-term scale. Research on the impact of environmental changes on hunter-gatherer societies in this region can enhance our knowledge of the complexity and diversity of human-environment interactions during the Mesolithic of Northern Europe (Griffiths and Robinson, 2017: 1; cf. Jørgensen and Riede, 2019).

Here we explore the factors influencing transitions in material culture during the Mesolithic (11 500 – 6000 cal. BP) of southeastern Norway (Fig. 1). During the last decade, technological analysis of lithic assemblages has played a pivotal role in Mesolithic research in the region (e.g. Berg-Hansen, 2017; Damlien, 2015, 2016; Eigeland, 2015). Our starting point is technological analysis of lithic assemblages from sites dated between 11 500 and 6000 cal. BP. The main aim is to investigate if changes in lithic technology and environmental changes are related. By combining detailed technological analysis with statistical analysis of experimental data, we explore temporal variation in lithic blade production methods and knapping techniques during the Mesolithic. We will then focus on two technological transitions identified in the lithic assemblages: 1) The introduction of the conical core pressure blade technology and ground macro tool technology c. 10 300–10 100 cal. BP. 2) The introduction of microblade production on handle cores and changes in the macro tool technology, c. 7700–7500 cal. BP.

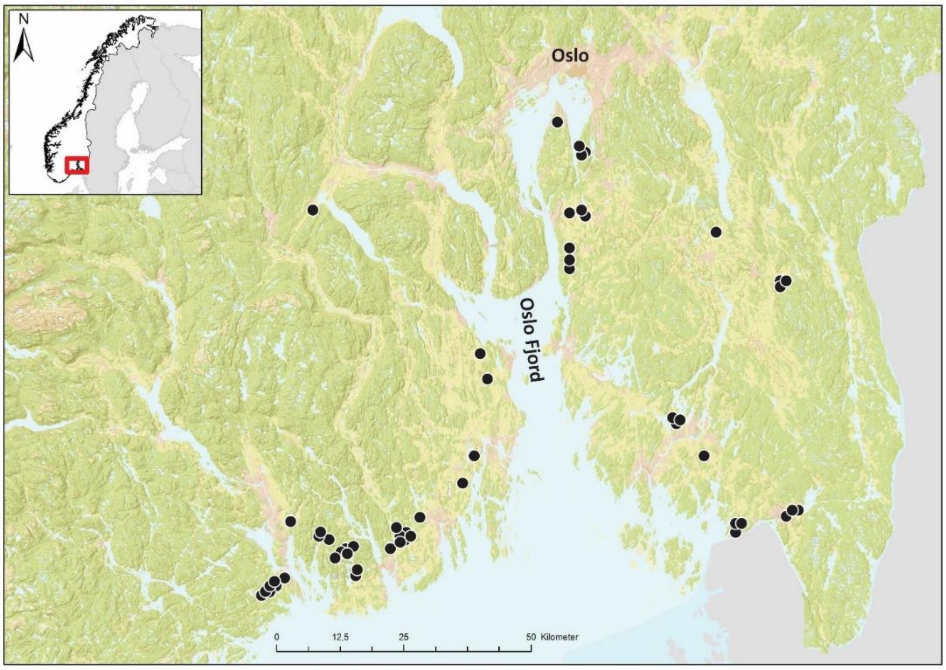


Figure 1. Map displaying the study area and the location of sites in southeastern Norway discussed in the text.

2. The regional setting

The area under investigation is the coastal area of southeastern Norway, situated between 58° and 60° latitude (Fig. 1). The earliest evidence of human settlement in the region dates to the Early Mesolithic, c. 11 500-11 300 cal. BP.

The Scandinavian Ice Shield retreated from southeastern Norway, c. 12 000 years ago and a rapid isostatic rebound started (Hughes et al., 2016; Stroeven et al., 2016; Romundset et al., 2019; Sørensen et al., 2014). The marine limit as well as the isostatic rebound varies in different parts of the region (e.g. Glørstad et al. 2019: fig. 6.2), but the regression rate was high during the Preboreal period and gradually decreasing in the Mid and Late Holocene.

The regional development indicates a rather rapid increasing temperature in the early Preboreal and a gradually increasing precipitation rate (Sørensen et al., 2014: 212). The Boreal period is characterized by mild winters and humid conditions, and temperatures are comparable with today's situation (Wieckowska-Lüth et al., 2017). The Holocene Thermal Maximum is dated locally to c. 8400–4400 cal. BP, and after the 8.2 ka event there is a rise in annual mean temperature until c. 6000 cal. BP. From 7500 cal. BP there is a change towards a more continental climate and higher summer temperatures in pollen records from the western part of the Oslo fjord area (Wieckowska-Lüth et al., 2017, 5). After 6000 cal. BP the temperatures are decreasing and fluctuating (Sørensen et al., 2014:212-213; Wieckowska-Lüth et al., 2017).

The dramatic rise in temperature in the early Holocene caused a transformation of the natural environment from arctic vegetation to a woodland landscape with subarctic, boreal fauna in the early Boreal (Sørensen et al., 2014; Wieckowska-Lüth et al., 2017). Pollen analytical investigations show that low bushes along with a variation of different herbs, plants and grasses characterized the earliest vegetation. Open birch forest was established c. 11 300–11000 cal. BP, followed by aspen (c. 11 000–10 500 cal. BP) and soon pine, hazel and elm (10 400–10 000 cal. BP) (Høeg et al., 2018; Sørensen et al., 2014; Wieckowska-Lüth et al., 2017). From c. 7500 cal. BP there is a marked increase of Lime and Oak implying a change from an oceanic climate towards more continental conditions.

Thus, climatic changes and geological processes, e.g. temperature changes and sea level changes, caused important changes in the vegetation during the first parts of the Holocene.

3. Material and methods

In discussions of climate's impact on culture change, it is necessary to demonstrate a temporal co-variance between climate change and behavioral change. By applying a technological approach using the material remains of lithic blade production as a proxy, we will further explore these research objectives.

Blades were the principal blanks for tool production in the Mesolithic of Northern Europe. During the Mesolithic, temporal and spatial variation is documented in lithic craft traditions in this area. The reductive process of producing lithic tools, such as blades, manifests itself as mechanical sequences of actions that is learned and shared among a social group and transmitted between generations, thereby reflecting social traditions (e.g., Pelegrin, 1990; Leroi-Gourhan, 1993 [1964)). A large number of studies have shown that the reasons behind any specific technological behavior within a society are likely to be multiple, including factors that are cultural or determined by the social environment as well as functional determined by the physical environment (e.g., Apel, 2007; Manninen and Knutsson, 2014). Blade production, thus, provides a relevant focus for tracking continuity and change in cultural behavior and for understanding the advent of material culture diversity.

Until recent years, few detailed technological studies of blade collections in southeastern Norway within a long-term perspective have been conducted. There is a need for studies that can clarify the long-term technological trajectories, as well as evaluate the dating of transitions in material culture. In order to investigate long-term trajectories of lithic technology during the Mesolithic of southeastern Norway, we have analyzed lithic blade assemblages from 39 sites dated between 11 500 and 6000 cal. BP (see Supplementary table 1). Additionally, a general assessment was made of the adze assemblage from the sites, along with technological features of lithic assemblages from 33 radiocarbon-dated sites as reference (see Supplementary table 2). The sites are located on both sides of the Oslo Fjord, comprising the regions of Østfold, Akershus, Buskerud, Vestfold and Telemark (cf. Fig. 1).

The central aim for the lithic analysis was to identify the lithic blade production concept – i.e. the recipe of action the knapper follows in order to achieve the desired end-product (Sørensen, 2012a) – by defining the production methods and knapping techniques used at the sites. The lithic analysis approach combines two complementary methods: *Dynamic technological classification* and *attribute analysis* (Sørensen, 2006). The first method permits reconstruction of the methods of core reduction as well as the stages of the production process by positioning each artefact in the operational chain of production (*chaîne opératorie*). The identification of knapping techniques is based on specific blade attributes found by experimental work and by analogy recognized in prehistoric lithic assemblages. The attribute analysis serves this purpose by providing quantitative data on the numerous morphological, technical and metrical attributes recorded on individual artefacts. The selected attributes are based on recent studies and have been shown to be valuable for understanding blade technologies in the Mesolithic of Northern Europe (see Damlien, 2016; Eigeland, 2014, 2016 for a comprehensive presentation of the methods and results of the dynamic technological classification and attribute analysis).

Previous studies have shown that simple analogies between particular blade morphology and the knapping technique used are difficult, due to a complex interaction between blade attributes and various force application variables (Damlien, 2015). In order to examine whether temporal variation in the archaeological blade assemblage is related to changes in knapping techniques, a predicative *Discriminant Function Analysis* (DFA) constructed on basis of an experimental dataset was used to make predictions about blade knapping techniques in the archaeological record (see Damlien, 2015 for a detailed presentation of the method and results). In the predicative DFA of experimentally produced blades, 56.5% were classified correctly to their original groups (Damlien, 2015). However, the hit ratio differs significantly between the various groups. Blades produced by pressure technique

(78.5%) and direct percussion technique by medium hard hammer stone (71.4%) were reclassified with the highest hit ratio, whereas the DFA discriminate power for the remaining techniques is lower. Despite this, the method has proven its utility to predict general tendencies in knapping techniques in archaeological blade assemblages on a population level.

The attribute analysis of the archaeological dataset includes 5410 blades. We have included seven blade attributes in the statistical analysis, which according to previous research (Damlien, 2015) are suggested to be dependent of the knapping technique used: Interior platform angle, blade regularity, lip formation, bulb morphology, bulbar scar, conus formation and butt morphology. The new composite variable, constructed on the basis of the predicted grouping of the replicative experiments, was used as the grouping variable in a discriminant analysis including the archaeological blade assemblages (Damlien, 2015).

In order to pin point the timing of the technological changes more precisely, we have collected radiocarbon data from sites where the two blade production concepts and different adze traditions are documented. To date the changes in lithic blade production concepts we have included 136 radiocarbon dates from 41 sites located around the Oslo fjord. To date the shift in adze production we have included 100 radiocarbon dates from 27 sites. The radiocarbon dates are provided as supplementary information (see Supplementary table 2, 4 and 5).

4. Results

4.1. Technological analysis

The archaeological data from Mesolithic sites suggest that the hunter-gatherers in southeastern Norway employed variable production concepts, i.e. methods and knapping techniques in lithic blade production. Three main production concepts are recognized in the data; blade production from 1) single- and dual platform cores by direct percussion techniques, 2) conical cores by pressure and indirect percussion techniques, and 3) microblade production from handle cores by pressure technique (Fig. 2).

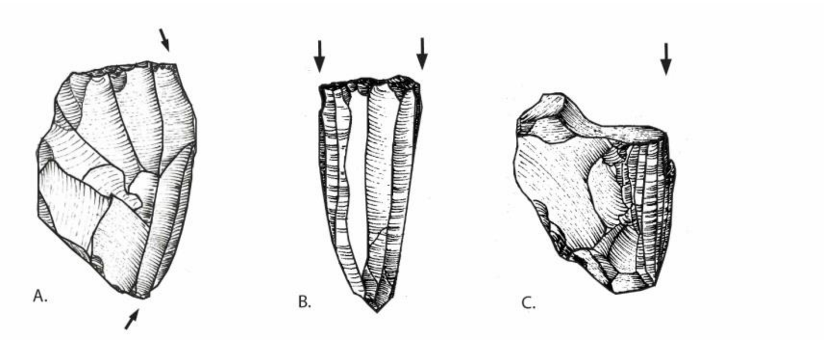


Figure 2. Main blade production methods in Mesolithic Southeast Norway, a) dual platform core, b) conical core and c) handle core (modified after Helskog et al., 1976).

Typical for the Early Mesolithic (c. 11 500–10 300 cal. BP) of Southern Norway is blade production involving knapping schemes derived from one-sided, single- and dual-platform cores. In contrast, the Middle Mesolithic (c. 10300–8 300 cal. BP) blade production concept involved blade production from single-platform, sub-conical and conical cores, thus demonstrating a change from combined uni- and bidirectional, to unidirectional core exploitation (Damlien, 2016). The Late Mesolithic blade production concept (c. 8300–5900 cal. BP), on the other hand, comprises a significantly different strategy, involving blade production from handle cores (Eigeland, 2015).

The three core reduction methods represent contrasting strategies for obtaining blade tool blanks. During blade production from dual- and single platform cores, and conical cores with elongated fronts, core maintenance was carried out by continuous shaping, adjustment and rejuvenation of the core platform. Consequently, during the reduction process, core dimensions, and therefore blade length and width gradually diminished in size. This resulted in relatively large size variation in blade blanks that provided blanks for a variety of tools of different sizes. Therefore, we can describe the Early and Middle Mesolithic core reduction methods as generalized production strategies. Contrary to the above mentioned core types, handle cores are most often made from large flakes, and were exploited from the narrow front along the relatively short longitudinal axis to produce exclusively microblades. In the handle core strategy the maximal dimension of the core is the platform, thus blade dimensions, i.e. length, width and thickness, remained relatively standardized during production. The handle core blade production concept can be considered a specialized production strategy, which instead of producing a large variety of blade blank sizes, yields a large number of standardized products (Eigeland, 2015; Hertell and Tallavaara, 2011). As shown in table 1 and Fig. 3, the different core reduction methods are clearly reflected in the metric dimensions among the analyzed blades.

Table 1

Date		**Length, mm**	**Width, mm**	**Thickness, mm**
EM	N	704	1805	1804
	Mean	40,23	13,58	4,02
	Minimum	11	3	1
	Maximum	123	58	16
	Std. Deviation	18,157	5,831	2,3
MM	N	489	3230	2936
	Mean	29,81	9,69	2,73
	Minimum	7	0	1
	Maximum	149	32	28
	Std. Deviation	14,356	3,75	1,748
LM	N	100	331	331
	Mean	20,59	5,76	1,49
	Minimum	11	3	1
	Maximum	40	19	8
	Std. Deviation	5,817	1,842	0,854

Table 1. Summary of metric attributes (length, width and thickness (in millimeters) for blades from Early- (EM), Middle- (MM) and Late Mesolithic (LM) sites

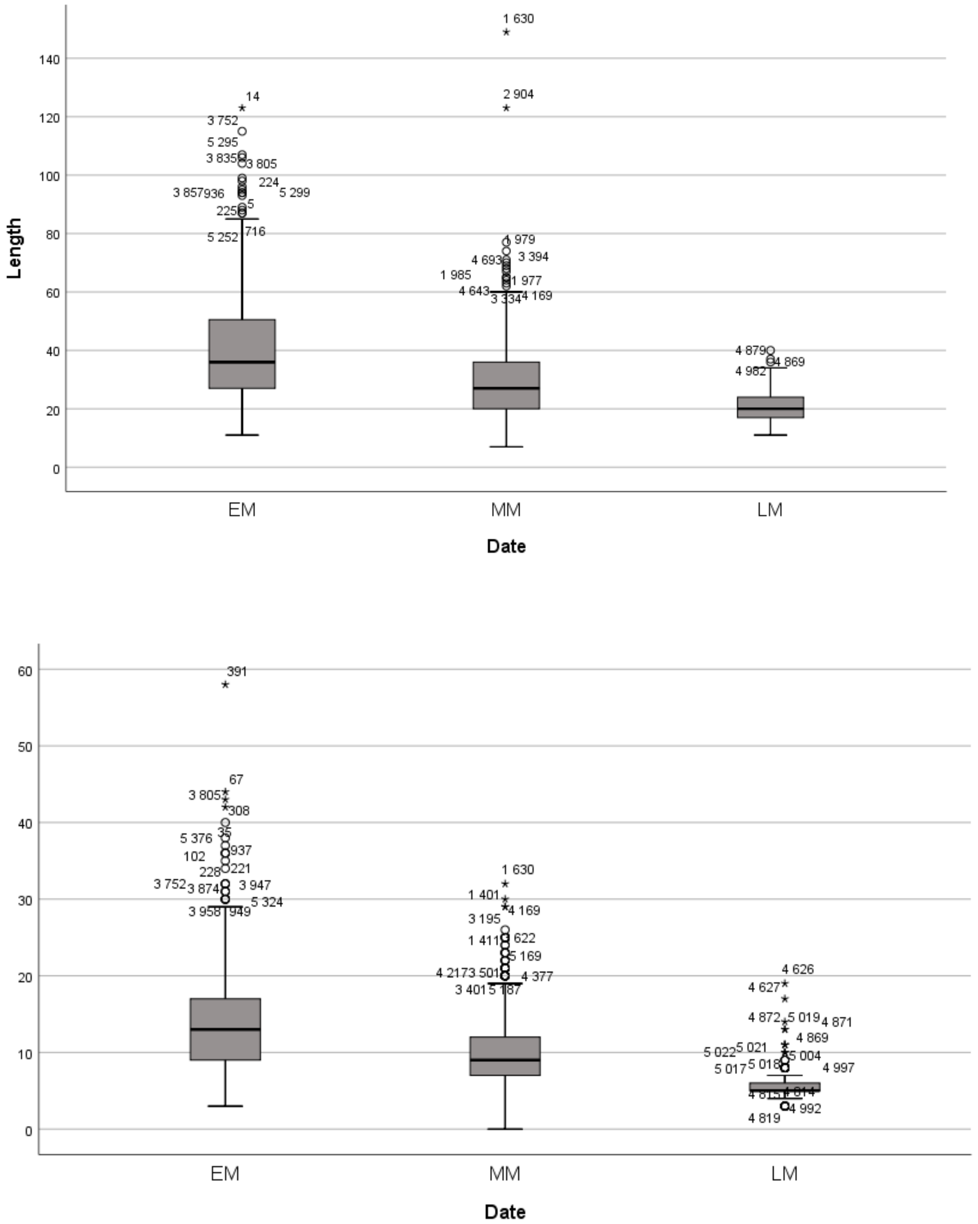


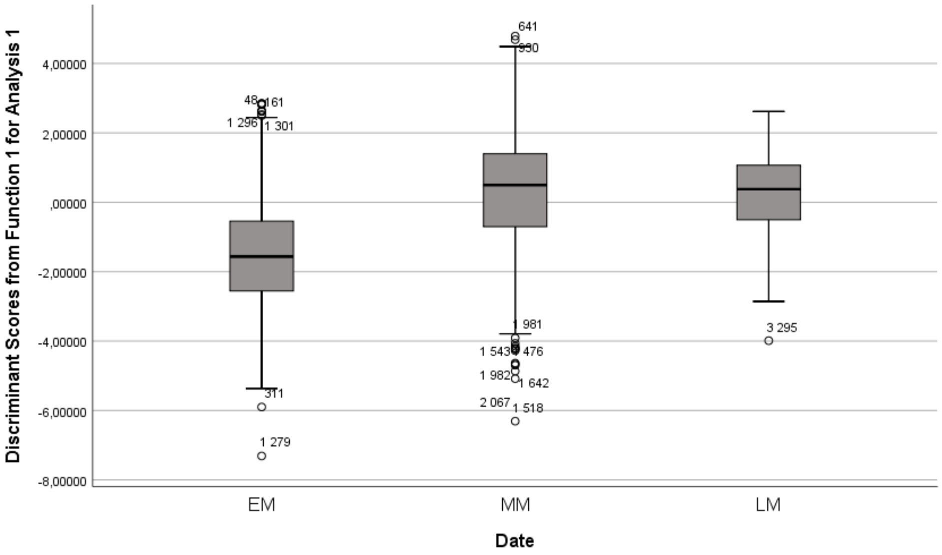
Figure 3. Box-plot of length and width values in millimeters of blades from Early- (EM), Middle- (MM) and Late Mesolithic (LM) sites.

Table 1 and Fig. 3 display metric attributes for blades from Mesolithic sites in southeastern Norway. Chronological variation in size measurements is evident. Blade production during the Early Mesolithic involved production of blades (> 8 mm in width). As indicated by the standard deviation (Std.Deviation) for the metric variables (table 1), Early Mesolithic blade assemblage is characterized by variation. For the Middle Mesolithic assemblages, blades display relatively less variation and are in general shorter, thinner and narrower. Moreover, the production of microblades (< 8 mm in width) appears to have been a part of regular blade production. Commonly, the Early and Middle Mesolithic blade production concepts are characterized by a gradual reduction of the core, obtaining progressively shorter and narrower blades. Blade dimensions for Late Mesolithic assemblages display a different strategy, where microblades dominates, and blades are low in numbers. Blades display a relatively low level of variation concerning size indicating a standardized microblade production concept.

Temporal variation is seen in the blade attributes often associated with the knapping technique used (see Damlien, 2016; Eigeland, 2014, 2016). The morphological characteristics and technical signatures characterizing blades from the Early Mesolithic sites largely correspond with the postulated diagnostic features for blades produced by direct percussion techniques (Damlien, 2015). Contrary, the Middle Mesolithic blades mainly display characteristics in accordance with blades produced by means of pressure and indirect percussion techniques (Damlien, 2015). The Late Mesolithic blade assemblage largely correspond with the postulated diagnostic features for blades produced by pressure technique. A central aim was therefore to test if the predictive DFA, constructed on basis of the experimental dataset, contributes to inform whether the observed temporal variation in the archaeological blade assemblages, is related to changes in knapping techniques.

Fig. 4 shows the distribution of discriminant scores for blades from the different chronological periods and archaeological blade collections, derived from the predictive DFA. Whereas, discriminant scores for blades from Early Mesolithic sites primary are located below the centerline, blades from the Middle and Late Mesolithic sites are primary located above, thereby illustrating chronological differences (see Supplementary table 3 for the predictive outcome for each site).

Early Mesolithic blade assemblages are primarily predicted to have been produced by means of direct percussion techniques. Although, a small collection of blades were predicted to belong to the indirect percussion and pressure technique groups, core assemblages from the sites do not support the use of these techniques. Importantly, and as shown by Damlien (2015: 126), a relatively high frequency of the experimental blades detached by direct percussion techniques was misclassified to the indirect percussion group. Based on this, and on the relatively low frequency of blades predicted to these groups, it is likely that the blades were produced by one of the direct percussion techniques. The general tendency is that direct percussion knapping techniques appears to have been used for blade production during the Early Mesolithic of southeastern Norway. These results support previous research, suggesting that Norwegian Early Mesolithic blade production primarily involved blade production from one-sided, dual and single platform cores by means of direct percussion techniques (e.g., Berg-Hansen, 2017; Bjerck, 2008; Damlien, 2015, 2016).



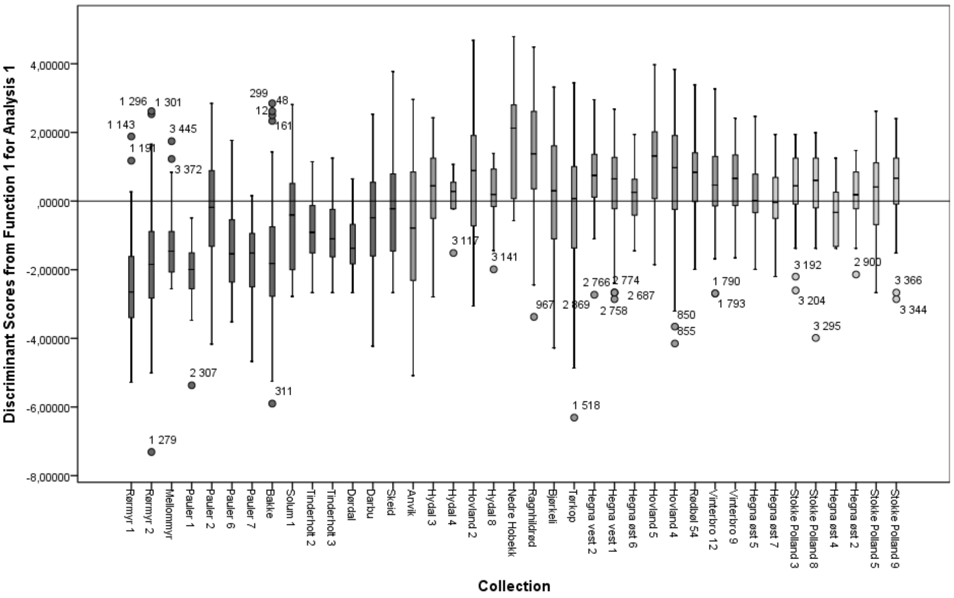


Figure 4. Boxplot comparing the distribution of discriminant scores for (a) the different chronological periods (EM= Early Mesolithic, MM=Middle Mesolithic, LM=Late Mesolithic) and (b) archaeological blade collections. The blade collections are organized chronologically (see supplementary table 1). For the archaeological blade collections Early Mesolithic sites are marked in dark grey, Middle Mesolithic sites are marked in grey and Late Mesolithic sites are marked in light grey. Mean value (group centroids) for the discriminants scores (DF1) for experimental blades detached by different techniques were 1,938 for pressure blades, 0,530 for indirect percussion blades, -0,755 for soft organic percussion blades, -1,249 for soft stone percussion blades and -2,436 for medium hard stone percussion blades (Damlien, 2015).

The results indicate that at the transition to the Middle Mesolithic, a shift in blade knapping techniques occurred in southeastern Norway. Blades from the Middle Mesolithic sites appear primarily to have been produced by pressure and indirect percussion technique. The sites' core assemblages, of which comprise very regular conical and sub-conical cores with faceted platforms and platform angles of 90°, support the use of these techniques (Damlien, 2016: 332–333). Additionally, a small amount of the blades was predicted to the direct percussion technique groups. Direct percussion techniques are known to have been used in combination with pressure and indirect percussion for the initial shaping of cores and for retaining the core geometry throughout the reduction sequence in Middle Mesolithic Southern Norway (Damlien, 2016; Eigeland, 2015).

In the Late Mesolithic, the results indicate a second change in the core reduction method. Despite this, the use of pressure technique continues throughout the Late Mesolithic. However, a modification in the use of different knapping technique is indicated. Compared to the Middle Mesolithic sites, the frequency of blades produced by indirect percussion technique is relatively low, whereas pressure and direct percussion techniques dominate. These results thereby support previous research, suggesting that the blade production concept during the Late Mesolithic primarily involved microblade production from handle cores by means of pressure and direct percussion techniques (e.g. Ballin, 1999, Eigeland, 2015).

A general assessment of the axe and adze assemblages from the analyzed sites, display distinct changes in the production concepts during the Mesolithic of southeastern Norway (see also Eymundsson et al. 2018). Whereas flake and core axes made of flint characterize the Early Mesolithic macro tool technology, a new concept involving production of round-butted adzes made of local volcanic rocks with a ground and/or pecked surface was introduced in the Middle Mesolithic. The majority of the recovered adzes from the first part of the Middle Mesolithic are ground adzes, while the adzed recovered from the later part of the period are pecked and then often partially grounded. Consequently, the technique of pecking appears to be introduced somewhat later in the region than the technique of grinding (Eymundsson et al. 2018: 218). A second change in the production concept is documented in the Late Mesolithic, with the introduction of the Nøstvet adzes. While the Middle Mesolithic round-butted adzes were shaped with bifacial technique, pecked and/or partially grinded, the Late Mesolithic adzes of Nøstvet type have a triangular cross section, and were shaped by detaching flakes from an oblong, flat platform and grinding of the edge.

4.2 Timing of the technological transitions in Mesolithic Southeastern Norway

Our results show two major shifts in the lithic technology during the Mesolithic of southeastern Norway. At this stage, there are no radiocarbon dates from Early Mesolithic sites in southeastern Norway. Due to the continuous postglacial land upheaval in the region, we can date sites with a relatively good precision (Solheim and Persson, 2018). By the use of shoreline displacement curves we can date the introduction of the conical core pressure blade technology to c. 10 300–10 000 cal. BP (e.g. Solheim and Damlien (eds.), 2013; Solheim ed., 2017). The, so far, earliest presence of this technology in the region as reflected by radiocarbon dated sites is documented for the site Langemyr in Larvik, Vestfold, dated to 10 165–9740 cal. BP (8853±43 BP, Ua-52063) (Koxvold, 2018).

Technological changes at the transition to the Late Mesolithic has long been recognized in the archaeological record for southeastern Norway. Gaute Reitan (2016) has recently reassessed the Mesolithic chronology in the region. Based on radiocarbon dates, technological features and selected artefacts, he argues that the regional Nøstvet technocomplex, including handle-cores and nøstvet adzes, were introduced c. 7600 cal. BP (Reitan, 2016) as opposed to c. 8400-8200 cal. BP as earlier suggested (e.g. Berg, 1995; Ballin, 1998).

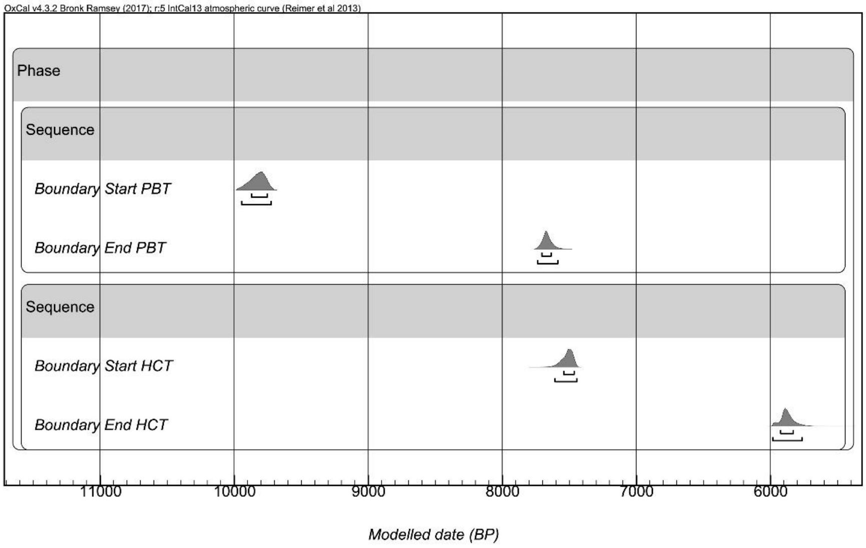


Figure 5: Age model multiplot comparing sequences of dates from sites with pressure blade technology and sites with the handle core technology. PBT = Pressure Blade Technology, HCT = Handle Core Technology. Posterior probability densities are presented in Supplementary information table 4.

We have developed a Bayesian age model in OxCal v 4.3.2 (Bronk Ramsey, 2017), using the IntCal 13 calibration curve (Reimer et al., 2013). The model and the dates is provided as supplementary information (see Supplementary table 2, 4 and 5). The Bayesian model provides estimates for the start and end phases of the two different blade production concepts (Fig. 5). The most interesting here, is the end phase of the conical core pressure blade technology (*PBT*) and the start of the handle core tradition (*HCT*). The end of the conical core pressure blade technology is estimated to take place between 7740 and 7590 cal. BP (95.4 % probability), or most likely between 7705 and 7640 cal. BP (68.2 % probability). The start of the handle core tradition is estimated to have occurred between 7605 to 7440 cal. BP (95.4 % prob.) or most likely from 7545 to 7460 cal. BP (68.2 % prob.). This indicate a rapid change in technological traditions.

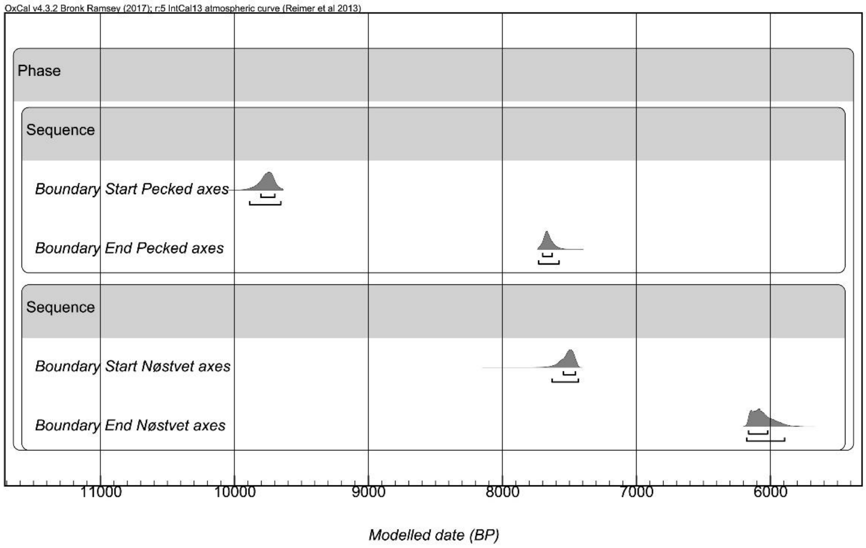


Figure 6. Age model multiplot comparing sequences of radiocarbon dates from sites with ground and pecked round-butted adzes and sites with nøstvet adzes. Posterior probability densities are presented in Supplementary information table 5.

The age model in Fig. 6 provides estimates for the start and end phases of the two different adze production traditions. It is the end of the ground and pecked round-butted adze tradition and the start of the nøstvet adze tradition that we focus on here. The end phase of the ground and pecked round-butted adze tradition is estimated to take place between 7730 and 7575 cal. BP (95.4 % prob.) or most likely between 7700 and 7625 cal. BP (68.2 % prob.). The start of the nøstvet adze tradition is estimated to have occurred between 7630 to 7430 cal. BP (95.4 % prob.) or most likely from 7545 to 7450 cal. BP (68.2 % prob.). As for the blade technology, the modelled date indicate a rapid shift in macro tool traditions, and that these shifts correspond in time.

5. Discussion

Hunter-gatherers live directly off the natural environment and respond to local changes in ecosystems (Kelly, 2016). The ecosystem influences the social system, which is suggested to adapt to environmental changes to maximize survival by strategies like local adaptation and/or adaptation through migration (Birks et al., 2015: 10). This means that environmental changes can be reflected in the archaeological record in various ways determined by the effects of the changes on the ecosystem. While we do not underestimate the effect of changes in climate and environment on past populations, our results highlights the diversity and complexity in human-environment interactions.

In the following we will focus on the two major changes taking place in southeastern Norway around 10 300–10 100 cal. BP and 7600–7400 cal. BP.

5.1 Case 1: The introduction of conical core pressure blade technology and ground/pecked macro tool technology

Major changes are demonstrated in the lithic technology at the transition to the Middle Mesolithic with the introduction of blade production from conical cores by pressure technique (Fig. 7; Damlien, 2016; Sørensen et al., 2013) and the ground and pecked macro tool technology (Eymundsson et al., 2018). Blade production by pressure technique and the ground macro tool technology are markers of a particular northeast European craft tradition that stretches over an extensive area including north-western Russia, the eastern Baltic region and most parts of Scandinavia in the Early and Middle Mesolithic (e.g., Damlien, 2016; Damlien et al., 2018a, 2018b; Eymundsson et. al., 2018; Rankama & Kankaanpää, 2011; Sørensen et al., 2013). The technologies arrived northern Fennoscandia from northwestern Russia and continued to spread rapidly westwards and then south along the Norwegian coast. Technological analysis of lithic assemblages from southeastern Norway (Damlien, 2016) demonstrate a definite and distinct division between the Early and Middle Mesolithic blade production methods and techniques as well as tool morphology *c*. 10 300–10 000 cal. BP, thereby indicating a replacement rather than admixture of blade tool making practices. The earliest evidence of macro tools modified by grinding comes from sites radiocarbon dated to 10 200–9600 cal. BP, while modification by pecking occurs on sites shoreline dated from *c.* 9900–9700 cal. BP (Eymundsson et al., 2018).

Figure 7. Left: Selection of blades (top) and cores (bottom) related to the conical core pressure blade concept. Right: Ground and pecked round-butted adze of volcanic rock. Photo: Ellen C. Holte/Museum of Cultural History. CC-BY-SA 4.0

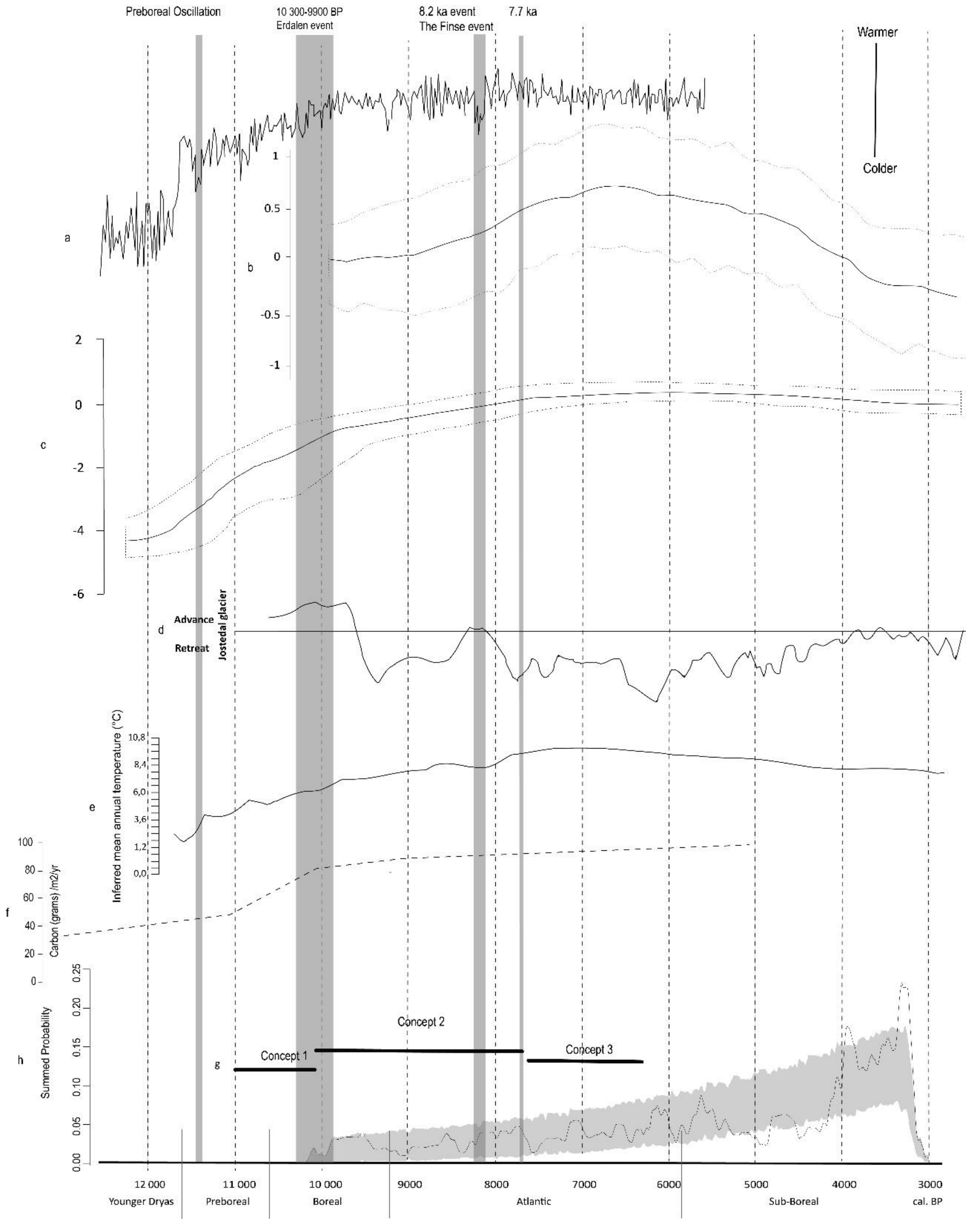


Figure 8: Stacked plots of paleoenvironmental reconstructions and population model. a) Greenland Ice Core (Rassmussen et al., 2007, fig. 2), b) Stacked pollen-based temperature deviations with uncertainties for Fennoscandia. Based on Sejrup et al. (2016), c) Pollen-based reconstruction of July surface air temperature for southern parts of coastal Norway. Based on Eldevik et al. (2014), d) reconstruction of Holocene glacier fluctuations in the Jostedalsbreen region in western Norway. Based on Nesje et al. (2001), e) Inferred mean annual temperature reconstruction for Lake Trehörningen, SW-Sweden (Antonsson and Seppä, 2007), f) change in bioproductivity in Skagerrak (Wassman, 1985), g) temporal distribution of discussed lithic blade production concepts, h) regional population model based on radiocarbon dates (Solheim, 2020).

The technological change corresponds in time with several shorter climate oscillations documented within the time period c. 10 400–9900 cal. BP (Fig. 8). Around 10 300 cal. BP lacustrine, ice-core, and marine records from the northern hemisphere indicate a distinct cooling event, attributed to disturbances in the North Atlantic thermohaline circulation (Berner et al., 2010; Björck et al., 2001; Rasmussen et al., 2006). In Southern Norway a two-phase glacier readvance termed the Erdalen event is dated to 10 400–9700 cal. BP, with the two glacial maxima dated to 10 100 cal. BP (Erdalen event 1) and 9700 cal. BP (Erdalen event 2) (Dahl et al., 2002; Matthews and Dresser, 2008). A decrease in pollen inferred temperature as well as increase in precipitation is documented in the mountain region during this time span (Panizzo et al., 2008, fig. 4). In the coastal region, however, palynological investigations (Sørensen et al., 2014, Wieckowska-Lüth et al., 2017), show that pine, hazel and elm were established in the region around 10 400–10 000 cal. BP, indicating a warm and dry climate and the establishing of a denser mixed woodland vegetation (Høeg et al., 2018; Sørensen et al., 2014: 196, 212). During this time stage the final deglaciation of the inland parts of eastern Norway took place (Høgaas and Longva, 2016; Mangerud et al., 2018), and this is closely linked with the outburst of the glacial lake Nedre Glomsjø, which inundated large parts of the southeastern Norway’s largest valley and river system. The drainage of Glomsjø and secondary Aeolian processes affected this landscape by erosion and deposition. This event is documented from a sediment core from the Skagerrak Sea, in the form of increased amount of ice rafted debris (Gyllencreutz, 2005:

359) which shows the magnitude of this event. If and in what ways this event had impact on the hunter-gatherers in the coastal areas of southeastern Norway is unclear at this point, and future investigations are needed.

A correlation between the 10.3 ka cooling event and the dispersal of the pressure blade technology and ground macro tool technology into northern Fennoscandia is suggested for other regions in Northern Europe. Based on archaeological data from eastern Fennoscandia, Miikka Tallavaara and colleagues (2014) have argued that the negative effects of the 10.3 ka cooling event resulted in a decrease in human activity and a pause in the northwestward colonization in the interval c. 10 250–10 100 cal. BP. Moreover, based on the sudden appearance and rapid spread of the pressure blade technology and ground macro-tool technology in southern Norway it is suggested that the technologies were introduced to the area by arriving groups (Damlien, 2016) in conjunction with a second wave of northwestward colonization in eastern Fennoscandia (Tallavaara et al., 2014; Manninen et al., 2017). This indicate a collapse of the existing technical system or even a demographic replacement.

The question of a demographic shift during the Late Preboreal is yet to be explored in detail for South Norway. Recent aDNA analysis of human remains from Scandinavia (Günther et al., 2018) makes it reasonable to assume that the technology was introduced due to intimate contact between the local population and the arriving groups of eastern origin (Damlien 2016), a contact that also had a genetic effect (Günther et al., 2018; Kashuba et al., 2019). Studies of population dynamics in the coastal areas of southeastern Norway argues for a stable population growth interrupted by minor, short-term deviations, in the period between 10 500 cal. BP and 4000 cal. BP (Solheim and Persson, 2018; Solheim, 2020: 49-51). Based on a summed radiocarbon probability distribution of radiocarbon dates and the distribution of shoreline-dated sites, no major fluctuations in population are identified, which is in accordance with the study by Kashuba and colleagues (2019).

Although the cultural changes at the Middle Mesolithic transition might have been ecological underwritten, the current data indicates that the introduction of the conical core pressure blade technology and ground macro tool technology in southeastern Norway, should be seen in relation to social and demographic processes at an inter-regional scale, rather than adaptive processes at a local scale (Damlien, 2016, Eymundson et. al. 2018). The pecked macro tool technology appears, however, to represent a regional innovation in the southern parts of Scandinavia (Manninen et al., in prep.).

5.2 Case 2: The introduction of handle cores and Nøstvet adzes

The second observed technological transition took place between 7600 and 7450 cal. BP with the introduction of microblade production on handle cores (Fig. 9). The preferred blanks for handle cores were thick, oblong flakes. The flint nodules found in glacial deposits along the Norwegian coast are small and of highly varying quality and character. As such, the handle core technology is not particularly well adapted to the local flint sources. Eigeland (2015: 276) have therefore argued that people introduced the technology to southeastern Norway from more flint abundant areas.

Figure 9. Left: Late Mesolithic microblades (top) and handle cores (bottom). Right: Nøsvet adze made of local volcanic rock. Photos: Ellen C. Holte and Ann Christine Eek/Museum of Cultural History. CC-BY-SA 4.0

The handle core tradition was a cultural trait shared by hunter-gatherers over a vast area stretching from northern Germany and western Poland to northernmost Lappland in Sweden during the Mesolithic (Knutsson et al., 2003), but the temporal distribution and spread of the handle core concept is poorly understood (e.g. Söderlind 2018: 4). In Denmark, the start of the handle core technology is dated to c. 8500 cal. BP during the Late Maglemose (Sørensen, 2012b). On the western coast of Sweden handle cores are associated with the Late Mesolithic Lihult technocomplex and are most likely introduced after 8000 cal. BP (Hernek, 2005: 249, 264; Nordqvist, 2000: 212). Interestingly, recent excavations in central Sweden have demonstrated that the handle core concept is present at sites radiocarbon dated to 9200–9100 cal. BP, thus predating the handle cores found in southern Scandinavia. These cores are not made of flint, but of different locally available raw materials, such as porphyry, jasper, and ash-tuff (Albeck and Guinard, 2016: 42). Our results suggest that the handle core concept was introduced in the coastal area of southeastern Norway between 7600–7400 cal. BP. Thus, the introduction appears to be slightly later in this area than in western Sweden and Southern Scandinavia.

During the same time as changes are seen in the blade technology, a new and regional distributed adze production concept is also introduced. The use of local, volcanic rock for adze production was already introduced in the Middle Mesolithic in southeastern Norway, but the adze technologies before and after c. 7500 cal. BP differs (Eigeland, 2015: 382; Reitan, 2016).

The technological change that took place in southeastern Norway between 7605 and 7440 cal. BP corresponds with a cold episode in the North Atlantic and the start of a minor glacier advance in the south Norwegian mountain region (Matthews and Dresser, 2008, 195; Nesje, 2009: 2124). This cooling is also identified in marine proxy records in the Barents Sea ca. 7800-7500 cal. BP (Manninen et al., 2017: 5 w. references; see also Eldevik et al., 2014), and it corresponds with important changes in the sea level in the Baltic Sea (e.g. Rößler et al., 2011). However, this climatic event is not documented in local climate records in the lower-lying regions of southern Norway. Rather, the period after c. 7500 cal. BP is characterized by a marked increase of Lime and Oak implying a change from an oceanic climate towards more continental conditions (Fig. 10; Høeg et al., 2018; Wieckowska Lüth et al., 2018). Inter-regional similarities in the blade production concept indicate that the introduction of the handle core technology in southeastern Norway between 7600 and 7400 cal. BP were likely a result of demographic or cultural transmission processes, involving neighboring areas to the south. The SPD in Fig. 8h show a negative deviation at the time when the conical core pressure blade technology disappears in the archaeological record and when the handle core tradition is introduced. The empirical curve is within the expected range of the exponential null-model but can possibly indicate a shift in the demographic signal. Interestingly, the technological reorganization correspond in time to the Littorina 1 transgression and demographic changes in the Baltic sea region, interpreted as part of a more general shift in population sizes in northern Europe (Apel et al., 2018). These demographic processes might be caused by the environmental development at an inter-regional scale. Contrary, the Nøstvet adze tradition was a regional development in Eastern Norway and Western Sweden and is not documented outside this area.

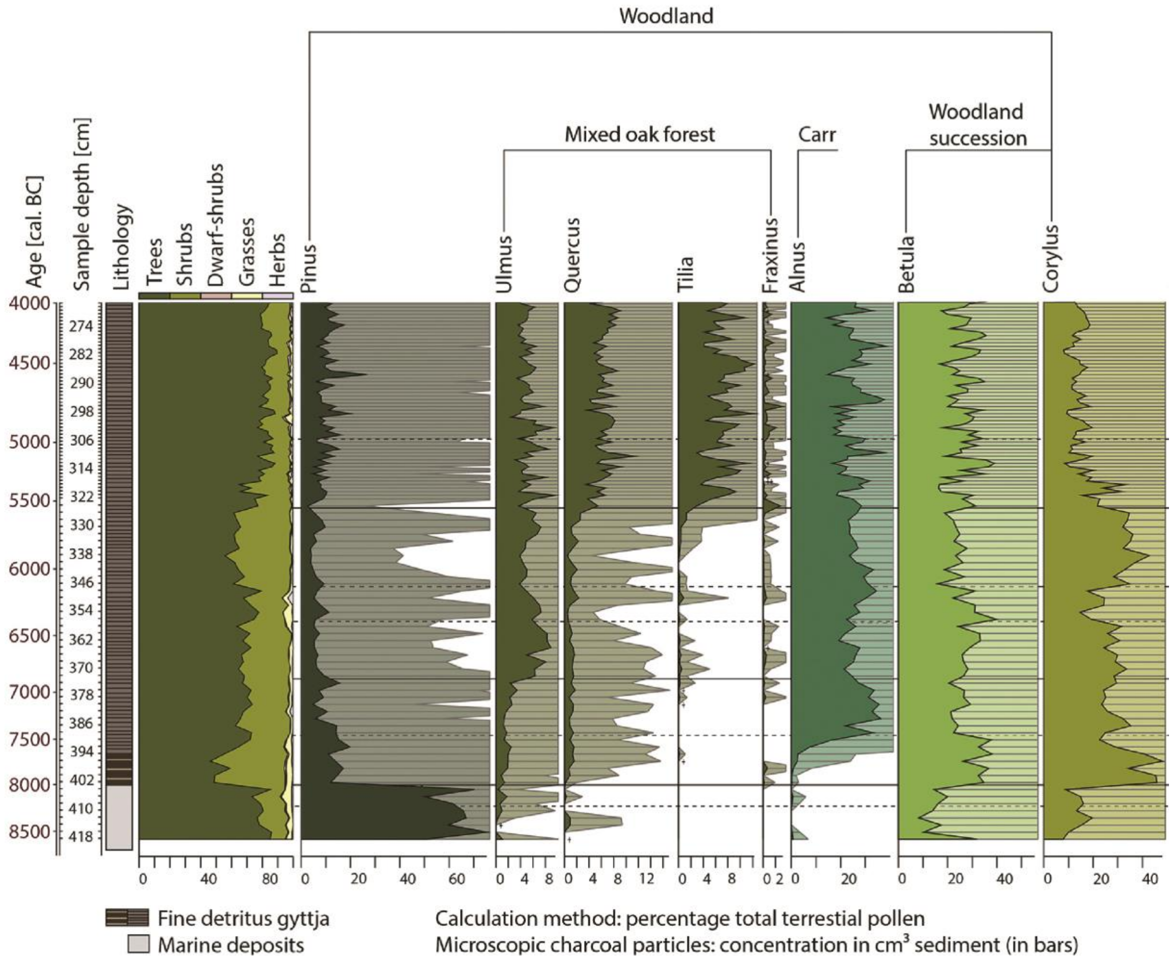


Figure 10. Percentage pollen diagram showing the woodland composition in the Early and Mid-Holocene section of the sediment core from Lake Skogstjern in Telemark (Wieckowska-Lüth et al., in 2017). Increasingly warmer conditions are seen by rapid rise in the warmth-demanding hazel tree, from c. 10 000 cal. BP. Reduction in the frost sensitive hazel is identified between 8270 and 8110 cal. BP, probably related to the 8.2 ka event. From c. 7500 cal. BP there is a strong decrease in pollen values of hazel along with a rapid increases in Lime and Oak. As these species are less sensitive to drought and require high mid-summer temperatures this implies a change from an oceanic climate towards more continental conditions. The figure is based on Fig. 4 in Wieckowska-Lüth et al., 2018.

6 Environmental trends and technological organization during the Mesolithic of southeastern Norway

The two major technological transitions discussed here display some clear resemblances. Sudden breaks in blade and macro tool technologies suggest the introduction of new technological traditions. These technological shifts correspond in time with climate events and vegetational development that possibly affected hunter–gatherers in neighboring regions of northwest Europe (Apel et al., 2018; Damm et al., 2019; Tallavaara et al., 2010). In our two cases we cannot, at this point establish a direct link between regionally observed climate events (10.3 cal. BP and 7.7 cal. BP) and technological change. In both cases, however, the observed technological changes corresponds temporally with a continuous rise in temperature towards a warmer continental climate as well as locally detected vegetation changes.

Our analysis indicates that the two transitions in blade technology and the introduction of ground macro tool technology are results of new groups of people arriving southeastern Norway or cultural transmission processes, rather than a local adaption of the cultural repertoire to a changing environment or climate. This allows for the hypothesis that these major technological changes or breaks were associated with social or demographic changes at an inter-regional scale rather than internal modifications due to local adaptive environmental responses (Damlien, 2016). Environmental changes in other regions, such as inundation of large areas of habitable land and/or shifts in local climate zones (e.g. Apel et al., 2018; Momber and Peeters, 2017; Sørensen and Casati, 2010), might have been push-factors that initiated the processes of migration that we see the effect of in southeastern Norway. The pecked macro tool technology seem, however, to represent an innovation in southern parts of Scandinavia whereas the Nøstvet adze tradition appears to be a regional development around the Skagerak coast. In the latter case, the introduction was potentially connected to change in the local environment, and several authors have argued that the use of adzes was related to a shift in the vegetation composition and especially the introduction and use of Lime as a raw material for wooden implements (Jaksland, 2005; Glørstad 2010; Wieckowska-Lüth et al., 2018). This demonstrates different modes of change during the Mesolithic of southeastern Norway.

Our results, thus, support previous research, indicating that although climate change is known to affect culture and behavior, there is no one to one relationship between climate change and culture change and that the link between climate impact on ecosystems and human populations is a complex matter (e.g. Arponen et al., 2019). It is evident that climate can affect populations in different ways. Climate changes identified at a global scale can be identified in human adaptation at a local scale but does not necessarily cause a severe impact on the local ecosystem or in human adaptation at a local scale (Griffiths and Robinson, 2017) as we have demonstrated. Climate changes will affect ecosystems depending on local site characteristics as well as the system's resilience (Birks et al., 2015: 9). As pointed out by Griffiths and Robinson (2017: 6), it is important to consider the scale of the study when comparing different proxies. Ecotones have been considered as especially vulnerable to climate change (Birks et al., 2015), but they can also be considered as favorable for habitation due to the potential to utilize different ecological niches and resources. Regions with abundant aquatic resources offer good conditions for maintaining a stable population size (Binford, 2001; Kelly, 2016), and it is suggested that marine environments allow pooling of resources, thereby making hunter-gatherers living in coastal regions less exposed to climatic variation (Rick and Erlandson, 2012; Yessner, 1980). This is of importance here, as most known Mesolithic sites in southeastern Norway were situated along the coastline and hence indicate an adaptation to aquatic resources. The Norwegian coastline experienced an increasing marine productivity during the Mesolithic (Fig. 8; Wassman, 1985), and it is possible that the region had a different demographic development and response to climate events than elsewhere in Northern Europe, or that the marine foragers were more resilient to sudden climate events (Bjerck, 2009; Breivik, 2014; Breivik et al., 2018; Solheim and Persson, 2016, 2018; Solheim, 2020).

As resource abundance and availability varied between regions, we can expect that environmental change potentially did not affect the population in the same manner in different areas and ecological niches. This is also evident in southern Norway. Based on variation in summed radiocarbon probability distribution Per Persson (2018: 204) has identified a decline in activity in the mountain regions of southern Norway immediately after 10 500 cal. BP and after 7800–7600 cal. BP. He argues that the latest decline probably was connected to environmental changes and an effect of the 8.2 ka event (Persson 2018: 214). Comparatively, we cannot see any significant decline in activity or any significant shifts in the technological organization in the coastal area following this cold event (Breivik et al., 2018; Fossum, 2020; Solheim and Persson, 2018). Further examples can be given. The 8.2 ka event is considered the most significant abrupt climate change event after the Younger Dryas, and is detected in palaeoclimatic records in the North Atlantic region (Seppä et al., 2009). Several studies have investigated the effect of the event on human society and identified different responses. For Northern Fennoscandia, Tallavaara et al. (2010) have detected a change in the technological organization, in settlement configuration as well as in land use following the event, but have not documented any significant drops in population sizes (see also Manninen 2014; Manninen et al. 2017). For the Netherlands, Robinson et al. (2013) have suggested that both sociocultural and technological changes followed the 8.2 ka event. It is however uncertain if this was caused by long term, gradual environmental change or the abrupt cold event.

While these examples demonstrates how climate oscillations and environmental change can be a driving force for technological and demographic change, they also illustrate the complexity and diversity of human-environment interactions and that consequences of climate-driven changes cannot be expected to be synchronous across different regions (Birks et al., 2015: 10; Nieuwenhuyse and Biehl, 2016: 4). Importantly, and as shown in our cases, climatic changes are not necessarily the main driving force behind changes in technology or demography among past population.

To summarize, we have explored the relation between technological transitions and environmental change during the Mesolithic of southeastern Norway. Although our study shows major technological reorganizations correlating in time with supra-regional climate oscillations, we cannot establish a direct link between the oscillations and technological change at a local scale. The 8.2 ka event is identified in palynological records but we cannot see any corresponding clear-cut changes in the archaeological assemblages in the coastal regions of southeastern Norway. We have not been able to document climatic oscillations c. 10 400–9900 cal. BP and 7700–7500 cal. BP in the available climate proxy data from around the Oslo fjord. Rather, we observe a continuous rise in temperature and the establishing of warmth demanding vegetation during this time-span, thus highlighting the need to explore the importance of gradual environmental development in human cultural evolution (Kelly et al., 2013). Local ecosystem responds differently to climate oscillations, and it is a possibility that the Oslo fjord region was not severely affected during these periods. We suggest that the succession of several events at an inter-regional scale led to the technological changes observed at the transition to the Middle Mesolithic in southeastern Norway. The changes might have been environmentally underwritten but were not locally adaptive responses to climate change. The effect of climate appears only to represent one part of a complex whole. This also appears to be the case for the introduction of the Late Mesolithic handle core technology, while the change in macro tool technology was probably a response to environment and vegetational development at a local scale.

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Supplementary information

Solheim, Damlien and Fossum

No.	Site	Region	Masl.	Lab.code	BP	cal. BP (95,4%)	Shoreline dating	Reference
1	Rørmyr 1	Østfold	155-160				11500/11200-10850	Jaksland and Persson (eds) 2014
2	Rørmyr 2	Østfold	155-160				11500/11200-10850	Jaksland and Persson (eds) 2014
3	Mellommyr	Østfold	155-160				11500/11200-10850	Jaksland and Persson (eds) 2014
4	Pauler 1	Vestfold	127-130				11200-10900	Jaksland (ed) 2012a
5	Pauler 2	Vestfold	124				11150-10850	Jaksland (ed) 2012a
6	Pauler 6	Vestfold	98				10850-10550	Jaksland (ed) 2012b
7	Pauler 7	Vestfold	96				10800-10500	Jaksland (ed) 2012b
8	Bakke	Vestfold	98-103				10900-10500	Jaksland (ed) 2012b
9	Solum 1	Vestfold	95				10800-10400	Melvold and Persson (eds) 2014
10	Tinderholt 3	Telemark	106-109				10700-10500	Solheim (ed) 2017
11	Tinderholt 2	Telemark	104-107				10700-10400	Solheim (ed) 2017
12	Dørdal	Telemark	100-101				10600-10400	Solheim (ed) 2017
13	Darbu/Fiskum	Buskerud	118				10400-10300	Eymundsson and Gaut 2013
14	Skeid	Telemark	94-95				10500-10300	Solheim (ed) 2017
15	Anvik	Vestfold	77				10300-10200	Eymundsson and Mjærum 2014
16	Hydal 3	Telemark	77-79				10300-10100	Solheim (ed) 2017
17	Hydal 4	Telemark	80				10300-10100	Solheim (ed) 2017

18	Hovland 2	Vestfold	65-70				10300-9900	Solheim and Damlien (eds) 2013
19	Hydal 8	Telemark	75				10200-10000	Solheim (ed) 2017
20	Nedre Hobekk 3	Vestfold	74				10200-10100	Melvold and Persson 2014
21	Ragnhildrød	Vestfold	80				10000-9900	Mjærum 2012
22	Bjørkeli	Hedmark	240	X3226	11270±710 bp	15360-11260	-	Stene (ed) 2010
23	Tørkop	Østfold	70	T-2134	8790±100	10160-9550	9200-8600	Mikkelsen 1975
			70	T-2194	8590±140	1050-9290	9200-8600	Mikkelsen 1975
			70	T-1872	8180±170	9490-8640	9200-8600	Mikkelsen 1975
24	Hegna vest 2	Telemark	61-64	Ua-50497	8708±38	9890-9540	10100-9800	Solheim (ed) 2017
25	Hegna vest 1	Telemark	60-61	Ua-50485	8788±34	10120-9660	10000-9800	Solheim (ed) 2017
			60-61	Ua-51461	8732±40	9890-9550	10000-9800	Solheim (ed) 2017
26	Hegna øst 6	Telemark	56-58				9900-9500	Solheim (ed) 2017
27	Hovland 5	Vestfold	70	Ua-45490	8775±52	10130-9550	10200-10000	Solheim and Damlien (eds) 2013
28	Hovland 4	Vestfold	65	Ua-45493	8568±51	9660-9470	10000-9800	Solheim and Damlien (eds) 2013
			65	Ua-45494	8526±52	9560-9440	10000-9800	Solheim and Damlien (eds) 2013
			65	Ua-45499	8630±49	9700-9520	10000-9800	Solheim and Damlien (eds) 2013
			65	Ua-45500	8747±64	10120-9540	10000-9800	Solheim and Damlien (eds) 2013
29	Rødbøl 54	Vestfold	73	TuA-5558	8630±45	9690-9520	10000-9500	Mansrud 2008
30	Vinterbro 12	Akershus	100				9800-9600	Jaksland 2001
31	Vinterbro 9	Akershus	92				9600-9500	Jaksland 2001
32	Hegna øst 5	Telemark	44-49				9500-9000	Solheim (ed) 2017
33	Hegna øst 7	Telemark	40-42				8200-8000	Solheim (ed) 2017
34	Stokke Polland 3	Telemark	37-40				8100-7400	Solheim (ed) 2017
35	Stokke Polland 8	Telemark	36-40	Ua-51840	6215±35	7250-7000	8100-7300	Solheim (ed) 2017
36	Hegna øst 4	Telemark	35-36				7400-7200	Solheim (ed) 2017
37	Hegna øst 2	Telemark	37-38	Ua-50501	5318±26	6190-5990	7800-7500	Solheim (ed) 2017
38	Stokke Polland 5	Telemark	29-37	Ua-48256	6196±40	7250-6980	7200-6300	Solheim (ed) 2017
			29-37	Ua-48257	6098±40	7160-6850	7200-6300	Solheim (ed) 2017
			29-37	Ua-48258	6177±42	7240-6940	7200-6300	Solheim (ed) 2017
39	Stokke Polland 9	Telemark	29-31				6200-6000	Solheim (ed) 2017

Table 1. Sites included in the technological analysis of blade production methods and techniques ** = OSL-date.

Lab_ref	C14age	C14_se	County	C14_Sample_material	Site_name	Blade technology	Nøstvet adze	Pecked adze
TUa-3276	5965	75	Østfold	Charcoal	Berget 1	HCT	x	
TUa-3275	5660	70	Østfold	Charcoal	Berget 1	HCT	x	
TUa-3225	5190	75	Østfold	Charcoal	Berget 1	HCT	x	
TUa-3980	6574	47	Vestfold	bone	Frebergsvik	HCT	x	x
TUa-894	5389	77	Akershus	Charcoal	Gjølstad	HCT		
TUa-893	5329	70	Akershus	Charcoal	Gjølstad	HCT		
T-8810	6529	135	Østfold	Charcoal	Halden lok. 2	HCT	x	
T-8803	6427	120	Østfold	Charcoal	Halden lok. 2	HCT	x	
T-8806	5796	89	Østfold	Charcoal	Halden lok. 5	HCT		
T-8816	5511	107	Østfold	Charcoal	Halden lok. 5	HCT		
TRa-2248	5910	50	Telemark	Charcoal	Langangen Vestgård 3	HCT		
TRa-2246	5400	55	Telemark	Charcoal	Langangen Vestgård 3	HCT		
TRa-2247	5325	50	Telemark	Charcoal	Langangen Vestgård 3	HCT		
TRa-2249	5325	45	Telemark	Charcoal	Langangen Vestgård 3	HCT		
TRa-2250	5325	50	Telemark	Charcoal	Langangen Vestgård 3	HCT		
TRa-4126	5095	45	Telemark	Charcoal	Langangen Vestgård 3	HCT		
TRa-2255	5695	50	Telemark	Charcoal	Langangen Vestgård 5	HCT		
TRa-2254	5645	45	Telemark	Charcoal	Langangen Vestgård 5	HCT		
Tua-4602	6565	45	Akershus	Bone	Nøstvet I	HCT	x	
Ua-3667	5950	60	Telemark	Charcoal	Rugtvedt	HCT	x	
Ua-3669	5860	75	Telemark	Charcoal	Rugtvedt	HCT	x	
Ua-3668	5505	65	Telemark	Charcoal	Rugtvedt	HCT	x	
Ua-48256	6196	40	Telemark	Charcoal	Stokke/Polland 5	HCT	x	
Ua-48258	6177	42	Telemark	Charcoal	Stokke/Polland 5	HCT	x	
Ua-48257	6098	40	Telemark	Charcoal	Stokke/Polland 5	HCT	x	
Ua-51480	6215	36	Telemark	Charcoal	Stokke/Polland 8	HCT	x	
TUa-4390	5610	40	Østfold	Burned bone	Torpum 13	HCT		
TUa-3845	5530	50	Østfold	Charcoal	Torpum 13	HCT		
TUa-3279	6530	70	Østfold	Charcoal	Torpum 9b	HCT	x	
TUa-3922	6505	55	Østfold	Charcoal	Torpum 9b	HCT	x	
TUa-3936	6495	40	Østfold	Hazel nutshell	Torpum 9b	HCT	x	
TUa-3934	6435	40	Østfold	Hazel nutshell	Torpum 9b	HCT	x	
TUa-3937	6435	45	Østfold	Hazel nutshell	Torpum 9b	HCT	x	
TUa-3933	6420	40	Østfold	Hazel nutshell	Torpum 9b	HCT	x	
TUa-3931	6380	40	Østfold	Hazel nutshell	Torpum 9b	HCT	x	
TUa-3233	6375	75	Østfold	Hazel nutshell	Torpum 9b	HCT	x	
TUa-3935	6365	45	Østfold	Hazel nutshell	Torpum 9b	HCT	x	
TUa-3280	6325	75	Østfold	Charcoal	Torpum 9b	HCT	x	
TUa-3234	6250	85	Østfold	Hazel nutshell	Torpum 9b	HCT	x	
TUa-3920	6205	50	Østfold	Charcoal	Torpum 9b	HCT	x	
TUa-3921	5270	45	Østfold	Charcoal	Torpum 9b	HCT	x	
Ua-45182	5770	35	Telemark	Charcoal	Vallermyrene 1	HCT	x	

Ua-45181	5748	35	Telemark	Charcoal	Vallermyrene 1	HCT	x	
Ua-45180	5373	34	Telemark	Charcoal	Vallermyrene 1	HCT	x	
Ua-45169	6489	50	Telemark	Burned bone	Vallermyrene 4	HCT	x	
Ua-45170	6381	37	Telemark	Burned bone	Vallermyrene 4	HCT	x	
Ua-45172	6197	40	Telemark	Charcoal	Vallermyrene 4	HCT	x	
Ua-45171	6067	41	Telemark	Charcoal	Vallermyrene 4	HCT	x	
T-13139	6145	89	Akershus	Charcoal	Vinterbro	HCT		
T-13136	5905	105	Akershus	Charcoal	Vinterbro 3	HCT	x	x
UBA-28736	7439	39	Vestfold	Charcoal	Brunstad 24	CCPBT		x
UBA-28735	7374	45	Vestfold	Charcoal	Brunstad 24	CCPBT		x
UBA-28734	7285	37	Vestfold	Charcoal	Brunstad 24	CCPBT		x
Ua-48383	7090	35	Vestfold	Charcoal	Brunstad 24	CCPBT		x
UBA-28279	6948	35	Vestfold	Charcoal	Brunstad 24	CCPBT		x
UBA-28732	6873	43	Vestfold	Charcoal	Brunstad 24	CCPBT		x
Ua-48381	6850	35	Vestfold	Charcoal	Brunstad 24	CCPBT		x
UBA-28740	7067	37	Vestfold	Charcoal	Brunstad 25	CCPBT		x
LuS-11115	7060	45	Vestfold	Charcoal	Brunstad 25	CCPBT		x
UBA-28743	7057	38	Vestfold	Hazel nutshell	Brunstad 25	CCPBT		x
UBA-28744	7032	34	Vestfold	Charcoal	Brunstad 25	CCPBT		x
UBA-28737	6943	44	Vestfold	Charcoal	Brunstad 25	CCPBT		x
UBA-28745	6920	37	Vestfold	Charcoal	Brunstad 25	CCPBT		x
UBA-28742	6886	47	Vestfold	Charcoal	Brunstad 25	CCPBT		x
Ua-55053	8303	39	Østfold	Burned bone	Eidsberg fengsel, tuft 1	CCPBT		
Ua-55120	8179	44	Østfold	Nutshell	Eidsberg fengsel, tuft 1	CCPBT		
Ua-55052	8001	33	Østfold	Burned bone	Eidsberg fengsel, tuft 1	CCPBT		
Ua-55119	7893	37	Østfold	Nutshell	Eidsberg fengsel, tuft 1	CCPBT		
Ua-55055	8306	34	Østfold	Burned bone	Eidsberg fengsel, tuft 2	CCPBT		x
Ua-55056	8283	38	Østfold	Burned bone	Eidsberg fengsel, tuft 2	CCPBT		x
Ua-55121	8202	44	Østfold	Nutshell	Eidsberg fengsel, tuft 2	CCPBT		x
Ua-55122	7980	43	Østfold	Nutshell	Eidsberg fengsel, tuft 2	CCPBT		x
Ua-55058	8321	34	Østfold	Burned bone	Eidsberg fengsel, tuft 3	CCPBT		x
Ua-55057	8319	35	Østfold	Burned bone	Eidsberg fengsel, tuft 3	CCPBT		x
Ua-55123	8181	44	Østfold	Nutshell	Eidsberg fengsel, tuft 3	CCPBT		x
Ua-55124	8140	44	Østfold	Nutshell	Eidsberg fengsel, tuft 3	CCPBT		x
UBA-19158	7210	38	Telemark	Charcoal	Gunnarsröd 4	CCPBT		x
UBA-19159	6941	36	Telemark	Charcoal	Gunnarsröd 4	CCPBT		x
Ua-50485	8788	34	Telemark	Charcoal	Hegna vest 1	CCPBT		x
Ua-51462	8732	40	Telemark	Charcoal	Hegna vest 1	CCPBT		x
Ua-50497	8708	38	Telemark	Charcoal	Hegna vest 2	CCPBT		
Ua-45675	8623	50	Vestfold	Charcoal	Hovland 1	CCPBT		x
AAR-16884	8582	33	Vestfold	Birch bark tar	Hovland 1	CCPBT		x
TRa-3410	8465	55	Vestfold	Charcoal	Hovland 1	CCPBT		x

Ua-45507	8609	54	Vestfold	Charcoal	Hovland 3	CCPBT		x
Ua-45515	8606	50	Vestfold	Hazel nutshell	Hovland 3	CCPBT		x
Ua-45509	8594	48	Vestfold	Charcoal	Hovland 3	CCPBT		x
Ua-45508	8591	50	Vestfold	Charcoal	Hovland 3	CCPBT		x
Ua-45504	8584	49	Vestfold	Charcoal	Hovland 3	CCPBT		x
Ua-45514	8552	50	Vestfold	Charcoal	Hovland 3	CCPBT		x
Ua-45517	8540	51	Vestfold	Hazel nutshell	Hovland 3	CCPBT		x
Ua-45505	8467	53	Vestfold	Charcoal	Hovland 3	CCPBT		x
Ua-45511	8465	48	Vestfold	Charcoal	Hovland 3	CCPBT		x
Ua-45506	8458	48	Vestfold	Charcoal	Hovland 3	CCPBT		x
Beta-325802	8450	40	Vestfold	Hazel nutshell	Hovland 3	CCPBT		x
Ua-45516	8428	50	Vestfold	Hazel nutshell	Hovland 3	CCPBT		x
Ua-45522	8398	49	Vestfold	Hazel nutshell	Hovland 3	CCPBT		x
Ua-45520	8387	47	Vestfold	Hazel nutshell	Hovland 3	CCPBT		x
Ua-45519	8383	47	Vestfold	Hazel nutshell	Hovland 3	CCPBT		x
Ua-45503	8376	51	Vestfold	Charcoal	Hovland 3	CCPBT		x
Ua-45512	8348	47	Vestfold	Charcoal	Hovland 3	CCPBT		x
Ua-45518	8291	48	Vestfold	Hazel nutshell	Hovland 3	CCPBT		x
Ua-45500	8747	64	Vestfold	Burned bone	Hovland 4	CCPBT		
Ua-45499	8630	49	Vestfold	Hazel nutshell	Hovland 4	CCPBT		
Ua-45493	8568	51	Vestfold	Charcoal	Hovland 4	CCPBT		
Ua-45494	8526	52	Vestfold	Charcoal	Hovland 4	CCPBT		
Ua-45490	8775	52	Vestfold	Hazel nutshell	Hovland 5	CCPBT		x
TUa-1547	7437	68	Akershus	Nutshell	Kvestad lok. 2	CCPBT		x
Lus-13499	7055	45	Akershus	Burned bone	Kvestad lok. 2	CCPBT		x
Lus-13500	7040	45	Akershus	Burned bone	Kvestad lok. 3	CCPBT		x
TRa-4117	8030	55	Telemark	Charcoal	Langangen Vestgård 1	CCPBT		x
TRa-4118	8005	45	Telemark	Charcoal	Langangen Vestgård 1	CCPBT		x
TRa-4121	7945	45	Telemark	Charcoal	Langangen Vestgård 1	CCPBT		x
UA-52063	8853	43	Vestfold	Hazel nutshell	Langemyr	CCPBT		
Ua-47916	7970	44	Vestfold	Burned bone	Pjonkerød 49/1	CCPBT		x
Ua-45176	8671	45	Telemark	Hazel nutshell	Prestemoen 1	CCPBT		x
Ua-45177	8620	45	Telemark	Burned bone	Prestemoen 1	CCPBT		x
Ua-45178	8593	46	Telemark	Hazel nutshell	Prestemoen 1	CCPBT		x
UBA-29478	8379	66	Østfold	Hazel nutshell	Sandholmen	CCPBT		
Ua-51254	7735	41	Østfold	Burned bone	Sandholmen	CCPBT		
LuS-13365	8420	50	Østfold	Charcoal	Sarpsborg pukkverk	CCPBT		x
LuS-13366	8380	50	Østfold	Charcoal	Sarpsborg pukkverk	CCPBT		x
Beta-449376	8260	30	Østfold	Hazel nutshell	Sarpsborg pukkverk	CCPBT		x
TUa-7727	8385	50	Akershus	Charcoal	Strand	CCPBT		
TUa-7729	8300	55	Akershus	Charcoal	Strand	CCPBT		
TUa-7725	8170	65	Akershus	Charcoal	Strand	CCPBT		
TUa-7726	7795	50	Akershus	Charcoal	Strand	CCPBT		
Ua-45460	8583	48	Akershus	Charcoal	Svingen	CCPBT		
TRa-3406	8460	55	Vestfold	Hazel nutshell	Torstvet	CCPBT		

TRa-3407	8425	55	Vestfold	Hazel nutshell	Torstvet	CCPBT		
Ua-49212	7977	44	Akershus	Charcoal	Trolldalen FV152	CCPBT		x
Ua-49209	7876	53	Akershus	Nutshell	Trolldalen FV152	CCPBT		x
TUa-1549	7745	75	Akershus	Charcoal	Trosterud 1	CCPBT		x
TUa-1548	7435	75	Akershus	Charcoal	Trosterud 1	CCPBT		x
T-2134	8790	100	Østfold	Charcoal	Tørkop	CCPBT		
T-2194	8590	140	Østfold	Nutshell	Tørkop	CCPBT		

Table 2. Radiocarbon dated reference sites and technological features (HCT= handle core technology, CCPBT= conical core pressure blade technology). Radiocarbon dates are applied in figure 5 and 6 in the main text and Table 4 and 5 in the Supplementary information.

		Predicted Group Membership					Total (n)
e		Pressure	Indirect	Direct soft organic	Direct soft stone	Direct medium hard stone	
%	Rørmyr 1	1.6	8.1	12.9	12.9	64.5	62
	Rørmyr 2	1.9	15.2	22.8	20.3	39.9	158
	Mellommyr	0	10.1	23.2	56.5	10.1	69
	Pauler 1	0	0	17.9	64.3	17.9	56
	Pauler 2	26.8	16.3	13.0	26.8	17.1	123
	Pauler 6	8.1	8.1	8.1	38.4	37.2	86
	Pauler 7	0	0	22.2	48.1	29.6	27
	Bakke	3.2	18.0	8.5	16.8	53.5	316
	Solum 1	0.0	26.3	47.4	15.8	10.5	19
	Tinderholt 3	8.7	17.4	13.0	17.4	43.5	29
	Tinderholt 2	8.7	17.4	17.4	17.4	39.1	29
	Dørdal	9.1	0	9.1	18.2	63.6	11
	Skeid	9.7	3.2	9.7	9.7	67.7	31
	Darbu	19.1	27.9	41.2	4.4	7.4	68
	Anvik	10.6	43.3	10.6	7.7	27.9	104
	Hydal 3	43.6	9.1	1.8	1.8	43.6	55
	Hydal 4	25.0	12.5	12.5	0	50.0	8
	Hovland 2	35.7	40.0	5.7	4.3	14.3	70
	Hydal 8	44.4	11.1	0	5.6	38.9	18
	Nedre Hobekk 3	50.0	50.0	-	-	-	8
	Ragnhildrød	51.4	32.4	2.7	8.1	5.4	37
	Bjørkeli	25.0	43.1	12.5	4.2	15.3	72
	Tørkop	16.2	45.9	8.6	4.5	24.8	266
	Hegna vest 2	56.3	18.8	0	6.3	18.8	32
	Hegna vest 1	51.4	5.9	6.3	5.0	31.5	222
	Hegna Øst 6	22.2	22.2	11.1	11.1	33.3	9
	Hovland 5	38.6	37.1	11.4	2.9	10.0	70
	Hovland 4	38.9	40.0	4.4	3.9	12.8	180
	Rødbøl 54	13.3	81.4	0.0	4.4	0.9	113

	Vinterbro 12	44.2	23.3	14.0	11.6	7.0	43
	Vinterbro 9	43.2	29.5	4.5	20.5	2.3	44
	Hegna Øst 5	38.2	10.9	3.6	1.8	45.5	55
	Hegna Øst 7	26.8	10.7	3.6	3.6	55.4	56
	Stokke/Polland 3	51.7	5.2	0	3.4	39.7	58
	Stokke/Polland 8	44.7	4.3	0	6.4	44.7	47
	Hegna Øst 4	16.7	8.3	0	8.3	66.7	12
	Hegna Øst 2	45.2	7.1	2.4	2.4	45.2	42
	Stokke/Polland 9	60.0	4.0	4.0	8.0	24.0	25
	Stokke/Polland 5	45.1	8.5	2.4	2.4	41.5	82

Table 3. Classification table showing the DFA prediction of knapping technique membership for blades from archaeological sites. Predictor variables were regularity, interior platform angle, lip formation, bulb morphology, bulbar scar, conus formation and butt morphology. Highest predicted group for each assemblage is highlighted in red bold, in order to illustrate chronological differences. In the DFA prediction of knapping technique membership for experimentally produced blades 56.5% of original grouped cases and 54.5% of cross-validated grouped cases were correctly classified (Damlien 2015).

	Modelled (BP)						Indices
							Amodel 91.6
							Aoverall 97.9"
	from	to	%	from	to	%	C
Phase							
Boundary Start Conical cores	9870	9750	68.2	9940	9715	95.4	95.3
Boundary End Conical cores	7705	7640	68.2	7740	7590	95.4	98.5
Boundary Start Handle cores	7545	7460	68.2	7605	7440	95.4	97.4
Boundary End Handle cores	5925	5830	68.2	5985	5770	95.4	98.5

Table 4: Posterior probability densities for the start and end of the pressure blade and handle core technologies.

Name	Modelled (BP)						Indices
							Amodel 95.3
							Aoverall 95.6"
	from	to	%	from	to	%	C
Phase							
Boundary Start Pecked adzes	9805	9695	68.2	9890	9650	95.4	98.5
Boundary End Pecked adzes	7700	7625	68.2	7730	7575	95.4	98.2
Boundary Start Nøstvet adzes	7545	7450	68.2	7630	7430	95.4	98.9
Boundary End Nøstvet adzes	6165	6020	68.2	6180	5890	95.4	97.7

Table 5: Posterior probability densities for the start and end of the ground pecked adze and Nøstvet adze tradition.

OxCal code for modelled radiocarbon dates in figure 5

```
Plot()
 {
 Phase()
 {
  Sequence()
  {
   Boundary("Start PBT");
   Phase("PBT")
   {
    R_Date("UBA-28736", 7439, 39);
    R_Date("UBA-28735", 7374, 45);
    R_Date("UBA-28734", 7285, 37);
    R_Date("Ua-48383", 7090, 35);
    R_Date("UBA-28279", 6948, 35);
    R_Date("UBA-28732", 6873, 43);
    R_Date("Ua-48381", 6850, 35);
    R_Date("UBA-28740", 7067, 37);
    R_Date("LuS-11115", 7060, 45);
    R_Date("UBA-28743", 7057, 38);
    R_Date("UBA-28744", 7032, 34);
    R_Date("UBA-28737", 6943, 44);
    R_Date("UBA-28745", 6920, 37);
    R_Date("UBA-28742", 6886, 47);
    R_Date("Ua-55053", 8303, 39);
    R_Date("Ua-55120", 8179, 44);
    R_Date("Ua-55052", 8001, 33);
    R_Date("Ua-55119", 7893, 37);
    R_Date("Ua-55055", 8306, 34);
    R_Date("Ua-55056", 8283, 38);
    R_Date("Ua-55121", 8202, 44);
    R_Date("Ua-55122", 7980, 43);
    R_Date("Ua-55058", 8321, 34);
    R_Date("Ua-55057", 8319, 35);
    R_Date("Ua-55123", 8181, 44);
    R_Date("Ua-55124", 8140, 44);
    R_Date("UBA-19158", 7210, 38);
    R_Date("UBA-19159", 6941, 36);
    R_Date("Ua-50485 ", 8788, 34);
    R_Date("Ua-51462", 8732, 40);
    R_Date("Ua-50497 ", 8708, 38);
    R_Date("Ua-45675", 8623, 50);
    R_Date("AAR-16884", 8582, 33);
    R_Date("TRa-3410", 8465, 55);
    R_Date("Ua-45507", 8609, 54);
    R_Date("Ua-45515", 8606, 50);
    R_Date("Ua-45509", 8594, 48);
    R_Date("Ua-45508", 8591, 50);
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    R_Date("Ua-45514", 8552, 50);
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    R_Date("Ua-45511", 8465, 48);
    R_Date("Ua-45506", 8458, 48);
    R_Date("Beta-325802", 8450, 40);
    R_Date("Ua-45516", 8428, 50);
    R_Date("Ua-45522", 8398, 49);
    R_Date("Ua-45520", 8387, 47);
    R_Date("Ua-45519", 8383, 47);
    R_Date("Ua-45503", 8376, 51);
    R_Date("Ua-45512", 8348, 47);
    R_Date("Ua-45518", 8291, 48);
    R_Date("Ua-45500", 8747, 64);
    R_Date("Ua-45499", 8630, 49);
    R_Date("Ua-45493", 8568, 51);
    R_Date("Ua-45494", 8526, 52);
    R_Date("Ua-45490", 8775, 52);
    R_Date("TUa-1547", 7437, 68);
    R_Date("Lus-13499", 7055, 45);
    R_Date("Lus-13500", 7040, 45);
    R_Date("TRa-4117", 8030, 55);
    R_Date("TRa-4118", 8005, 45);
    R_Date("TRa-4121", 7945, 45);
    R_Date("UA-52063", 8853, 43);
    R_Date("Ua-47916 ", 7970, 44);
    R_Date("Ua-45176", 8671, 45);
    R_Date("Ua-45177", 8620, 45);
    R_Date("Ua-45178", 8593, 46);
    R_Date("UBA-29478", 8379, 66);
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        R_Date("Ua-51254", 7735, 41);
        R_Date("LuS-13365", 8420, 50);
        R_Date("LuS-13366", 8380, 50);
        R_Date("Beta-449376", 8260, 30);
        R_Date("TUa-7727 ", 8385, 50);
        R_Date("TUa-7729 ", 8300, 55);
        R_Date("TUa-7725 ", 8170, 65);
        R_Date("TUa-7726 ", 7795, 50);
        R_Date("Ua-45460", 8583, 48);
        R_Date("TRa-3406", 8460, 55);
        R_Date("TRa-3407", 8425, 55);
        R_Date("Ua-49212", 7977, 44);
        R_Date("Ua-49209", 7876, 53);
        R_Date("TUa-1549", 7745, 75);
        R_Date("TUa-1548", 7435, 75);
        R_Date("T-2134", 8790, 100);
        R_Date("T-2194", 8590, 140);
      };
      Boundary("End PBT");
    };
    Sequence()
    {
      Boundary("Start HCT");
      Phase("HCT")
      {
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        R_Date("TUa-3275", 5660, 70);
        R_Date("TUa-3225", 5190, 75);
        R_Date("TUa-3980", 6574, 47);
        R_Date("TUa-894", 5389, 77);
        R_Date("TUa-893", 5329, 70);
        R_Date("T-8810", 6529, 135);
        R_Date("T-8803", 6427, 120);
        R_Date("T-8806", 5796, 89);
        R_Date("T-8816", 5511, 107);
        R_Date("TRa-2248", 5910, 50);
        R_Date("TRa-2246", 5400, 55);
        R_Date("TRa-2247", 5325, 50);
        R_Date("TRa-2249", 5325, 45);
        R_Date("TRa-2250", 5325, 50);
        R_Date("TRa-4126", 5095, 45);
        R_Date("TRa-2255", 5695, 50);
        R_Date("TRa-2254", 5645, 45);
        R_Date("Tua-4602", 6565, 45);
        R_Date("Ua-3667", 5950, 60);
        R_Date("Ua-3669", 5860, 75);
        R_Date("Ua-3668", 5505, 65);
        R_Date("Ua-48256", 6196, 40);
        R_Date("Ua-48258", 6177, 42);
        R_Date("Ua-48257", 6098, 40);
        R_Date("Ua-51480", 6215, 36);
        R_Date("TUa-4390", 5610, 40);
        R_Date("TUa-3845", 5530, 50);
        R_Date("TUa-3279", 6530, 70);
        R_Date("TUa-3922", 6505, 55);
        R_Date("TUa-3936", 6495, 40);
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        R_Date("TUa-3233", 6375, 75);
        R_Date("TUa-3935", 6365, 45);
        R_Date("TUa-3280", 6325, 75);
        R_Date("TUa-3234", 6250, 85);
        R_Date("TUa-3920", 6205, 50);
        R_Date("TUa-3921", 5270, 45);
        R_Date("Ua-45182", 5770, 35);
        R_Date("Ua-45181", 5748, 35);
        R_Date("Ua-45180", 5373, 34);
        R_Date("Ua-45169", 6489, 50);
        R_Date("Ua-45170", 6381, 37);
        R_Date("Ua-45172", 6197, 40);
        R_Date("Ua-45171", 6067, 41);
        R_Date("T-13139", 6145, 89);
        R_Date("T-13136", 5905, 105);
      };
      Boundary("End HCT");
    };
  };
};
```

OxCal code for modelled radiocarbon dates in figure 6

```
Plot()
 {
  Phase()
  {
   Sequence()
   {
    Boundary("Start Pecked adzes");
    Phase("Pecked adzes")
    {
     R_Date("Ua-50485 ", 8788, 34);
     R_Date("Ua-45490", 8775, 52);
     R_Date("Ua-51462", 8732, 40);
     R_Date("Ua-45176", 8671, 45);
     R_Date("Ua-45675", 8623, 50);
     R_Date("Ua-45177", 8620, 45);
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    Boundary("End Pecked adzes");
   };
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    Phase("Nøstvet adzes")
    {
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     R_Date("TUa-3225", 5190, 75);
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    };
   Boundary("End Nøstvet adzes");
  };
 };
};
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