Computational modelling of the coastal Mesolithic in south-eastern Norway

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Chapter 1

Introduction

One way to conceive of scientific inquiry is as a form of strategy by which we try to confront theoretical constructs with empirical observation, aimed at aligning our beliefs as reliably as possible with what is true (Godfrey-Smith 2003, 161). A lot remains to be unpacked from this sentence. However, for now it is enough to note that the empirical side of this equation is a critical point for archaeology, as the fragmented and uncertain nature of the archaeological record means that there will always be a multitude of possible explanations that could account for any observed empirical pattern. Reducing this number of candidate explanations is first and foremost dependent on data, which in the case of archaeology are scarce.

The goal of this study is to map and contrast empirical trends that have been deemed of importance for understanding past hunter-fisher-gatherer societies, drawing on the extensive material from the coastal Mesolithic of south-eastern Norway. Based on this, the project aims to culminate with the generation and presentation of some hypotheses concerning possible casual drivers behind the observed patterns. The project is thus first and foremost descriptive and exploratory. These inferential goals could perhaps be deemed unambitious by some. However, it is my belief that attempting to maintain a degree of inferential modesty is for the better of the discipline.

Establishing true explanations of a past social reality is at best exceedingly difficult, perhaps impossible, and must be the result of cumulative and recursive efforts from entire research communities over time—it is not achieved by individual researchers. Accepting this social and cumulative nature of archaeological inquiry means that one can adopt a strategy to try to make ones research as open and amenable to scrutiny, extension, criticism and alternative approaches as possible. While easier said than done, an attempt at adopting such a strategy is done here. Inferential stringency, on the other hand, can be argued to necessitate a degree of separation between exploratory and explanatory studies.

Focusing on the exploratory side here means that the goal is to identify empirical trends, while attempting to leave causation a largely unresolved question, and suggest as many possible competing explanations for their occurrence as possible. The reason for why this separation is of benefit is that this facilitates a freer exploration, transformation and combination of empirical patterns, as it reduces the risk of forcing the treatment of empirical patterns, consciously or not, towards a single end-goal. As multiple explanations can always account for any empirical pattern, performing the challenging task of arriving at multiple competing explanations that are equally likely should be perceived as a unreservedly positive result. A complete analytical distinction between exploratory and explanatory is likely not possible nor desirable to maintain in practice, but explicit attempts at remaining agnostic with regards to causation will likely force a better exploration of the available data.

As in many other areas of the world, the last few decades have seen a dramatic increase in the material generated by Norwegian archaeology. In terms of sheer number of sites and associated data, this is most marked for the coastal Stone Age material (e.g. Bergsvik et al. 2020; Damlien et al. 2021). Given that this increase in material is achieved on the back of public spending, it is arguably a disciplinary obligation to utilise this data for research purposes. While there are many possible arguments for why archaeology is worthwhile at all, some more vague than others, the economic burden of archaeological practice is clearly easier to justify if the data we generate also informs the research we do. However, getting even a basic overview of this now vast material necessitates the use of quantitative and computational methods designed to handle, describe, explore, present, summarise and infer from such quantities of data. Following some early optimism in the 60s and 70s, such methods have, until recently, seen sporadic and relatively limited application for research purposes in Norwegian archaeology.

Quantification offers standardisation and simplification, and by extension scalability and comparability. As with all disciplines concerned with the complexity of social life, whether past or present, archaeology also benefits from shifting perspectives that move between the nuance of particularities and the general trends illuminated by aggregated analysis. I would argue that the latter is at present still underdeveloped in Norwegian archaeology. With renewed and ongoing enthusiasm for such approaches, it is important that this is combined with a continually critical view of the answers these approaches can provide, and those which they cannot.

The great disciplinary benefit of archaeology, as compared to other disciplines concerned with the study of human societies, is by many argued to follow from the time depth it offers. Furthermore, while there are instances where the archaeological record allows what could be called glimpses into an ethnographic past of individual lives, the vast majority of the material we have access to is hampered by a degree of temporal uncertainty and lumping of events that necessitates a perspective that is developed to meet the nature and quality of the archaeological record on its own terms (Perreault 2019). Both fully utilising the archaeological material and playing to the strengths of the discipline is thus dependent on knowledge of the quality of the material available to us, while also being dependent on developing methodologies fit for treating the material given the empirical resolution it holds.

1.1 Aims and research questions

The overarching goal of this thesis is to contribute to answering the following:

i) What characterises the extent and quality of the archaeological record from Mesolithic Norway?
ii) What analytical implications, consequences for our disciplinary agenda, and potential for understanding the Norwegian Mesolithic does this hold?

The answer to these questions is a disciplinary-wide undertaking, and no single thesis can hope to answer these. However, to contribute to their elucidation, the thesis is centred on three more specific research questions derived from these overarching goals. The first of these can be viewed as largely instrumental in that it pertains to the degree and certainty with which we can fix the occurrence of our data on the calendar scale:

1) What chronological control do we have of the occupation of coastal Stone Age sites within the study area?

As (**vankilde?**) has put it: 'Chronology is the backbone of social'. Thus, following from an answer to this first question, the following two questions can be explored:

2) What general patterns characterises the lithic inventories of the sites over time?
3) How is the frequency of sites distributed across time?

These latter questions have more direct substantive implications, as their answer can be expected to be directly related to cultural developments. It should be noted that these are stated in an open and exploratory manner. What patterns are explored in the lithic assemblages and how any variation in the frequency of sites over time is interpreted in substantive terms are not done following some pre-defined framework but is rather approached in an inductive and exploratory manner.

1.2 Study area

What is termed the coastal Mesolithic here naturally didn't exist in isolation from inland regions. While the Mesolithic sites in Norway are concentrated to the coast (Bjerck 2008), the reason behind the geographical limiting of the study is mainly analytical. First, while Mesolithic data is available from wider region of south-eastern Norway, including inland areas, the last few decades have seen an virtual explosion of investigations in the coastal region between Horten municipality in the north east to Arendal in the south west. This has also been accompanied by geological studies to map the dramatic sea-level change that has impacted the Norwegian coast through the Holocene. The region thus represents an archaeologically well-sampled area where we also have good control of the trajectory of shoreline displacement. Furthermore, while the region holds high-quality archaeological data investigated and recorded using modern methods, legacy data, especially in the form of comparatively low-resolution and low-quality survey data, is also abundant. The region thus also offers an excellent case-study for exploring the implications of dealing with data of wildly varying quality.

Finally, methods and approaches developed for the coastal sites are not necessarily directly transferable to inland areas. This pertains most clearly to the concept of shoreline dating, which is based on dating sites with reference to their present altitude and the relative sea-level fall that characterises the region (see Paper 1). This offers a degree of large scale temporal control that is independent of the preservation of organic material for ^{14}C-dates that is unique to the coast.

1.3 The quality of the archaeological data

The first two papers of this thesis are mainly aimed at mapping and improving the quality of our temporal grasp on the archaeological record in coastal south-eastern Norway. The quality of the available data is fundamental for knowing what questions we can and cannot hope to answer about the past (Perreault 2019). Lower quality data will lead to averaging and smoothing, where for example a reduced temporal resolution can lead to chronological smearing that hides smaller scale oscillations and variability (Bailey 2007). The same principle extends to the dimensionality of the data, where loss will result in a reduction of variability and richness, for example in the composition of artefact assemblages. Loss and mixing are consequently more subtle effects than complete absence of data, which can be more easily recognised. Furthermore, effects such as loss, mixing of past events and analytical lumping will most likely not impact the quality of the data in a uniform way. Taphonomic loss is likely to be more severe the further back in time one moves (Surovell et al. 2009), and analytical bias following from disciplinary interests or what geographical areas have been subjected to archaeological investigation will also skew our impression of the past (Binford 1964). Mapping the spatial and temporal quality of the archaeological record is thus critical for knowing what past processes we would be able to discern, and by extension what explanations we can hope to reject and what questions we can hope to answer. ## Model-based archaeology Moving on from establishing a firmer grasp on the temporal dimension of the archaeological record in the two first papers, the final two papers of the thesis are more directly aimed at elucidating past cultural historical dimensions by tracking developments in empirical trends that have been linked to the understanding of past hunter-gatherer societies. This will be done within a framework of model-based archaeology. Models can be seen as partially independent representations of theory and data (Morgan and Morrison 1999). By being a concrete realisation of an abstract theory in which its claims and conditions holds true, the model allows for a transfer of the logic of the theory to the modelled data, and a subsequent evaluation and manipulation of the fit between the two. Models are thus both descriptive and analytical, and can be seen as mechanisms or mediators allowing for the coupling of the two dimensions (e.g. D. L. Clarke 2015[1972]; Kohler and van der Leeuw 2007; Lake 2015). The inferential modesty called for above follows from the defining characteristic that 'All models are wrong, but some are useful', as Box (1979, 202) famously put it.

Barton (2013) proposes a conscious and explicit modelling practice in archaeology for the same reasons. Traditionally, archaeological explanation is based on inductive and informal construction of narratives based on the inferential strategy of including as much data as possible and arriving at a single explanation that is perceived to be the best fit in a *post-hoc* manner. This is argued to have a tendency to result in explanatory complacency and high personal investment into the credibility of any given explanation. By embracing the explicit uncertainty and falsity that is a defining part of model-based approaches, this will therefore increase disciplinary progress, as it will lower the threshold for probing, adjusting and discarding one's own models.

1.4 The hunter-gatherer model and the coastal Mesolithic of south-eastern Norway

The concept of hunter-fisher-gatherers will function as a foundational model from which to derive empirical avenues to be explored, and to propose possible causal drivers behind any observed patterns (cf. Warren 2022, 29). An example of a source from where this will be derived is the seminal work *The Lifeways of Hunter-Gatherers: The Foraging Spectrum* (Kelly 2013). In the introduction of the book, Kelly (2013, 4) states that it is aimed at providing its readers with 'some knowledge of the variation that exist among foragers and some idea of what accounts for it'. Thus, while comprehensive in scope, Kelly (2013) is also very explicit in the limitations of his review and cautions against. The societal variation among more recent hunter-gatherer societies is immense, and as foraging has constituted the predominant life-way for humanity for as much as, the variation that can be expected among past hunter-gatherer societies is comparatively vast (Singh and Glowacki 2022). Consequently, this thesis attempts to balance insights from hunter-fisher-gatherer studies more widely with an open and exploratory perspective. While preconceptions of hunter-fisher-gatherer societies necessarily dictates some of the analytical avenues taken and influence the type of questions that are asked, the aim is to have idiosyncrasies of the archaeological record in the context of coastal south-eastern Norway dictate the conclusions that are reached.

Another challenge in determining what empirical trends are of interest and how these are to be understood follow from the explicitly coastal setting of the study. Historically, both work on world prehistory and ethnography has focused on terrestrial contexts (e.g. Bailey 2004; Yesner et al. 1980). This issue also extends to the methodological realm, where for example the use of Geographical Information Systems (GIS) in archaeology has predominantly been used in terrestrial contexts (see e.g. Conolly and Lake 2006). This is especially pertinent for the study of the coastal Mesolithic of Scandinavia, which is characterised by dramatic sea-level change throughout the period (e.g. Bjerck 2008; Astrup 2018). Out-of-the-box procedures are therefore often not directly applicable and have to be adjusted to meet the demands of a geologically dynamic coastal context.

1.5 Open research and reproducibility

In making the case for open sharing practices in archaeological research, Marwick (2017, 426) compares the principle of artefact provenancing with dissemination of raw data and methods that underlie a study. Without knowing the origin and find-context of an artefact, it's archaeological value is practically none. Comparatively, by openly sharing data and programming code that underlies a study, other researchers can assess the procedures that have led to the results. Apart from facilitating an evaluation of its reliability, this allows others to extend on the analysis and the employed data, to learn and reconstruct how methods are implemented, and to attempt to repeat all or parts of the analysis themselves. Open research is thus beneficial to archaeology as a cumulative research endeavour as it will both increase the frequency of model rejection and adjustment, by allowing others to explore their foundations and inner workings, and because it will increase the pace of method sharing, evaluation and adjustment.

This thesis has been written in its entirety using the R programming language (R Core Team 2021). Unlike for example mouse-driven computational analyses, this means that an unambiguous record of the entire analytical pipeline is recorded in the form of programming scripts, moving from the initial loading and cleaning of raw data, through to analysis, visualisation and final reporting of results. Given the large amount of analytical choices that have to made in the course of any analysis, this can never be adequately presented in prose. Furthermore, what a researcher believes they have done need not correspond with what they have actually done. The high-resolution analytical record that is the pro-

Table 1.1: Overview of repositories and preprints.

Text	Preprint	GitHub repository	OSF repository
Synopsis	NA	github.com/isakro/thesis	osf.io/h3jfd
Paper 1	osf.io/cqaps	github.com/isakro/exploring-assemblages-se-norway	osf.io/7f9su
Paper 2	osf.io/3x7ju	github.com/isakro/assessing.sealevel.dating	
Paper 3		github.com/isakro/shoredate	osf.io/ehjfc
Paper 4			

gramming script makes this entirely transparent. All data, programming code, figures and text used in this thesis is freely available in version-controlled online repositories on GitHub (https://github.com/isakro) and on persistent archiving services where the repository is provided a digital object identifier (DOI). A complete overview with links to the various online archives associated with the individual papers and this synopsis is provided in Table 1.1.

1.6 Overview of papers

1.6.1 Paper 1: *A simulation-based assessment of the relation between Stone Age sites and relative sea-level change along the Norwegian Skagerrak coast*

The first paper of the thesis offers an approach for integrating the various sources of uncertainty associated with reconstructing the relationship between ^{14}C-dated archaeological phenomena and past sea-level change. This is used to quantify the distance between Stone Age sites and the prehistoric shoreline within the study area. That coastal sites would have been located on or close to the prehistoric shoreline is a fundamental premise in Norwegian Stone Age archaeology. In combination with reconstructions of past shoreline displacement, this is frequently used to date the sites based on their altitude relative to the present day sea-level—a method known as shoreline dating. The findings of the paper largely reflect the development proposed in the literature, with a predominantly shorebound coastal settlement in the Mesolithic, followed by a few sites being located some distance from the shoreline at the transition to the Early Neolithic (c. 3900 BCE) and a more decisive shift with the Late Neolithic (c. 2400 BCE). The result of this analysis is used to propose a formalised method for shoreline dating sites older than the Late Neolithic. This takes into account uncertainty as related to the displacement of the shoreline and the likely distance between sites and the shoreline when they were occupied.

1.6.2 Paper 2: *shoredate: An R package for shoreline dating Stone Age sites on the coast of south-eastern Norway*

Based on the findings from the first paper, the second paper of the thesis is a presentation of the R package *shoredate*, which provides tools for performing and handling shoreline dates along the Norwegian Skagerrak coast. This is freely available for anyone to install from the Comprehensive R Archive Network (CRAN) https://cran.r-project.org/pacakge=shoredate. The paper itself is a brief presentation of the package, but the formal publication of software with the *Journal of Open Source Software* also involves a useful review process of the software itself. Having published the package and released it as open source software on CRAN means that the method for shoreline dating is now available for researchers and student to employ, and that underlying code is available for anyone to explore, evaluate, criticise or extend upon.

1.6.3 Paper 3: *Exploring the composition of lithic assemblages in Mesolithic south-eastern Norway*

The second part of the thesis is aimed more squarely on elucidating past cultural history, as opposed to the more instrumental focus of the first part on establishing tools for . The third paper of the thesis is an exploratory study aimed at identifying variability in the contents of a set of lithic assemblages. The main goals of the paper is to evaluate the typo-technological framework currently in use in Norwegian Mesolithic research, and to assess the temporal development for variables that have been linked to variation in land-use and mobility patterns. It is demonstrated that elements of the so-called Whole Assemblage Behavioural Indicators (WABI, e.g. Clark and Barton 2017) align with previous research into developments of mobility patterns in Mesolithic Norway, suggesting that the WABI could be a relevant framework also in this context. This is specifically reflected in a negative relationship between density of lithics, and the proportion of secondarily worked lithics in the assemblages over time, which is taken to reflect a transition from a more curated towards a expedient technological organisation with the transition from the Early Mesolithic (c. 8200 BCE). This is in turn argued to follow from a shift in land-use patterns and a overall reduction in mobility.

1.6.4 Paper 4: *Comparing summed probability distributions of shoreline- and radiocarbon dates on the Norwegian Skagerrak coast*

Unpacking the complex interplay between environmental conditions, settlement patterns and population density has been deemed of fundamental importance to archaeological inquiry (e.g. S. Shennan 2000; French 2016). The fourth and final paper of the thesis is aimed at combining findings from the previous papers to evaluate the interplay between some empirical indicators suggested in the literature to be related to these dimensions. Concretely, the paper aims at elucidating the relationship between variation in relative population size as potentially reflected in the density of shoreline dated sites over time and the radiocarbon record.

The use of 'inductive' in the title of the paper is meant to underscore the exploratory nature of the approach taken. While it is possible to have some expectations as to what patterns might emerge based on previous research, there is not enough grounds on which claim that any hypothesis is being 'tested' in any real way. That is, if the patterns do not seem to correspond to these expectations, these are not specified enough for there to be grounds on which to pre-emptively say that anything will necessarily be disproved based on such a mismatch. In other words, the paper will most decidedly provide so-called *post-hoc* accommodative explanations of data after it has been collated and analysed (Clark 2009, 29).

Chapter 2

The Norwegian Mesolithic

This chapter presents the context of the study

2.1 Environmental setting

The environmental setting for the Mesolithic in Scandinavia is first and foremost defined by the end of the Weichselian and the retreat of the Fennoscandian Ice Sheet (see **skar2018?**; **skar2022:106?**). Most pronounced of the resulting environmental impacts is the melting of the ice sheet itself, corresponding eustatic sea-level change and isostatic rebound, changes in the ocean currents, as well as the developments of the Baltic Sea, which transitioned between being open and closed off from the North Sea. These developments form a backdrop to which human societies developed.

The global climate reconstructions based on oxygen isotopes from the Greenland ice cores gradual heating interspersed with cold events c. 10 300 cal BP, c. 9200 cal BP and 8200 cal BP. However, how these events played out locally and what consequences this development had for local ecosystems and human populations appears to vary quite dramatically across Northern Europe and thus cannot be assumed a priori to have been of relevance or concern for the societies dealt with in this thesis.

2.1.1 Climactic oscilations

Regional increase in temperature and perticipation rates from the early Preboreal, followed by mild winters and humid conditions in the Boreal with the Holocene Thermal Maximum, locally dated to c. 6400–2400 BCE.

At the transition to the Boreal, the vegetation in the region goes from arctic vegetation characterised by to

2.1.2 Sea-level change

Following the retreat of the ice

Depending on the scale of, sea-level change can impact not only the habitational suitability of any individual location, but can have far-reaching effects that impact shoreline morphology, drainage systems and (e.g. Groß et al. 2018; Astrup 2018). While the at times dramatic magnitude of these changes would have required a response from human populations inhabiting the impacted areas, it is by no means given that these would have negative consequences for these societies. In fact, areas impacted by sea-level change can be attractive for hunting, fishing and gathering precisely because of these factors. The study of human response to sea-level change should therefore not assume that this would be the result of. How sea-level change impacts the population of any given area will thus depend on a wide range of factors pertaining to the amplitude of shoreline displacement, the topographic setting, and the nature of the societal systems which respond to these changes.

2.2 Archaeological background

Having presented the environmental developments of the period, the following section gives a general outline of how chronological and societal developments in the Mesolithic have been characterised and understood archaeologically. The first focused research on the Norwegian Mesolithic is ascribed (**hansen1904?**), who studied the material that (**brøgger1905?**) later saw as a defining element of the Nøstvet culture (Bjerck 2008, 61). In 1909, Nummedal made discoveries of flint artefacts in western Norway that were deemed likely to have an earlier date than the Nøstvet material (**rygh1911?**; **nummedal1912?**), and which led to the subsequent definition of another cultural unit termed Fosna (**nummedal1924?**). Nummedal later also discovered material in northern Norway that had parallels with, but was considered distinct from Fosna and which was given the label Komsa (**nummedal1927?**). While the geographical and temporal relationship between these cultural units were recognised as unresolved and was subject to much debate, the common understanding was for many decades that southern Norway was defined by the chronologically sequential phases Fosna and Nøstvet, while Komsa was seen as defining of the entire Mesolithic period in northern Norway (see e.g. **indrelid?**). With renewed debates in the 1970s, debates that were arguably founded on a better understanding of lithic technology than much of the preceding discussions (**bjerck1996?**), significant . Mikkelsen (1975) suggested a tripartie division of the Mesolithic in south-eastern Norway by dividing the period into the Early, Middle and Late Mesolithic. This was in turn also subdivided

The traditional chronological framework for the Mesolithic of south-eastern Norway has followed along the general lines of that presented by Glørstad (2010, 23, see table). Recently this has been. The degree to which the chronological shifts are. While they form a natural frame for the narrative structure of this text, these should not been seen as the impact of strict periodisation is to some extent counteracted by treating. This will be treated in more detail in the next chapter

In a comprehensive reassessment that also includes results from the last decades of excavations, (**reitan2022?**) has recently suggested a new chronological framework for the Mesolithic period in south-eastern Norway (also **reitan2016?**). As his focus has mainly been on technological and typo-chronologcal developments, and given their recent date of publication, this chronological framework has yet to be comprehensively evualuated in terms of correspondence with other societal developments. The presentation of major chronological trends in the sections below thus follows the traditional periodisation. However, in the discussion chapter, the results of this thesis will also be seen in relation to the framwework suggested by Reitan.

The following sections will outline general societal developments believed to characterise the Norwegian Mesolithic, divided into the periods Early Mesolithic (EM; 9300–8300 BCE), Middle Mesolithic (MM;) and Late Mesolithc (LM; . While focus is on south-eastern Norway, reference to a wider context and neighbouring regions in Norway and Sweden when perspectives

2.2.1 The Early Mesolithic (9300–8300 BCE)

The first human presence in Norway is recorded from around 9300 BCE, which marks the start of the EM. A central discussion has concerned whether people first migrated into the area of present-day Norway from a route along the coast of western Sweden, from the north-east along the northern-Norwegian coast (**bjørn1929?**), or across the Norwegian trench to south-western Norway from the the North Sea Plain (Doggerbank, **odner1966?**). The most recent evidence suggest that a crossing from Doggerbank would not have been feasible due to the distances involved at the time (Glørstad 2016; Glørstad, Gundersen, and Kvalø 2017). The present consensus is therefore that the earliest human dispersal into present-day Norway is likely to have originated on the coast of western Sweden around 9500–9300 BCE (e.g. Glørstad et al. 2020; Bjerck 2008). From here, human occupation is believed to have rapidly extended along most of the Norwegian coastline, while a north-eastern migration reached Kola and northern Norway some time before 9000 BCE (Manninen et al. 2021). These two routes are associated with the genetically defined 'western' hunter-gatherers that migrated from the south, and 'eastern' hunter-gatherers migrating from the north (**gunther2018?**), each identifiable also in terms of distinct material culture and technological traits (Manninen et al. 2021).

Pioneer sites in Norway and Western Sweden have traditionally been ascribed the archaeological cultures or techno-complexes Fosna and Hensbacka, respectively. Today these are seen as representing the same phenomena (e.g. Bjerck 2008, 75). Fosna/Hensbacka sites are to hold fairly homogeneous lithic inventories, and are held by many as having a common origin tracing back to South-Scandinavian and North-European Palaeolithic Ahrensburg groups (e.g. Bjerck (2008); Schmitt et al. (2009); Bang-Andersen (2012); Fuglestvedt (2012); (**riede2014?**), 564]. The analyses of artefact inventories, the presence of high-quality South-Scandinavian flint, and the chronological support of radiocarbon dates and shoreline dates have in sum led to the consensus on this continental connection (see Fischer 1996; Schmitt et al. 2006; Fuglestvedt (2007); Fuglestvedt (2009); Bang-Andersen (2012); Glørstad (2016)). The similarities has led Fuglestvedt (2012, 8) to propose that the terms Fosna/Hensbacka be abandoned altogether, in favour of Ahrensburg, as this would accentuate the continental elements that appear so defining for these pioneer sites. Although this has been met with varying degrees of enthusiasm (e.g. Åstveit 2014 with comments), particularly by those emphasising the strong marine orientation of the Fosna/Hensbacka, there has also been the occasional use of variations such as 'coastal Ahrensburg' to denote the Fosna/Hensbacka (Prøsch-Danielsen and Høgestøl (1995)). Following a recent analysis of lithic inventories from the transition from the Paleolithic to the Mesolithic in Northern Europe, and comparison with Fosna/Hensbacka sites in Norway and Sweden, Berg-Hansen (2017) has argued that the Fonsa/Hensbacka sites have a clear similarity with EM Maglemose sites in Denmark. While there are elements of this technology that point back to the Ahrensburg, there is also a clear break with the Paleolithic technology. She therefore argues that these societies should, as with the Maglemose, be considered Mesolithic and not a northern continuation of Palaeolithic life-ways. At any rate, these discussions do go to show that there is a clear affinity between the first human population on the Scandinavian Peninsula and continental hunter-gatherer groups.

To account for this apparent pan-regional homogeneity, a central question is by what process Norway and western Sweden were initially colonised (e.g. Bjerck 2009; Schmitt et al. 2009; Bang-Andersen 2012; Fuglestvedt 2012; Glørstad 2016; Berg-Hansen 2017). An important aspect in this regard is the fact that the coastal areas in western Sweden and Norway were largely ice-free early on, and must have been rich and desirable areas in terms of resources (**bjerck1996?**; **bjerck?**; Bang-Andersen 2012; **glorstad?**). Bjerck Bjerck (2017) has explained the fact that people did not start exploiting these regions until around 9300 BC with reference to less developed marine subsistence strategies among North-European hunter-gatherer groups. The coastal location of the majority of Fosna/Hensbacka sites will undoubtedly have necessitated extensive adjustment to marine environments, including by the use of boats. Following the delay induced by this, the hunting of seal, conceptually not that different from the hunting of large terrestrial mammals, might have spurred an increased development of boating technology, while at the same time lending itself to the continued use of a continental artefact inventory (**Bjerck?**; **bjerck2016?**). Proficient and effective use of boats might in turn have resulted in a relatively rapid colonisation of Fosna/Hensbacka areas, possibly as fast as over a period of only 200–300 years (Bjerck 1987a; Bang-Andersen 2012), providing a possible explanation for the homogeneous assemblages. These could reflect mobility of a kind not allowing for familiarisation with local resources for tool production, nor the development of distinct inventories adjusted to various geographical settings. The assemblages might therefore represent a sort of catch-all toolkit, suitable to meet the variable demands of a 'pioneer condition' (Bjerck 2017; see also Breivik and Callanan 2016). Furthermore, Berg-Hansen (2017, 232) has argued that the homogeneity in the lithic inventories could be related to relatively high population numbers with closely knit social ties, which in combination has enabled this technological conservatism. Homogeneity and continuity in lithic technology over vast expanses of Scandinavia would be difficult to envision with a thinly spread population consisting of more isolated groups.

In general, the Early Mesolithic in Norway is understood as consisting of highly mobile groups (**bjerck1996?**; Bjerck 2008; Fuglestvedt 2012). As there is little organic material on which to base inferences on subsistence, there is little direct evidence to go on when attempting to determine what available resources made up the diet of people in Norway in the first centuries of human occupation. The EM sites are mainly found along the coast, and so there is little doubt that aquatic resources have played an important role (Bjerck 2008; Bang-Andersen 2012; Fuglestvedt 2014). It can, however, not be excluded that land mammals, and various species of fowl and flora have also been important constituents of the diet (Åstveit 2014; Fuglestvedt 2014). While the settlement is focused on the coast, there is also a marked presence in the mountain regions of south- and north-western Norway from a very early stage (Hagen 1963; Bang-Andersen 2012), which are believed to have been related to the hunting of reindeer. Given the, an analysis settlement patterns has been argued to provide a possible way to make general inferences to subistence.

The coastal EM sites have been characterised as typically situated on small islands and been exposed to

As a counterpoint, in a recent study I found that the settlement patterns in a subregion of south-eastern Norway was fairly similar across the EM, MM and LM (Roalkvam 2020). Of the considered variables, the most important driver of settlement patterns was found to be degree of exposure, where the sites were found to be located with relatively open immediate surroundings while at the same time being sheltered from larger expanses of open sea. However, one of the locational patterns that was not considered was the location of the sites within the wider landscape. The term exposure has been used to denote both how commanding the view would have been from the sites and how exposed the sites would have been to wind and wave-action (**svendsen2014?**), but has also pertained to their location relative to deeper fjords and outermost coast. It has been argued that EM sites would have mainly been located on the outer coast, and that the fjords were not utilised until a later stage. This is argued to reflect a focus on the hunting of marine mammals, especially seal, in the EM.

Coupled to this discussion is also what motivated the initial human dispersion into these territories.

The blade technology of the Early Mesolithic is based on single- and dual-platform one-sided cores, typically by means of direct percussion (Solheim 2020).

Some central discussion that linger in the literature concerned with the period pertains to the nature of the first colonisation of Norway. Did the coastal areas represent an unprecedented opportunity in an extended Garden of Eden, or an obstacle to be overcome. Furthermore, discussions pertaining to the degree of mobility and unified nature of lithic assemblages

2.2.2 The Middle Mesolithic (8300–5600 BCE)

While the Middle Mesolithic (MM) was defined as a separate typo-chronological phase in the 1970s, Bjerck stated as late as 2008 that the period was associated with a limited archaeological material, thus posing an analytical challenge (Bjerck 2008, 92–98). This is in part related to sea-level transgressions in this period along the coast of southern and western Norway, and the fact that MM sites are located at elevations that are typically not impacted by . However, investigations in recent years have dramatically changed this picture, not least in south-eastern Norway, which has not been subject sea-level transgressions. The excavaton of sites such as Rødbøl 54 in and Anvik in marks the start of this, with prpjects such as E18 Bommestad-Sky, Vestfoldbaneprosjektet and

(**bjerkc2008?**), notes that period is characterised by a degree of regionalisation that is not evident in the EM material.

In the Middle Mesolithic blades are produced from conical and sub-conical cores with a single platform using pressure and indirect percussion (**damlien2016?**; Solheim 2020).

2.2.3 The Late Mesolithic (5600–3900 BCE)

Blade production in the Late Mesolithic is characterised by the introduction of handle cores (**eigeland2015?**). As pointed out by Solheim (2020, 4), this involves a shift from cores that will result in blades of gradually diminishing size as the core is exhausted in the EM and MM, to cores that result in blades of a uniform and comparatively small size (i.e. microblades).

Chapter 3

Analytical background

3.1 The quality of the archaeological record

3.2 Chronology, archaeological cultures and modifiable analytical units

The study area of this thesis, as situated firmly within south-eastern Norway, is for the most part believed to have followed the same unified trajectory in terms of overall cultural-historical developments and expressions of material culture through the Mesolithic. At least within the analytical detection limit that has characterised the field thus far. What has been of greater concern is the temporal transition between the occurrence of cultural taxonomic elements within the region. In Norwegian Mesolithic research more widely, however, the question of both regional variation in material culture and its timing has led to discussions of whether a concept known as 'chronozones' has any merit as a framework for systematising the archaeological material. While this is a concept that has remained marginal in archaeology as a whole, as it is mainly used by some practitioners in Norwegian Stone Age archaeology (e.g. Bjerck 2008; Nyland 2016), it is related to fundamental issues faced within archaeology in general.

The concept originates in a paper by Bjerck (1986), in which he attempts to tackle the distinction between the archaeologically defined cultures of Fosna and Nøstvet in Western Norway. Instead of an ever-continued nuancing of these terms as more variation and idiosyncrasies are encountered in the archaeological record, Bjerck (1986, 117–19) instead suggested a division of the Mesolithic period into a series of time intervals denoted chronozones, originally at a resolution of 500 years, which he argues could facilitate a Pan-Scandinavian framework for approaching the Mesolithic (Bjerck 2008, 72–73). The concept of chronozones is taken from geology, where the term is used to denote stratigraphic layers that formed over the same specific time-span on a regional or world-wide scale, known from geochronological terms such as. Bjerck's motivation for adapting this to archaeology is to form a framework that is neutral with respect to cultural variation across space and time. He argues that traditional archaeological units of analysis, typically denoted by terms such as cultures or techno-complexes that are discretely delineated in time and space, has led to an artificial partitioning of the archaeological material that is less open to gradual temporal change and spatial variation – an issue that has been recognised by many archaeologists through the years (e.g. **childe1956?**; Clark 2009; **reynolds2019?**). Bjerck argues that the use of neutral 500-year time-intervals will reduce the degree to which analyses will overemphasise homogeneity within, and exaggerate differences between such analytical units. To further illustrate the issues Bjerck attempted to tackle, it is useful with a detour via the concepts of the Modifiable Areal Unit Problem (MAUP), as taken from the field of geography (e.g. Harris 2006), and its recently coined temporal equivalent, the Modifiable Temporal Unit Problem (MTUP, Bevan and Crema (2021)).

Focusing first on the temporal dimension, Bevan and Crema (2021) have recently given a demonstration of how archaeological periodisation involving lumping and splitting of phenomena within disjoint time-intervals have analytical consequences that remain under-appreciated within archaeology. First, employing strict cut-offs between temporal units – units that often also vary in their duration – has major implications for comparison between these units, and can, as (**bjerck?**) also notes, lead to an artificial analytical overemphasis of the transition between these. Basic operations such as comparing counts will be skewed by variable duration of these units, and the position of breaks between them can be highly influential to the appearance of the frequency distribution of events over time.

Building on (**crema?**), Bevan and Crema (2021) also further define three types of uncertainty associated with this archaeological practice. The first is *phase-assignment uncertainty* – how certain can we be that a given phenomena can be ascribed to a given phase. The degree to which this varies between different material categories means that it can be difficult to compare their frequency across archaeological phases. As was found in the third paper for this thesis (Roalkvam 2022), the occurrence of formal tool types appears to be greater further back in time, as opposed to more generic debitage that can be more difficult to assign to a phase, which is more dominating in assemblages with a younger date. As formal tools can be more consistently ascribed a certain phase, this can have implications for how many sites are ascribed earlier periods. By extension, this could impact the comparison between phases. The second pertains to the *within-phase uncertainty*, the degree to which the occurrence of a various phenomena have an equal likelihood of occurrence throughout an archaeological phase. For example, it is typically assumed that the occurrence of the handle-core and the Nøstvet axe is uniform across the Nøstvet period. The final dimensions Bevan and Crema (2021) highlight is the *phase boundary* *uncertainty*, which pertains to the start and end points of the archaeological phases themselves. As these are typically defined by a complex interplay of multiple cultural phenomena, they are seldom meant to operate on the scale of individual years, but will in practice often be operationalised as such.

While possible methodological solutions are presented by Bevan and Crema (2021) and others, neither the MAUP nor the MTUP have any clear solutions, and the magnitude of their impact will depend on the given research question and accompanying analytical scale. However, their formulation arguably form a better frame for understanding these issues than the concept of chronozones. I believe chronozones can instead obfuscate the distinction between the temporal and the spatial scale, and that it can lead to a conflation of typology – understood in its widest possible sense – as a methodology for systematising archaeological material and its potential use as a dating method. As Bjerck (1987b) states, typology obviously has its place as both a culturally responsive framework in time and space. Chronozones, on the other hand, are supposed to make comparisons across typologically inferred boundaries in space and time tractable. In her comment to Bjerck's paper, Skar (1987, 35) notes that geological chronozones couple pan-regional stratigraphic layers with the calendar scale, but that there is no equivalent pan-regional archaeological phenomena that equally consistently correspond to a section of the calendar scale. As Bjerck (1987b, 40) further underscores in his response, archaeological chronozones are therefore not, unlike typological frameworks, meant to be culturally responsive, but are to represent a neutral temporal scale, typically instantiated as 500-year intervals. However, as Østmo (1987) and Mikkelsen (1987) note in their comments to Bjerck's original paper, this purpose is already fulfilled by the calendar scale. If the stratigraphic information related to a specific time-interval is removed from the geological chronozone, only 'chrono' remains. Similarly, if the archaeological chronozone is not meant to hold any culturally responsive component, only the time scale remains. As a culturally independent scale, the calendar scale will always be preferable to the that of chronozones. Not only because it is firmly established, but also because it already allows for more variation in the temporal resolution associated with different phenomena to be systematised, and allows for their duration or uncertainty of occurrence to span a wider range of aggregative time-units.

In replying to this critique, Bjerck (1987b, 40) states that questioning the need of chronozones when we already have the calendar is like asking 'Do we need the term "month" when we have numbered days?'. If one accept this then the question becomes if the terminology used with chronozones is better than simply stating what 500-year intervals we are dealing with. For example, Bjerck (2008) uses the term Middle Mesolithic (MM) to denote the three chronozones MM1, 8000–7500 BCE; MM2, 7500–7000 BCE; and MM3, 7000–6500 BCE. A reader coming across 'MM3' instead of '7000-6500 BCE' therefore has to keep in mind that this simply refers to this specific time-interval, and be aware that the term Middle Mesolithic should be disregarded, as it is in this use meant to be devoid of any cultural meaning. One could perhaps change terminology to something that doesn't have as many cultural and research historical connotations as the Middle Mesolithic, but this strikes me as altogether unnecessary exercise, solved by only referring to the calendar scale in the first place. If one wants to use a time-scale of 500-year intervals it would in my mind be better to simply define this independently of the now inflated discussion of chronozones, not least because I believe the discussions of the concept demonstrates that its use can lead to unnecessary confusion – if not for practitioners, then likely for readers.

In their comments to the original paper by Bjerck (1986), Østmo (1987) and Mikkelsen (1987) deem chronozones an unnecessary and complicating concept. Commenting on these critiques, Nyland (2016, 53–56) states that both of the authors make their comments in light of typological frameworks for Mesolithic south-eastern Norway, but that neither address the issue of the geographical coverage that these have. This is first and foremost an empirical issue rather than something to be solved by new terminology, and clearly not by the chronozone, which is a concept meant to be culturally unresponsive.

Drawing on an example given by Nyland (2016, 55); if the question is if central Norway falls within the same cultural sphere as south-eastern Norway, understood to be determined by comparable material culture, then this is dependent on two dimensions, assuming the problem of the initial delineation of these two regions has been resolved. The first is an evaluation of the degree to which characteristics of archaeological material in the two regions is considered to be similar, according some criteria. The second pertains to the timing of the occurrence of this material. To establish this necessarily demands temporal data that is independent of the typological framework itself, or possibly by reference to some principle of seriation with the uncertainty that this entails. If a set of artefact types occurs in both central Norway and south-eastern Norway, this could lead one to suggest that a similar kind of cultural expression is common to the two regions. If independent temporal data associated with this material, such as radiocarbon dates, additionally indicates that there is a temporal synchroneity between their occurrence, then this would lead one to conclude that this cultural expression appears to occur simultaneously – within some level of temporal certainty. Depending on the magnitude of artefactual and temporal evidence for this coincidence, this could then lead one to apply this typological framework as a dating method in the case that one excavates a site in either region and discover material of the type in question. A continuous adjustment and evaluation of the reliability of the identified cultural affinity and the derived typological dating frame will of course be necessary, but will have to be founded on material culture and the position of their occurrence on the calendar scale. This also pertains to the co-occurrence of various archaeological evidence and their wider cultural implications, for example whether or not some artefact type tends to be associated with agricultural activity. If either region lack artefactual or temporal data, then either the nature or the timing of cultural affinity cannot be resolved. The concept of chronozones cannot overcome these issues, and, I think, is more likely to confuse them.

In conclusion, I therefore agree with Østmo (1987) and Mikkelsen (1987) in that the concept of chronozones represents an unnecessary complication. Although some of these complications follow from misunderstandings of the original proposition (as pointed out by **bjerck?**), it nonetheless appears to sometimes lead to the muddling of several culturally taxonomic, spatial and temporal issues that are best handled by reference to already well-established terminology, and by the use of modern methods that allows for the formal definition and handling of fuzzy and uncertain categorisation in the aggregation of data, both on the scale of material culture, time and space (e.g. Crema 2012; Fusco and Runz 2020; Bevan and Crema 2021; C. Shennan Stephen and Kerig 2015). As a purely chronological reference frame, the calendar scale already allows us to aggregate data in 500-year intervals and reference these as such. The amount of ink now spent discussing chronozones also means that invoking the term carries with it the necessity to clarify how one intends to use it, which can be circumvented by avoiding the term altogether. Furthermore, as a term suggested for use in Pan-Scandinavian Mesolithic research, I believe this idiosyncratic terminology will also unnecessarily divorce the field from discussions of the same issues within archaeology more widely, while also making the field less accessible to outsiders, more difficult to couple with adjacent disciplines, and possibly lead to confusion with the geological chronozone. It is therefore unclear what the concept now provides beyond what well-established archaeological and colloquial terminology already covers, perhaps apart from making us aware of these universal archaeological issues.

Rather than being based on predefined discrete time intervals beyond the calendar scale, the analyses undertaken in the papers for this thesis largely rely on absolute dates from radiocarbon- and shoreline dates. These provide continuous longitudinal time-series data, with associated uncertainty. However, it is important to underscore that given the scarcity of radiocarbon dates, and the relative low resolution of shoreline dates, typological frameworks responsive to variation in material culture can most decidedly offer valuable chronological insights, even though this is not directly integrated in the studies undertaken here. Furthermore, while the analyses are done with dating methods that largely operate irrespective of archaeological periodisation, the results are frequently narratively and informally associated with general cultural developments believed to characterise the Stone Age of south-eastern Norway, as roughly outlined in Chapter 2. This is predominately done in an approximate manner with reference to what are best viewed as temporally and spatially fuzzy frameworks, and is based on the underlying logic that frequent co-occurrence of a range of material expressions in time and space, as suggested by others, reflects some level of meaningful cultural cohesion. This also means that the term culture is used in a loose archaeological sense and is not presumed to equate to a people or a unified unit in terms of language, genetics, or social structures (see e.g. **robert2011?** for a thorough discussion of the culture term as used in archaeology). While it appears reasonable to assume that such cohesion has largely resulted from the same cultural or environmental factors within the geographically limited area of south-eastern Norway, it is also worth noting that empirical correspondence can be driven by other factors. This includes cases where people have arrived at the same technology in disjoint regions of time and space, known as convergence, as well as cases where a range of different cultural or environmental conditions have seemingly resulted in the same technological expression (which for example has been argued to be the case with slotted bone tool technology in Northern Europe, Manninen et al. 2021).

3.3 Hunter-fisher-gatherers

As representing adaptation to diverse environments, marine habitats are deemed an essential component in the evolution of modern humans and determining for the spread of the species across the globe. In Palaeolithic archaeology the coast has traditionally been seen as a hostile environment for early hominins. Marine habitats and resource-use has also been characterised as a central for the evolution and

A note should be made on the fact that in the literature the terms *coastal adaptation* and *coastal resource use* are sometimes taken to imply different and quite specific things (see e.g. Faulkner et al. 2021; Marean 2014; Will, Kandel, and Conard 2019). Coastal resource use is in this understanding seen as something that is conducted sporadically or occasionally, and will have limited transformative feedback effects on the life-ways of the societies in question. Conversely, coastal adaptation involves a degree of coastal engagement and commitment that has an altering effect on these societies. I do not use the terms in this manner here. The conceptual distinction is certainly an important one, especially as marine exploitation is believed to potentially, but not necessarily (e.g. **erlandson2001?**), lead to technological ratcheting and increased societal complexity. However, these quite specific connotations of the terms stand in danger of leading to misunderstandings for readers that have another understanding of adaptation, which need not be defined by some threshold in the intensity of coastal engagement. One response to the specifics of a given marine habitat might for example be movement and extended use of terrestrial resources, which would fall within a more inclusive definition of adaptation to a given coastal environment. While the above division might have merit in some analytical settings, the dependence on marine resources is arguably better understood along a continuum that I believe this might unnecessarily dichotomise.

Hunter-gatherers or foragers are useful but fuzzy and not unproblematic synonyms that are typically, but not exclusively, used to denote societies that have a subsistence-base that is for the most part not based on agricultural produce.

Some expectations can be made on the bassi

3.4 Palaeodemography

Palaeodemography or the study of temporal and spatial variation in the size and structure of past populations is a fundamental problem for archaeology (e.g. **shennan2001?**; French et al. 2021). This follows from the fact that demography is a determining factor in processes such as genetic diversification, social network structure and scaling, technological innovation and accumulation, as well as. As human culture is in large part determined by human interaction,

One Known as the forager paradox. (French et al. 2021, 4) One of the implications of these findings is that the interpretation of archaeological proxies for population size is not as straightforward as one might immediately think. This in turn, needs to be kept in mind both when devising and comparing multiple population proxies, and in the construction of the narrative that builds on any numerical results.

Demographic modelling in early Holocene Fennoscandia has taken on a few different. In most recent years this is the SPD approach (Solheim and Persson 2018; Solheim 2020; **nielsen20?**; Jørgensen, Pesonen, and Tallavaara 2020). The SPD approach is based on summing the probability distribution associated with ^{14}C-dates. However, there are a series of methodological and conceptual issues with this procedure, some of which have been dealt with and others which are integrated into the methodology and needs to be accounted for when interpreting any results.

Chapter 4

Model-based archaeology

Over the years, several works have purported the benefits of a model-based archaeology (D. L. Clarke 2015[1972]; Wylie 2002, 91–96), which has especially gained a footing within the sub-field of computational archaeology (e.g. Kohler and van der Leeuw 2007; Lake 2015; Romanwoska 2015; **brughmans2021?**). The goal of the next two chapters is twofold. First to elucidate what defines or can define a model-based scientific approach, and in the next chapter to demonstrate how this can form a useful framework for archaeological inquiry by drawing on examples from the papers of this thesis. Central to the following sections are four problem areas in the understanding scientific models, as identified by Frigg and Hartmann (2018, 1): 1) The ontological: what are models? 2) The semantic: what do models represent? 3) The epistemological: how do we learn with models? And 4) what consequences do the use of models have for overarching principles such as scientific realism, reductionism and explanation?

One fairly common understanding of models simply entail seeing them as a set of simplifications or assumptions concerning real-world phenomena (e.g. Barton 2013, 154). Any representation could thus be considered a model whether it is generated physically, digitally, verbally, simply imagined, or is construed in a natural or formal language. Scholars arguing the case for model-based archaeology often start out by making the point that whether we acknowledge it or not, we always employ such abstractions when attempting to understand past reality (Kohler and van der Leeuw 2007, 4; Lake 2015, 7). The infinite complexity of reality means that any description of it has to be a simplification, and even if we were able to, a complete rendition of reality would not be a worthwhile endeavour in its own right. A perfect reconstruction of reality would be a tautology, which without perspective offers neither insight nor understanding (Yarrow 2006, 77). Put differently, whether we understand archaeology as tasked with providing explanation, understanding, or interesting narratives about the past, any demand for a higher empirical resolution, for its own sake, would be a refutation of theory (see Healy 2017). These are, however, universal scientific points, variations of which have been made under diverse headings of archaeological theory (e.g. **johnson2010?**). It would thus follow that if the term model is taken to denote all generalisations or abstractions of reality, which in its ubiquity would include any description or explanation, it is not given why this would have to be dealt with within a comprehensive model-based archaeology. The arguments in favour of a distinct model-based archaeology tend to follow from *how* this necessary simplification should be made, and in turn handled. What this entails can be foreshadowed here by invoking the classic quote from Box (1979, 2): 'All models are wrong but some are useful'. But if all models are wrong, what is their epistemic value? To begin to answer this question, the above view of models, simply seeing them as abstractions, will be accepted for now without regard for their demarcation to data, theory and hypotheses.

4.1 Confronting beliefs with data

The explicit testing of archaeological explanations was assertively introduced to the discipline with processualism, which argued that archaeology should adopt the explanatory goals of positivist social sciences. How this was to be done first follows from the standard processual view on what the archaeological material represents. Here, material culture was seen as an integrated part of – and the result of – total, multidimensional cultural systems (e.g. Binford 1962). As such, theories concerning how all aspects of cultural systems would influence and manifest in the material record should be conceived. Central to this is that the archaeological material represents an objective, albeit complex empirical record that reflects empirical causes, irrespective of our beliefs about what these causes are. The empirical material will in this processual understanding therefore offer a direct link back to this systemic whole. Archaeological material is therefore representative of the multidimensional causal chain from cultural system to the archaeological record. Theories concerning the prehistoric systemic whole and what processes have influenced the remnants available to us must therefore come prior to an archaeological investigation for it to be possible to evaluate their veracity. As complex integrated wholes, such models of entire systems were then to be tested by drawing on the hypothetico-deductive approach. Furthermore, drawing on the covering-law framework as taken from Hempel's logical positivism/empiricism, the ultimate goal was to establish laws pertaining to the conjunct occurrence of certain types of material remains with certain types of societal systems, irrespective of time and place.

It should be noted here that the programme of logical positivism, and the more mature logical empiricism, were far more nuanced that what they are typically given credit for in the archaeological literature concerned with establishing why these views were misguided (see **gibbon1989?**). This is equally true for the over-simplifying presentation that is given here. However, this can in part be justified with reference to the naive versions of these programmes that were adopted by positivist social science and archaeology at the time.

According to Hempel, the goal of science is to establish laws that are deductively valid, of the kind given by the classic example *All men are mortal / Socrates is a man / Therefore, Socrates is mortal*. If the premises are true, then the conclusion will always be true. However, when adapted to archaeology, the proposed laws were so banal that (**flannery1973?**) stated that the attempt at adopting Hempelian empiricism 'has produced some of the worst archaeology on record'. The search for covering laws was therefore quickly abandoned by most practitioners. Furthermore, whether an argument is deductively valid or not is not dependent on whether or not the premises are true. If it happens to be true that all men are mortal and Socrates is a man, then the deductively valid argument is said to be sound. However, determining whether the premises are true depends on non-deductive reasoning. A deductively derived test that successfully corresponds with data only supports the hypothesis inductively (Chapman and Wylie 2016, 27). Giving up on the search for covering laws and deductive certainty need not entail that hypothetico-deductive testing is misguided, and more modest goals of confronting beliefs pertaining to specific contexts or research questions with data is, I will argue, still very much a viable goal.

Smith (2015, 2017) has stated that one of the most central questions we can ask about our archaeological explanations is 'How would you know if you are wrong?'. Archaeological explanation often take the form of what Binford (1981) termed a *post hoc* accommodative argument. This involves first gathering and categorising the data of interest, often using variables chosen by convention and convenience, and then building an explanation around any discerned patterns (Clark 2009, 29). This inductive data-dredging or pattern-searching approach is argued to constitute a limited inferential framework for a couple of reasons. First, what among the virtually infinite aspects of the material available to us is considered interesting will always be determined by our beliefs concerning the processes that have resulted in their manifestation. What characteristics of the material is recorded and drawn on to organise it will dictate what patterns one can hope to reveal. As philosopher Popper (1989, 46) framed it, without an underlying theory, how would we know what to look for? If one follows what has been done conventionally, without taking any explicit stance towards this, one will be dependent on how others have conceived of what questions are of interest and how these can be answered. Furthermore, at no point in this process is *Post hoc* accommodative arguments can provide the identification of empirical patterns with respects to the employed units of analysis, which in turn can form the basis for social and behavioural hypotheses. However, Binford (1981, 85) has argued that such arguments can at best be 'treated as provocative ideas in need of evaluation'. Clark (2009, 29) states that a necessary next step is to derive empirical implications of this hypothesis, which can be evaluated against a part of the archaeological record that is independent from the material originally used to derive it (also Barton 2013). Subsequent testing thereby provides an opportunity to reveal if one's accommodative belief is wrong.

Within a classic hypothetico-deductive system, an initial goal is to derive as many empirical implications of an explanation as possible. These implications are then to be tested by comparing these implications to actual observed data. Drawing on Carnap's (1936, 425) 'gradually increasing confirmation', this entails that each time a model matches the data, the confidence that the model is true is increased. If, on the other hand, the model fails, it can be discarded as untrue. This should thus lead to the continual rejection of false models, and move us ever closer to, but not necessarily to, the actual model of reality. Although certainly an enticing prospect, there are problems related to this approach, irrespective of any goals of establishing covering laws.

A fundamental issue for hypothetico-deductivism, and scientific inference as a whole, follows from Hume's problem of induction (e.g. Ladyman 2002, 31–61). As an empiricist, all knowledge about the world was for Hume derived from sensory perception. Any reasoning that extend beyond observation, past or present, is based on cause and effect. However, since we can never observe a causal connection between events, the conjoined occurrence of observations is all we have to draw on. As there is no logical necessity for regularity in patterns to hold beyond what we can observe, there is no logical foundation for inductive reasoning – there is no logical connection between the observable and unobservable. While we might observe the sun rise every day, there is no logical contradiction in believing it will not rise tomorrow. Hume held that while inductive reasoning will continue to be fundamental to science, and our every-day lives, it has no logical justification. Following from the problem of induction, an issue for hypothetico-deductivism therefore pertains to the value of testing an hypothesis, and whether with successful tests our belief in the hypothesis should increase.

The logical empiricist attempts at working around the problem of induction and establishing a logical justification for confirmation was never successful, and a move to stating our beliefs in probabilistic terms never dissolved this fundamental issue. Central here is what is known as the paradoxes of confirmation (e.g. Sprenger 2023), of which Hempel's own raven paradox is a classic example. If the hypothesis is that all ravens are black, this is logically equivalent to the statement that if something is not black it is not a raven. If we were to observe a black raven, this is clearly evidence in support of the hypothesis. The paradox follows from the second statement: Given their logical equivalence, the observation of a green apple would be evidence in support of the hypothesis. Paradoxically then, we can study ravens by looking at apples. While problems of confirmation such as this are simple, they have proven difficult to resolve and a solution is yet to be agreed upon (e.g. Godfrey-Smith 2003, 39–56).

One of the most influential contentions with the issue of testing is found with Popper and his concept of falsificationism. Popper, also a sceptic of induction, held that the problems of induction cannot be resolved. However, this is not of concern, as science in fact progresses not with confirmation but with falsification. In an attempt at demarcating science from non-science, Popper (e.g. Popper

1989, 33–66) stated that a theory can only be considered scientific if it has the potential to be refuted by observation. A theory that is compatible with all empirical variation is unscientific. The test of an hypothesis should be aimed at falsifying it, not confirming it, and an hypothesis that is not proven false should simply be subjected to even more stringent and elaborate tests. It is with each new rejection of an hypothesis that science progresses and we learn something about the world. Although it will inevitably be falsified, a good theory for Popper is therefore one that is bold, risky and corresponds with the world in surprising ways. There are, however, further issues related to the fundamental prospect of confronting our beliefs with data.

As insight from complex systems theory demonstrates, sensitivity to initial conditions can lead both different causes to produce similar empirical results, and similar causes to produce different empirical results (van der Leeuw 2004:121; Premo 2010). This reflects the problems of equifinality and underdetermination, as presented above, where several models can agree on the empirical data, but disagree on the underlying causal mechanisms. This follows from the ubiquity of measuring error and the sensitivity of complex systems to minute variation. One classic example in this regard is the complex system of the weather, which can only be reliably predicted a few days into the future. Human systems are far more complex than that of the weather. Consequently, this renders the prospects of empirical confirmation or falsifiability weakened, and preference among different, even contradictory explanations, can often not hope to be based on observable data. In the case of archaeology, explanatory models are additionally faced with our generalisations of an already sparse and fragmented archaeological record, further increasing the likelihood that several explanations account equally well for the data at hand. However, this sensitivity to initial conditions can also impact the assumptions underlying an explanation. To show how this is an issue we can draw on what is known as the Duhem problem (after **duhem1906?**), which states that nothing is necessarily learned from rejecting an hypothesis on the grounds of a test.

Drawing on (**hvidsten?**), we may postulate a simple model holding that mechanism A, under assumption B, implies C. If in a test we can reliably measure whether or not C is true, it would in a hypothetico-deductive understanding increase our belief in the model if C is true. In the case of Popper, the model is simply yet to be falsified. If, on the other hand, C is not true this would imply that either A or B are untrue. We would not, however, be able to derive logically which of A and B are untrue. This would perhaps not appear to be an immediate reason for concern. As long as one aspect of the model is untrue, the model is untrue, and should be rejected. The problem is that we know that models always contain a multitude of untrue assumptions. Drawing on the classic quote from Box above and the earlier discussion on abstraction, all models involve subsuming the virtual infinite complexity of reality and thus cannot work without an equal amount of untrue assumptions that could impact a test (a point made in the context of archaeology by Salmon 2009).

In exemplifying the Duhem problem, Ladyman (2002, 77–78) gives the example of testing Newtonian gravitational theory by observing the travel of a comet. The theory of gravity alone does not provide a prediction for this path. It also depends on factors such as the mass of the comet, the mass of other objects in the solar system, and their relative positions, velocities and initial positions, as well as Newton's other laws of motion. If the test was to fail, this failure can follow from an untrue hypothesis, but also from a misspecification of an assumption that is subsumed in the test – such as background conditions, measurement error, and initial conditions of the system. At some level a decision of whether the explanation has in fact been interfaced with observation is needed. As stated by Ladyman (2002, 80), 'falsification is only possible in science if there is intersubjective agreement among scientists about what is being tested.' While a severely complicating issue for falsificationism, as Popper also recognised, his proposition still holds if it is qualified by stating that for a hypothesis to be scientific, it has to have the potential to be refuted by some kind of observation – it has to risk exposure to observation (Godfrey-Smith 2003, 66). The challenge then is determining what kind of observations this is.

Drawing on this issue with testing and falsificationism, several authors have argued that these are not the factors that determine the progression of science. This is known as a naturalistic perspective on science, which is concerned with understanding by precisely what processes science has arrived at its current beliefs about the world. While attempts at establishing formalistic recipies for undertaking research can offer important insights on what can constitute good components of strategies for scientific inquiry, such as aspects of Poppers falsificiationism, the scientific undertaking has been argued to be a far more messy enterprise. For example, Galilei's work to establish the Copernican model of the solar system is widely held as a classic example of the success of science, and has often been used to illustrate the text-book understanding of the scientific method in which one moves from making an observation, establishing an hypothesis, testing it against data, and then rejecting or adjusting one's hypothesis before repeating the process. However, several historians of science have argued if this understanding was in fact how science was done, the erroneous Aristotelian model of the solar system should in fact have been preferred by Galileo, given the evidence at hand at the time. On the grounds of data alone there would be no reason for Galileo to have given any credence to the Copernican model, and due to seemingly contradictory evidence he should not have persisted in trying to prove this alternative explanation. Parallels can be found in archaeology. For example, when new dates that dramatically push back the earliest human occupation in the Americas have been presented over the recent years (e.g. **holen2017?**), these have often been met with scepticism as related to their veracity (**braje2017?**; **magnani2019?**). That an earlier occupation in the Americas than c. appear to thus far have been falsified does not mean that this hypothesis should be abandoned. Furthermore, how convincing an explanation is also clearly depends on more than data, not least because data is more than a simple binary category that is either observed/not observed. What data is accepted and what it is understood to represent is in part dependent on a decision by the person who observes and the wider research community. What we observe should to some degree dictate what we believe about the world. However, the examples above demonstrate that stringent empirical positivism is untenable and is not in fact how scientific insight is achieved.

4.2 Scientific realism

Arguments such as those above have in sum both rendered suspect the empirical positivist's absolute demand and adherence to observable data, and presents a significant challenge to the prospect of testing our beliefs about the world. Following from (**levins1966?**), a defining element of modern MBA is consequently the realisation that models cannot at the same time maximise generality, realism and precision, which means models cannot and will never be constructed or evaluated purely on the grounds of observable data (Kohler and van der Leeuw 2007, 7; Lake 2015, 26). However, if we were to concede to the fact that all models are wrong, how can we ever trust model-based inference?

In a classical instrumental understanding, the goal of science should be the prediction of phenomena that matter (e.g. **hausman1998?**), a view famously forwarded by (**friedman2008?**). Whether prediction is achieved through the use of models that build on true causal mechanisms is not relevant. As long as the predictions of the model has a satisfactory correspondence with the empirical variation of interest, it is deemed a success. This view is therefore compatible with the constraining realisation that all models are wrong, both because the truth of postulated causal mechanisms in and of itself does not matter, and because of the resulting relaxed demand for accordance with total empirical variation – degree of empirical adequacy determines the choice between models. Related views have also been advanced within archaeology. The most clear example can be found in the domain of archaeological locational (sometimes termed 'predictive') modelling, concerned with understanding where archaeological sites are located in the landscape. These studies have sometimes focused on identifying where sites are located in the present-day landscape, irrespective of past motivations, so as to potentially reduce costs of land-development, or to help guide archaeological surveys in large areas where a complete coverage of the landscape is not possible. The concern then is knowing where sites are and are not located, not why. However, one of the criticisms forwarded towards instrumentalism is that if the ultimate goal is manipulation of relevant variables for the improvement of society, this will depend on uncovering true causal mechanisms. While mere prediction depends on stable correlation, control necessitates causality (**hausman1998?**). As Elster (2015:18) puts it, explanation demands causation, and causation can never be revealed solely through prediction (see also **gibbon1989?**). Instrumentalism, therefore, can never hope to explain social phenomena. Of course, causal explanation does not necessarily have to be the main concern for archaeology. One could argue that academic interest in explanation should not always be the guiding principle behind archaeological inquiry but rather, for example, that mitigating costs associated with land-development or assembling interesting, albeit more speculative narratives about the past can be more important goals. My view in this context, as stated in the introduction to the thesis, follows from a form of realist understanding of truth, and that scientific inquiry is as a strategy by which we try to confront theoretical constructs with empirical observation, aimed at aligning our beliefs as reliably as possible with what is true (Godfrey-Smith 2003, 161), where the ultimate aim is to answer why something we believe to be true has occurred.

Scientific realism entails the philosophical position that there exist real observable and unobservable entities and properties, and that claims concerning the veracity of either dimension cannot be set apart (**hausman1998?**; **psillos1999?**; **gibbon1989?**; Wylie 2002, 97–105). The goal is to reveal these truths, where truth typically follows a commonsensical definition of being determined by what is the case, and not, for example, what we believe to be true or what is most beneficial (Ladyman 2002, 157–58; see also Malnes 2012, 19–30). Regardless of whether or not it is possible to ever achieve, the goal of the realist is to reveal true, yet unobservable causal mechanisms that generate and shape the flux of observable phenomena.

In a realist view, even the most careful empirical approach depends on theoretical assumptions that will determine what hypotheses are deemed relevant, what evidence empirical data are believed to represent, and how these are evaluated against hypotheses (Wylie 2002, 100). This point was also central to the post-processual critique of processualism, where Hodder (1984) argued that objective data is never tested against separate independent theories. These theories already underlie and determine how the archaeological material is recorded – there is no theory-free data. To the realist, however, the realisation that we might view the world differently does not take away from the belief that we inhabit a common reality that exists and is true independently of what we think about it (Godfrey-Smith 2003, 174). (**shapin1985?**) stated that 'it is ourselves and not reality that is responsible for what we know.' This, however, is a false dichotomy. As human knowledge is a part of reality, not something outside of it, it is better understand human knowledge as the result of both ourselves and the world (Godfrey-Smith 2003, 132). By extension, and by drawing on, Godfrey-Smith (2003) states that it is not enough to say that observation is theory-laden. The challenge is determining what theories influence observation, how they do so, and how reality manifests in observation.

As an extension of this view, the form of feminist perspective advocated by Longina's -(**longina?**) contextual empiricism follows from treating the social group as the foundational.

So far induction has here been used to denote all non-deductive reasoning, and been exemplified by what is sometimes termed its enumerate or statistical form. That is, induction as the repeated observation of conjoined phenomena. However, other forms of non-deductive inference clearly exist. Archaeology is often, if not most often, concerned with explaining singular or infrequent events. Scientific realist often lean on this mode of inference to provide a way around the problem of induction. (**lipton1991?**) states this mode of inference simply as 'Given our data and background beliefs, we infer what would, if true, provide the best of the competing explanations we can generate of those data.' (Fogelin 2007, 604).

4.3 What are models?

Building on the above, we can return to the issue of scientific models. While the H-D framework in a sense sees every model as a truth-candidate, they are for advocates of a model-based archaeology instead often understood as 'pieces of machinery that relate observations to theoretical ideas' (D. L. Clarke 2015[1972], 1). A similar view can be found with Morgan and Morrison's -Morgan and Morrison (1999) view of 'models as mediators', where a model is a concrete or explicit representation of observables or theoretical beliefs, and allows for a confrontation between these two dimensions. This is very much in line with the model as envisaged by Kohler and van der Leeuw (2007), who sees them as constructions that have similarities with, but exist independently of the target systems that they are to represent. Models are constructions used to draw further inferences about the reality they are to represent, and are construed on the basis of what mechanisms we believe shaped the observables available to us. What is studied directly is the model, in the hope that when confronted with the world, the mechanisms of the model that the researcher is interested in correspond with those of the target system. This is how models have often been cast in a realist understanding, and variations on this are sometimes termed idealised or isolating models (Gilbert 2008; Frigg & Hartmann 2018). These entail the inclusion of boundary conditions or assumptions considered essential for the model to function, the explicit or silent omission of aspects deemed unessential, and can involve an exaggeration of the characteristics of interest (**maki2009?**).

In a realist conception of models these can thus be seen as analytical tools, the purpose of which is to provide a concrete representation of the researchers beliefs, used to isolate or create a closed and credible surrogate system where causal mechanisms are allowed to work without impediment from surrounding noise (see Sugden 2000; Cartwright 2009; Mäki 2009 for variations on this; Sugden 2009). The aim, according to (**cartwright2009?**), is to reveal the capacities and differential contributions of unimpeded causal effects within such an idealised structure. However, this does not necessarily entail that the causal contribution is stable outside the surrogate system. In an open target system, the complex interplay of several causal mechanism can render the contribution from the modelled causal effects completely transformed, compared to their role in an idealised surrogate system (**gibbon1989?**). Therefore, although stable correlations can point to the possible existence of a causal relationship, the relevance of the realist study of capacities, unlike positivist regularities, does not presuppose closed target systems (Groff 2004:12–16). Positivism necessitates a closed system with regular conjunctions between events, such that an event of type A is always followed by an event of type B (**gibbon1989?**). (**cartwright2009?**) contends that even though the realist surrogate system is credible, in the sense that the mechanisms could conceivably occur and result in the phenomena in question, the system is almost always different from all real cases in ways that matter. Drawing on the oft-invoked *ceteris paribus* statement – all other things are in fact not equal (cf. Cartwright 2003[1983]:44–47) – all models are wrong. The confrontation of model and data can therefore never avoid the problems of induction. The question of interest then is not whether the model is true or false in its entirety, but if the model resembles the world in the relevant dimensions, given its purpose (K. A. Clarke and Primo 2007, 747).

One solution to this issue could perhaps be to probe the model for sensitivity to changes in assumptions and omissions, but (**cartwright2009?**) demonstrates that this is ultimately unsatisfactory. She exemplifies that if A and B imply C, A and D imply C, A and E imply C etc., can this mean that A and anything implies C? This relates to Hume's problem of induction, and the fact that even if we have observed. True causality can be understood as dependent on a counterfactual condition (e.g. Lewis 1973), i.e. if not A then not C. This echoes the earlier discussion on equifinality, and means that emulation can never determine whether true causal mechanisms have been revealed (cf. Lake (2015), 23–24).

When evaluating a model in this view, the concern is if it corresponds with the world in ways that matter. A classic example in the literature is subway maps. These are clearly extreme simplifications of the world, and confronting them with how the world actually looks would easily show that they are not true renditions of reality. However, given it's purpose, the subway map should instead be evaluated by the degree to which it helps commuters get from A to B. Furthermore, any tests of models has been argued to be best done by comparing them to the ability of substantive competing alternatives to fulfill the same purpose, and not just their negation, the null-model (Smith 2015; Wylie 2002; **perrault2019?**). Pitching alternative models against each other will lead away from a pure search for corroborative evidence that Popper warned against. Relating this to the subway map, one could then for example compare its ability to help commuters to that of the topographic map. All models are wrong, but given the problem at hand, the subway map is likely to be the most useful alternative. While there might still exists other ways of representing the subway system that would be better than the current subway maps, given the problem and current models at hand, the subway map would be the model of choice.

Following from a concern Popper, aim was demonstrate how theories such as Marxism or were unscientific as they are compatible will all empirical data.

However, several authors have argued that is likely to be a dead end. An underlying belief that class struggle is an important historical driver. Concrete instantiations, models, of this belief can, however, be rejected. If theory then is

4.4 Archaeology, abduction and models

Theoretical discussions in archaeology have often framed the field as situated at extremes of positivism and relativism, or humanistic and scientific perspectives, harking back to Snow's -(**snow?**) distinction between 'The Two Cultures'. Transitions between these theoretical stances within large swathes of the field are then typically denoted by terms such as "paradigm shifts", "crises" or "turns" (e.g. **sørensen2017?**). However, Chapman and Wylie (2016) and others (Fogelin 2007) have argued that this perspective does not inform how archaeology has in fact progressed, and that these positions are caricatures that do not capture what are in fact the main drivers behind archaeological insights and advances. This is not to say that these discussions cannot hold important points for elucidating the nature of our inferential frameworks. Rather, this then naturalistic argument is that these discussions are over-simplified, hyperbole and largely unrepresentative of an archaeology that generally progresses by drawing on a far more complex web of theoretical and philosophical influences (see also Johnson 2006). A choice between epistemological positivism towards establishing deductively certain knowledge or a whole-sale rejection of the possibility of therefore doesn't represent an adequate reference frame for understanding what constitutes good archaeology, how to conduct it, nor how consensus and synthesis on claims about the past have been arrived at.

Given the lack of an infallible logical foundation with which to establish these explanations, Chapman and Wylie (2016) speak for an iterative epistemological process where a scaffolding for how data is cast as evidence by drawing on multiple methodologies and lines of reasoning is continuously adjusted, extended and reassembled as a temporary framework. Crucially, these scaffolds are to be subjected to critical reflexivity, but be grounded in domain-specific norms of what constitutes evidence, so as to tackle what Binford (1981, 21) presented as the challenge of 'how to keep our feet on the "empirical" ground and our heads in the "theoretical" sky.' (Chapman and Wylie 2016, 8).

A central component of Chapman and Wylie's (2016, 37) argument is illustrated by a quote from Toulmin (1958, 37): 'The proper course for epistemology is neither to embrace nor to armour oneself against sceptisim, but to moderate one's ambitions – demanding of argument and claims of knowledge in any field not that they should measure up against analytic standards but, more realistically, that they shall achieve whatever sort of cogency or well-foundedness that can relevantly be asked for in that field.' Important here is that there is no universal recipe for inferential adequacy, but that inference is domain specific.

Drawing on (**norton?**), Chapman and Wylie (2016, 40) terms this 'hypothetico-contextualism'. As (**clarke?**)

Echoing the point made by Godfrey-Smith (2003), referenced above, Chapman and Wylie (2016, 41–43) argue that theory-ladenness will differentially impact what archaeologists consider evidence. Some biophysical observations will be relatively transferable between contexts, and their role as archaeological evidence less integrated with theoretical . Inferences to do with symbolic behaviour is less transferable as they will be more insecure and contingent on the context-dependent evidential scaffolding surrounding them. However, this does not mean that symbolic behaviour is in any sense more off-limits than for example inferences drawing on radiometric dating. Neither can reach deductive certainty, and their role as evidence for past events is differentially dependent on the warrants and assumptions that underlie them (Chapman and Wylie 2016, 42).

Along similar lines, several authors have argued that archaeology is now characterised by methodological and theoretical eclectiveness (**ortega?**; Chapman and Wylie 2016, 11). As (**preston2014?**) states, archaeology 'is intellectually *distinctive*, even if not intellectually *unified*. The latter, I would argue, is an inappropriate goal for the discipline'. Considering the complexity of the questions we deal with, it is difficult to argue that this situation is anything but positive. Furthermore, accepting this eclectic state of affairs is as a far more fruitful way of trying to understand archaeological practice, rather than insisting on casting this in some dichotomous light that poorly captures how the archaeological enterprise is actually undertaken. Furthermore, embracing eclecticism can hopefully lead to a research-environment were practitioners are open to dialogue and are not overly committed to any single approach and dismissive of alternatives (**hemon2017?**).

Drawing on (**longino2002?**), (**chapman?**) see objectivity as pragmatic and 'On this account, the goal of inquiry is not to produce knowledge claims that are true in all contexts and transcendent of local interest, but rather to warrant knowledge claims as credible given available resources, and reliable for specific purposes. Objectivity is, then, characterized in terms of norms of practice something

Given the case where multiple models achieve empirical adequacy, that is, they predict the empirical pattern of concern equally well, realist have argued that inference to the best explanation is the best way forward and that this represents a way to handle the unavoidable problem of induction.

While these might be sensible guiding principles for arriving at good explanations. Chapman and Wylie (2016, 7) as aims at 'establishing claims that are empirically irreproachable they may foreclose (some) risk of error but at the expense of abandoning the very questions that make archaeology worth doing, and if they do not self-limit in this way they may have nothing to offer but speculation.'.

The understanding of archaeological inquiry outlined above need not be cast within a model-based understanding. The term model has been noted to increasingly involve aspects that were previously seen as a domain of theory (**preston?**), and their role has conceived of here also touches middle-range theory, bridging or scaffolding. However, I believe the model terms offers a sensible way of thinking about these issues, as it forces us to see explanations as fallible explicit constructs which are thus easily

What are models? "It is […] more appropriate to describe models than to attempt a hopelessly broad or hopelessly narrow definition for them" (D. L. Clarke 2015[1972], 2)

Following Clarke, no conclusive definition of models is sought here. The concept is notoriously difficult to pin down as its use varies across different disciplines, between various authors, and a multitude of classificatory schemas of model types have been proposed (e.g. Hausman 1992; Morrison & Morgan 1999a; Gilbert 2008:5; Godfrey-Smith (2009); K. A. Clarke and Primo (2007)). Nonetheless, some possible understandings of the term are presented below, mainly in order to set up an understanding of modelling in relation to the practice of archaeological inquiry and to understand what could demarcate model-based archaeology (MBA) from other forms of archaeological inference.

Godfrey-Smith's (2009, 102) understanding of a model-based style of science sees this as a distinct approach, starting at remove from the phenomena, or target system, of interest. A model-based approach is in this understanding thus different from an analysis that starts by trying to describe and understand the system under study. Instead it begins with the exploration of a hypothetical, fictional model, simplified and largely independent of the target system, before this is ultimately interfaced with empirical data, involving thus 'a deliberate detour through fiction' (Godfrey-Smith 2009, 103). As the modeller in this instance would be in control of all parts of the artificial model and their interactions, it is in the empirical confrontation that the model can yield the most fruitful results, either by capturing the empirical variation of interest or by allowing for an exploration and understanding of where it fails.

For all the ambiguities in the above account of what can be taken to constitute models, a common element is the view that they are constructed and explicit representations of our beliefs. Precisely this is also central to the contention that one of the most important aspect of model-based approaches follow from their explorative side (Hausman 1992:77; Aydinonat 2007; Premo 2010). This results both from the assembly process itself, and from subsequent probing and manipulation of the model (Morrison & Morgan 1999b). In the initial construction of a representation of theory and data, the researcher is forced to concretise their assumptions and beliefs. This will likely lead to the adjustment of inconsistencies, the discovery of additional theoretical implications or relevant empirical patterns, and increase the opportunity for explicit handling and reporting of uncertainty. Through stringent and explicit aggregation of model features, further theoretical and empirical consequences are also likely to be revealed. Thus, in its construction, the model will already have provided valuable insights, regardless of its future archaeological life-span. Even so-called caricature models that are wildly unrealistic, extreme distortions have been argued to generate such insights (Gibbard & Varian 1978). Following its construction, further insight can be achieved through direct manipulation of model parameters and assumptions (Morrison & Morgan 1999b:32-35). This holds the potential of revealing additional causal propensities and limitations that are difficult to reveal by passive study of the model, and can reveal how sensitive it is to such adjustments (Premo 2010). The same effects are subsequently extended by any attempts at evaluating the correspondence between model and target system, and by the involvement of an audience that comments, criticises, dismisses or helps align model and target system (Mäki 2009).

A realist understanding holds that unobservable theoretical constructs should be conceived of as true mechanisms and events, and that these should not be distinguished from observables. In a realist view, the progression of science is not achieved by a random and undirected trial-and-error search by exploring empirical patterns, nor is it achieved by rejecting relevant hypotheses only on the basis of empirical adequacy. Our beliefs concerning unobservables shape how we observe, order and confront theoretical constructs with empirical data.

Why model?

The last chapter laid out the analytical framework that was used when thinking about these issue. The last section. This was not drawn on directly in the papers, but form a good frame both for considering their contribution and for setting up some future avenues along wich these could be explored.

Chapter 5

Modelling the Norwegian Mesolithic

The last chapter laid out the foundation for a model-based archaeology. This chapter will explore how casting

5.1 Modelling the relationship between Mesolithic sites and the prehistoric shoreline

In the first paper of this thesis I have proposed a method for shoreline dating Mesolithic sites on the Norwegian Skagerrak coast, based on an empirically derived model of the relationship between the sites and the prehistoric shoreline (Roalkvam 2023). This was based on simulating the distance between sites and the shoreline using 67 ^{14}C-dated sites and local reconstructions of shoreline displacement. The study found the sites to typically be located on or close to the shoreline up until some time just after 4000 BCE, when a few sites are located further from the shoreline. At around 2500 BCE there is a clear break, and the sites are from this point on situated further from and at variable distances from the shoreline. Building on these findings, the likely elevation of sites dating to earlier than 2500 BCE were, in aggregate, found to be reasonably approximated by the gamma function given in Figure. This is the model that forms the foundation of the proposed method for shoreline dating presented in the paper.

In one sense this model is instrumental as the *reason* for the location of the sites has not been considered explicitly. By combining the present altitude of a site, its likely elevation above the shoreline when it was in use, and local shoreline displacement curves, this model makes it possible to assign a probabilistic absolute shoreline date to coastal sites in the region. On a realist view, however, it is still true that the treatment of the data and the conception of the model followed from an underlying belief of what mechanisms shaped the patterns in the data deemed relevant. While the model and derived method can be viewed as a instrumental dating tool, they are determined by the proclivity for sites to be located on the shoreline. As such, they are likely to be tightly integrated with both overarching cultural developments, as well as behaviour at the site level. By extension, the multitude of factors that can have shaped the site-sea relationship on the large and small scale, both temporally and spatially, offers a challenging causal web of possible interacting effects that ultimately determine this relationship. Having first derived this largely instrumental model, it gives opportunity to further test it's correspondence with other empirical data, and explore and expound underlying theoretical assumptions and implications.

To illustrate this, below I have constructed a suggestion for a causal model concerning what determines the vertical distance between coastal Mesolithic sites and the shoreline in south-eastern Norway. The direction of the arrows in the model illustrates what variables are believed to impact other variables. An arrow going directly between two variables means that there is a direct effect. If there is a direct effect between A and B, but variable Z also impact each of these, Z is said to be confounder. An arrow from variable A to B that go through one or more other variables indicate that the effect of A on B is mediated by the intermediate variables. A central element of this model is that the effect of the other variables on the distance between site and shoreline are all mediatated through the exposure of the site to the surroundings and accessibility to and from the site.

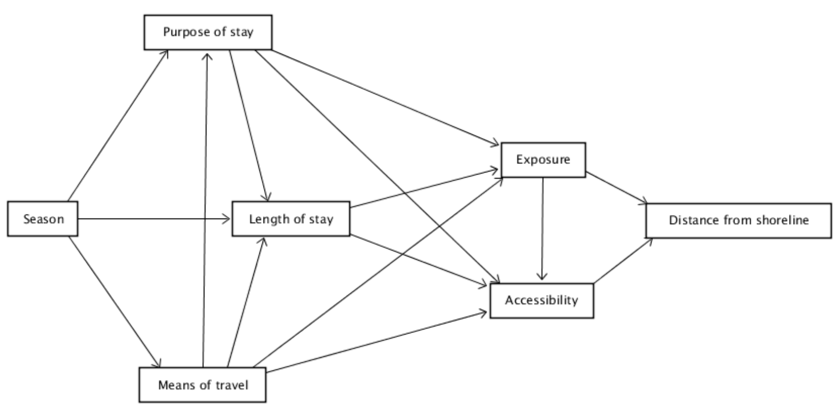

Figure 5.1: Sugggested causal model for the drivers behind the relationship between site location and the prehistoric shoreline in Mesolithic south-eastern Norway.

A likely important factor for how exposed and accessible a site could be is the purpose of the visit to the site. The purpose of the visit is therefore given a direct effect on exposure and accessibility. For example, is the site meant to be used as a stop to rest and repair tools, to be used as a hunting camp or a location from where to acquire raw-materials for tool-production? Is it a base-camp for the entire residential group from where further forays are made, or is it meant to be a meeting place for several groups? The purpose of the stay is likely also to impact the length of the stay, which in turn might have implications for how close to the shoreline the site is established. A longer stay could for example mean that the site is more withdrawn from the shoreline, so as to make sure storm surges do not reach the site.

Means of travel is also included in the model. Most travel is assumed to be done by boat in this period, which means accessibility to the site from the sea is likely to be of concern, as well the ability to safely beach and store the boats. However, some travel was also likely done by foot, for example from a base-camp to a site close by for gathering and processing resources such as shellfish, where the need for the carrying capacity offered by boats might not have been necessary. Travel by sledge on the ice is also a possible alternative. Not having to land boats could presumably have implications for how exposed and accessible a location could be.

The season also presumably has implications for how often one had to establish camp, possibly reducing mobility in colder periods. The season might also have implications for the kinds of dwelling structures that were necessary to erect, and likely determines the kinds of resources that were exploited, thus potentially impacting the purpose of the stay. The season is also believed to have implications for the degree of wind and wave-action at a location, thus affecting the exposure of the site to the elements, and impacting accessibility. Season is therefore given a direct effect on all of these variables.

Some variables and nuance that have been left out of the model are worth commenting on. The weather is for example likely to impact a lot of these factors, but is near if not entirely impossible to determine archaeologically. Furthermore, the purpose of the stay is here indicated using a single variable, but a stay need not, or perhaps likely did not have a single purpose. A simple example might be a case where multiple kinds of resources were to be exploited from a site. A possible alternative would be to operationalise these as individual variables, where for example the magnitude of seal-hunting and the gathering of hazelnuts to be done from the site is kept as separate variables. These would in turn likely be determined by factors such as the density of these resources in the landscape, their caloric return, their cost in terms of handling-time and -energy, and the potential prestige associated with hunting a specific species or the accruement of enough food to allow for sharing. Furthermore, the entire picture is also further complicated by other latent variables that are left of the model. Social structure, overarching mobility patterns, territoriality, group size and composition, as well as religious beliefs could all impact land-use, site-structure and ultimately how sites were positioned relative to the sea.

However, I still believe the model forms a reasonable starting point and that it has the potential to reveal some important and true causal determinants for the site-sea relationship. A central challenge is of course how these factors are to be operationalised and determined archaeologically. The exercise of setting up the causal model is nonetheless useful in its own right, if not simply by forcing me to think through and concretise what elements I believe are important and how these are related. It also forms a framework that dictates how these variables would have to be handled statistically. Furthermore, with reference to the concept of inference to the best explanation presented in the last chapter

Some assumptions concerning the directionality of influence between the variables are made here, which might be discussed. For example, it is assumed here that the length of the stay influences how exposed the location is. This in a sense places primary weight on the planning of the inhabitants. One could envisage a situation where arrival in fair weather leads to a case where a worsening of the weather could prove that the location was in fact too exposed, and the site is moved. The purpose of the visit did in this case determine what was initially an acceptable degree of exposure, but, although not modelled here, the purpose of the visit might change with the weather.

Focusing first on its instrumental value, shoreline dating will often provide the highest resolution date that one can hope to achieve for a site, given that material to radiocarbon date is quite rare due to taphonomic loss, and as established typological frameworks in the region operate on the millennial scale. By facilitating a dating method, the model can thus be drawn on to explore traditional long-term chronological questions, such as the frequency of sites throughout the period (**roalkvam?**), the assessment of typological frameworks, or the timing and spread of various cultural phenomena, to give some examples. Furthermore, the finding that sites tend to be located further from the shoreline from around 4000 BCE and 2500 BCE, correspond with major socio-economic developments, where these dates roughly correspond to the first introduction and subsequent firm establishment of agriculture in the region. Although it still remains to be tested on data independent from where it was derived, the instrumental utility of the model is therefore clear.

However, as it is difficult to determine the longevity of use and re-use of the open-air sites that dominate the Mesolithic record in the region, the number and duration of settlement events being dated in each instance is not clear. Previous consideration of these questions typically range from characterising the sites as the result of short visits of only a few hours up to a few months, and range from single visits to seasonal re-visits over a few decades—possibly centuries in the most extreme instances. However, given the resolution that shoreline dating provides, even at its best, the method does not by itself provide a precision high enough to weigh in on this issue, and can therefore not inform the number or length of stays within the determined date range. This has implications both for the questions that the method can be used to answer, and causal drivers behind site location that we can hope to disentangle using the model, given that these dimensions are likely to have been of importance for the location of the site relative to the sea. (e.g. Bailey 2007; **perrault2019?**)

Having established the model also opens up for a shifting of perspective back and forth from the large to the small scale, and from shoreline date to site location relative to the shoreline. Such an approach can illuminate implications of the model and its workings, and, in turn, potentially also feed back to and lead to a refinement of the model. One such example is now given by considering the location of the site Pauler 1, relative to sea according to the model.

The mean elevation of the site is masl. Based on the likely elevation of the site when it was in use, as informed by the shoreline model, the resulting shoreline date is. The benefit of having a model where all three parameters are clearly defined is that this allows us to shift perspective between the date of the use of a site and the implication this has for the relative position of the shoreline. Thus, looking now instead back from the calendar scale (the x-axis in Figure), to the likely elevation of the site above sea (the exponential function on the y-axis in Figure), and combining this with the elevation of the sea-level above it's present altitude at this time (represented by the displacement curve in Figure)–effectively rearranging the equation–thus allows for an instantiation of the model implications for individual sites in the spatial domain. In Figure, this is done by simulating the sea-level that the shoreline date implies.

Given the commutative nature of the relationship between shoreline date and the elevation of the site above sea-level, it is possible to translate directly between these dimensions and treat the resulting sea-level

The model, while a reasonable approximation of the relationship between sites and shoreline in aggregate, could still be substantially off when applied to individual sites, as was demonstrated here by the in-depth analysis of Pauler 1. However, this model failure has to be qualified. First, the articulation and exploration of *how* the model is wrong has allowed for a further understanding of both the site and the model. Furthermore, this can also function in a step towards generating causal models explaining why, in any given case, the site was located as it was. While an immensely challenging task, this would

The concept of shoreline dating touches upon such a wide range of issues that it can in sense be seen as a microcosm of archaeological inquiry as such. While physical sciences underlie the framework, as it is ultimately dependent on reconstruction of shoreline displacement, the question is inherently social and cultural. Furthermore, perspectives from a vantage of social and humanistic can not only be used to derive cultural significance from the observed patterns, but these can also be used to further improve the method for shoreline dating. My view is that this is defining of archaeology as a whole. While here nested in model-based archaeology, which I found a useful framework with which to think about these issues, I also think this illustrates the heterogeneous nature of archaeology and the value of drawing on multiple strains of evidence and perspectives. The iterative move between aggreagte model and individual cases could just as easily have been cast within a hermeneutic understanding of archaeological research. This also highlights the inadequacy of attempting to understand archaeological research as being situated somewhere on a scale between more or less scientific or humanistic, more or less processual or post-processual, as these are simply unable to capture the necessary nuance of archaeological inquiry.

Chapter 6

Conclusions and future directions

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Papers

Paper 1

A simulation-based assessment of the relation between Stone Age sites and relative sea-level change along the Norwegian Skagerrak coast

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A simulation-based assessment of the relation between Stone Age sites and relative sea-level change along the Norwegian Skagerrak coast

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ABSTRACT

A central premise for the Stone Age archaeology of northern Scandinavia is that most coastal sites were located on or close to the contemporary shoreline when they were in use. By reconstructing the trajectory of rapid and continuous relative sea-level fall that characterises large regions of Fennoscandia, this offers a dating method termed 'shoreline dating' which is widely applied. However, while the potentially immense benefits of an additional source of temporal data separate from radiometric and typological methods is unquestionable, the geographical contingency and thus relative rarity of the method means that it has been under limited scrutiny compared to more established dating techniques in archaeology. This paper attempts to remedy this by quantifying the spatial relationship between Stone Age sites located below the marine limit and the prehistoric shoreline along the Norwegian Skagerrak coast. Monte Carlo simulation is employed to combine the uncertainty associated with independent temporal data on the use of the sites in the form of ^{14}C-dates and the reconstruction of local shoreline displacement. The findings largely confirm previous hypotheses that sites older than the Late Neolithic tend to have been located on or close to the shoreline when they were occupied. Drawing on the quantitative nature of the results, a new and formalised method for the shoreline dating of sites in the region is proposed and compared to previous applications of the technique.

1. Introduction

The post-glacial relative sea-level fall that characterises large areas of Fennoscandia is fundamental to its archaeology. This follows not only from the dramatic changes to the landscape that this process created throughout prehistory, but also from the fact that if archaeological phenomena were situated close to the contemporary shoreline when they were in use, a reconstruction of the trajectory of shoreline displacement can be used to date these phenomena based on their altitude relative to the present day sea-level. This method, also called shoreline dating, has long history of use in the region and is frequently applied to assign an approximate date to diverse archaeological phenomena such as rock art, grave cairns, various harbour and sea-side constructions and, as is the focus of this study, Stone Age sites (e.g. Åkerlund, 1996; Bjerck, 2005; Gjerde, 2021; Løken, 1977; Nordqvist, 1995; Schmitt et al., 2009; Sognnes, 2003; Tallavaara and Pesonen, 2020; Wikell et al., 2009).

The close association between Stone Age settlements in the northern parts of Scandinavia and shifting prehistoric shorelines was proposed at the end of the 19th century (De Geer, 1896), and was first applied as a dating method at the turn of the century (Brøgger, 1905; Hollender, 1901). Shoreline dating has been fundamental to Norwegian Stone Age archaeology ever since (e.g. Berg-Hansen, 2009; Bjerck, 1990, 2008a; Breivik, 2014; Johansen, 1963; Mansrud and Persson, 2018; Mikkelsen, 1975a; Mjærum, 2022; Nummedal, 1923; Olsen and Alsaker, 1984; Shetelig, 1922; Solheim et al., 2020; Solheim and Persson, 2018). The method is used both independently, and to compliment other sources of temporal data such as typological indicators or radiometric dates. However, given the coarse and fuzzy resolution of established typological frameworks, the vast number of surveyed sites that only contain generic lithic debitage that could hail from any part of the period, and as the conditions for the preservation of organic material is typically poor in Norway, dating with reference to shoreline displacement is often the only and most precise method by which one can hope to date the sites. Shoreline dating is consequently

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fundamental to our understanding of the Norwegian Stone Age. This is both because it is central to the temporal framework on which our understanding of the period is based, but also because the method is only applicable so long as the societies in question have continuously settled on or close to the contemporary shoreline. Consequently, adherence or deviation from this pattern also has major implications for the socio-economic foundations of the societies in question.

Despite its important role for Fennoscandian archaeology, the applicability of dating by reference to shoreline displacement has only been evaluated using relatively coarse methods. The aim of this paper is to provide a systematic and comprehensive review of the degree to which radiocarbon dates correspond with the dates informed by our current knowledge of shoreline displacement in a larger area of south-eastern Norway, using a more refined methodological approach. The goal here is to quantify the degree to which the assumption of shore-bound settlement holds through the Stone Age in a relatively well sampled portion of Scandinavia, and in turn have this quantification inform the development of a formalised method for shoreline dating. As presented in more detail below, this problem involves the combined evaluation of three major analytical dimensions. One is the questions of when the sites were in use, the second pertains to the reconstruction of the contemporaneous sea-level, and the third follows from the fact that the relation between site and shoreline is inherently spatial. Taking inspiration from studies that have integrated various sources of spatio-temporal uncertainty through Monte Carlo simulation (e.g. Bevan et al., 2013; Crema et al., 2010; Crema, 2012, 2015; Yubero-Gómez et al., 2016), a similar approach is adopted here and adapted to post-glacial sea-level change and the Stone Age settlement of southern Norway.

2. Background

Relative sea-level (RSL) can be defined as the mean elevation of the surface of the sea relative to land, or, more formally, the difference in elevation between the geoid and the surface of the Earth as measured from the Earth's centre (Shennan, 2015). Variation in this relative distance follow from a range of effects (e.g. Milne et al., 2009). Of central importance here is eustasy and isostasy. Eustatic sea-level is understood to be the sea-level if the water has been evenly distributed across the Earth's surface without adjusting for variation in the rigidity of the Earth, its rotation, or the self-gravitation inherent to the water body itself (Shennan, 2015). The eustatic sea-level is mainly impacted by glaciation and de-glaciation, which can bind or release large amounts of water into the oceans (Mörner, 1976). Isostasy, on the other hand, pertains to adjustments in the crust to regain gravitational equilibrium relative to the underlying viscous mantle caused by mass loading and unloading, which occurs with glaciation and deglaciation. These effects causes the lithosphere to either subside due to increased weight, or to rebound and lift upwards due to lower weight (Milne, 2015).

Following the end of the Weichselian and the final retreat of the Fennoscandian Ice Sheet (e.g. Hughes et al., 2016; Stroeven et al., 2016, see Fig. 1), the isostatic rebound has caused most areas of Norway to have been subjected to a continuous relative sea-level regression, despite corresponding eustatic sea-level rise (e.g. Mörner, 1979; Svendsen and Mangerud, 1987). In other words, the RSL has been dropping throughout prehistory. As this process is the result of glacial loading, the rate of uplift is faster towards the centre of the ice sheet relative to the distal aspects. Thus, there is differential glacio-isostatic impact to a site's location depending on its relation to the ice sheet's centre of mass, leading some areas on the outer coast to have had a more stable RSL or been subject to marine transgression (e.g. Romundset et al., 2015; Svendsen and Mangerud, 1987). These conditions are directly reflected in the archaeological record. In areas where the sea-level has been stable over longer periods of time, people have often reused coastal site locations multiple times and over long time spans, creating a mix of settlement phases that are difficult to disentangle (e.g. Hagen, 1963; Reitan and Berg-Hansen, 2009). Transgression phases, on

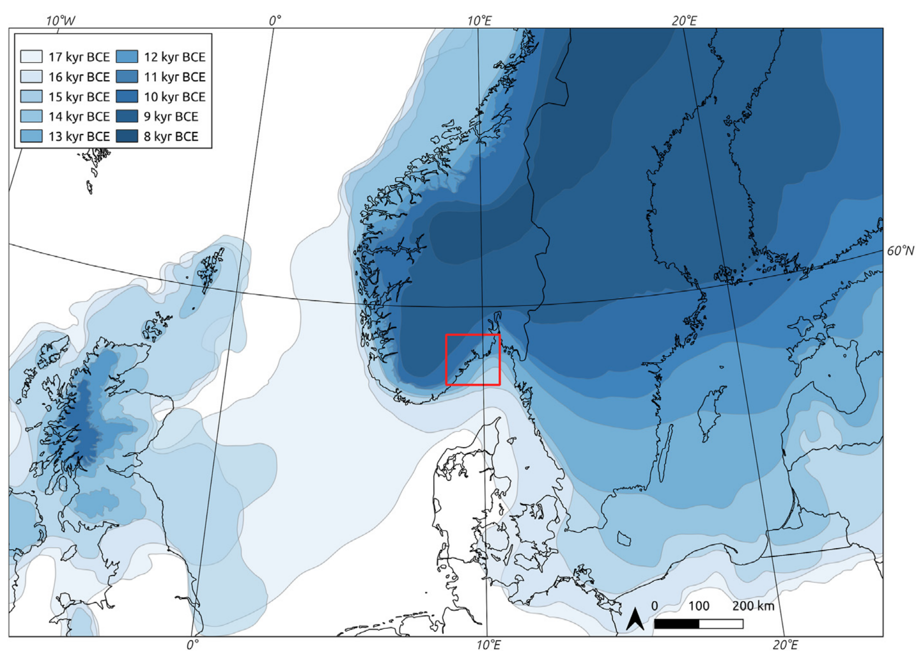

Fig. 1. Deglaciation at 1000-year intervals from c. 17–8 thousand years (kyr) BCE. The study area defined later in the text is marked with a red outline (deglaciation data from Hughes et al., 2016, but see also Romundset et al., 2019 in relation to the study area). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

the other hand, can lead to complete destruction of the sites, bury them in marine sediments, or in the outermost periphery, submerge them (Bjerck, 2008a; Glørstad et al., 2020). Transgression can therefore lead to a hiatus in the archaeological record for certain sub-phases in the impacted areas despite the fact that there were likely coastal settlements during the inferred hiatuses. Comparatively, given a continuous and still ongoing shoreline regression from as high as c. 220 m above present sea-level in the inner Oslo fjord, any one location in south-eastern Norway has only been shore-bound within a relatively limited time span, and the sites have not been impacted by any transgressions (Hafsten, 1957, 1983; Romundset et al., 2018; Sørensen, 1979). This makes the region especially useful for evaluating the assumption of a shore-bound settlement pattern over a long and continuous time span.

The method of shoreline dating has been met with scepticism as related to the fundamental premise that most sites would have been consistently shore-bound, it has been characterised as a relative dating method for sites located within a constrained geographical area, or it has been argued to offer no more than an earliest possible date for when a site could have been in use (see review by Nordqvist, 1999). The most common application in Norway has arguably been to use shoreline dating to provide an approximate date for the occupation of the sites, often in combination with other dating methods (see for example chapters in Glørstad, 2002, 2003, 2004; Jaksland, 2001; Jaksland, 2012a, 2012b; Jaksland and Persson, 2014; Melvold and Persson, 2014a; Reitan and Persson, 2014; Reitan and Sundström, 2018; Solheim, 2017; Solheim and Damlien, 2013 and below). Recently the method has also been used independently to date a larger number of sites to get a general impression of site frequency over time. This is done by aggregating point estimates of shoreline dates in 100-, 200- or 500-year bins (Breivik, 2014; Breivik and Bjerck, 2018; Fossum, 2020; Mjærum, 2022; Nielsen, 2021; Solheim and Persson, 2018; see also Jørgensen et al., 2020; Tallavaara and Pesonen, 2020). In his review, Nordqvist (1999) argues that there can be little doubt concerning the general applicability of the method—what is less clear is the level of reliability and chronological resolution that it can offer (see also Johansen, 1963, 1997; Mikkelsen, 1975b:100).

The shore-bound settlement location of prehistoric hunter-fisher-gatherers in Norway is generally believed to follow both from the exploitation of aquatic resources and from movement and communication, which would have been efficient on waterways (Bjerck, 1990, 2017; Brøgger, 1905:166; also discussed by Berg-Hansen, 2009; Bergsvik, 2009). The same logic has also been extended to the hinterland and inland regions, where sites are believed to be predominantly located along rivers and lakes (Brøgger, 1905:166; Glørstad, 2010:57–87; but see also Gundersen, 2013; Mjærum, 2018; Schülke, 2020). This is to take a dramatic turn at the transition to the Late Neolithic, around 2400 BCE, with the introduction of the Neolithic proper (Prescott, 2020; cf. Solheim, 2021). The introduction of a comprehensive Neolithic cultural package, including a shift to agro-pastoralism and the development of settled farmsteads is to have led site locations to be more withdrawn from the shoreline (e.g. Bakka and Kaland, 1971; Østmo, 2008:223; Prescott, 2020). That is not to say that waterways and aquatic resources were no longer exploited, but rather that these activities would not have been as tightly integrated with settlement and tool-production areas as in preceding periods (Glørstad, 2012). At an earlier stage, at the transition to the Early Neolithic (c. 3900 BCE), pottery is introduced to the sites, and there are some indications of an initial uptake of agriculture at some sites in the Oslo fjord region. However, this appears to be small in scale and is believed to be combined with a continued and predominantly hunter-gatherer life-way, possibly followed by a return to foraging and complete de-Neolithisation in the Middle Neolithic (Hinsch, 1955; Nielsen et al., 2019; Østmo, 1988:225–227). Nielsen (2021) has recently argued that the initial uptake of agriculture in Early Neolithic south-eastern Norway is combined with a more complex settlement pattern, and that a simple foraging/agricultural dichotomy would underplay the variation present in the Early and Middle Neolithic settlement data (see also e.g. Amundsen et al., 2006; Østmo, 1988; Solheim, 2012:74; see e.g. Bergsvik, 2002; Bergsvik, 2012 for similarly nuanced considerations of the coastal settlement of Neolithic western Norway). Seen in relation to the question of interest here, the empirical expectation for the above outlined development would thus be a predominantly shore-bound settlement in the Mesolithic, possibly followed by a more varied association between sites and the shoreline with the transition to the Early Neolithic around 3900 BCE, and finally a decisive shift with the Late Neolithic c. 2400 BCE.

Based on the generally accepted premise that most pre-Late Neolithic sites in south-eastern Norway located lower than the marine limit (the highest elevation of the sea after the retreat of the ice) were situated on or close to the contemporaneous shoreline, it is common to err on the side of a shore-bound site location unless there is strong evidence to suggest otherwise. This is for example reflected in archaeological survey practices, which are often guided by both a digital and mental reconstruction of past sea-levels (see e.g. Berg-Hansen, 2009; Eskeland, 2017; Nummedal, 1923; Simpson, 2009). Similarly, following an excavation, if typological indicators in the assemblages correspond with available shoreline displacement curves, a shore-bound site location is often assumed, even if the typologically informed date span is too wide to decisively verify this. It is also common to combine this with a qualitative consideration of the landscape surrounding the sites, and an evaluation of the degree to which the site location would appear to have been sensible if the site was not shore-bound (e.g. Jaksland, 2014; Johansen, 1963; Nummedal, 1923). This can for example pertain to accessibility. If the site is situated on a ledge in a steep and jagged area of the present-day landscape it would make intuitive sense that the site was in use when the ocean reached closer to its elevation, as the site would have been accessible by means of watercraft. Although it appears that the arguments for such site locations can for the most part be assumed to hold, comprehensive evaluations and attempts at quantification of this tendency are relatively few (see also Berg-Hansen et al., 2022:644; Ilves and Darmark, 2011).

One of the more extensive evaluations of the relationship between archaeological radiocarbon dates and RSL-change was done by Solheim and colleagues (Breivik et al., 2018; Solheim, 2020), who compared 102 radiocarbon dates from 29 Mesolithic sites on the western side of the Oslo fjord to the displacement curve for the Larvik area. They found an overlap between the probability distribution of the radiocarbon dates with the shoreline displacement curve for 86.3% of the dates (Solheim, 2020:48). However, where there was a discrepancy, the main occupation of the sites is still believed to have been shore-bound rather than associated with the deviating ^{14}C-dates. This is based on typological and technological characteristics of the assemblages. Whether these mismatches represent later shorter visits that are responsible for the younger radiocarbon dates, or whether these dates are entirely erroneous can be difficult to evaluate (e.g. Persson, 2008; Schülke, 2020). However, this distinction is not deemed critical here, as what is of interest is settlements and tool-production areas as evidenced by artefact inventories or multiple site features. Not remnants of stays as ephemeral to only be discernible by isolated features or dubious ^{14}C-dates. The evaluation of the relevance of radiocarbon dates to settlement activity will here therefore be entirely dependent upon and follow the discretion of the original excavation reports.

Other previous evaluations of the correspondence between radiocarbon- and RSL-informed dates have typically followed the same structure as that of Breivik et al. (2018), involving a visual inspection of radiocarbon probability mass functions plotted against local shoreline displacement curves based on the elevation of the site (e.g. Åkerlund et al., 1995; Åstveit, 2018; Berg-Hansen et al., 2022; Solheim, 2020; see also Bjerck, 2008b; Kleppe, 1985; Ramstad, 2009). This approach has a couple of limitations. First, the displacement curves are sometimes applied directly to larger study areas, analogous to what Borreggine et al. (2022) term a bathtub model, with only some studies having taken the variable uplift-rates into account when performing this comparison (e.g. Åstveit, 2018; Fossum, 2020; Møller, 1987; Persson, 2008; Rosenvinge et al., 2022). Secondly, with this method, the wider the uncertainty range associated with either radiocarbon date or displacement curve, the higher the probability that the confidence intervals overlap, and the higher the probability that the conclusion supports the hypothesis. This thus leads to an inferential framework that favours uncertainty, which is hardly desirable. In statistical terms this follows from the fact that while one cannot conclude that two dates are different if their confidence intervals overlap, this does not necessarily mean that they are the same. The question thus necessitates a flip from a null-hypothesis of no significant difference, to one of equivalence (e.g. Lakens et al., 2018), as the question of interest is effectively one of synchroneity between events (cf. Parnell et al., 2008). Another limitation of this often-employed method is that it only takes into account the vertical distance between the sites and the sea-level. While this is the main parameter of interest for shoreline dating, the practical implications of a vertical difference in RSL will be highly dependent on local topography and bathymetry. RSL-change can have more dramatic consequences in a landscape characterised by a low relief, as the horizontal displacement of the shoreline will be greater. Taking the spatial nature of the relationship between site and shoreline into account will consequently help get more directly at the behavioural dimension of this relation and help move the analysis beyond a purely instrumental consideration of the applicability of shoreline dating.

3. Data

To get at the relationship between sites and the contemporaneous shoreline, this analysis was dependent on identifying a study area with good control of the trajectory of prehistoric shoreline displacement. While there is displacement data available for other areas of south-eastern Norway (e.g. Hafsten, 1957; Sørensen, 1979, 1999), considerable methodological developments in recent years means that the most well-established displacement curves are from the region stretching from Horten county in the north-east, to Arendal in the south-west (Fig. 2). This area has newly compiled displacement curves for Skoppum in Horten (Romundset, 2021), Gunnarsrød in Porsgrunn (Sørensen et al. in press; Sørensen et al., 2014a,b), Hanto in Tvedestrand (Romundset, 2018; Romundset et al., 2018), and Bjørnebu in Arendal (Romundset, 2018).

The shoreline displacement data used in this study are based on the so-called isolation basin method (e.g. Kjemperud, 1986; Romundset et al., 2011), which involves extracting cores from a series of basins situated on bedrock at different elevations below the marine limit, and dating the transition from marine to lacustrine sediments. Each basin thus represents a high precision sea-level index point (SLIP) which are combined in a continuous time series for RSL-change adjusted to a common shoreline isobase. The isobases are here contours indicating equal shoreline displacement over the same time span (Svendsen and Mangerud, 1987:116). To minimise the impact of variable uplift rates, the cored basins are located in as constrained of an area of the landscape as possible. Following from the morphology of the retreating ice sheet, the uplift is more stark towards the north-east, which needs to be adjusted for in the case that any basins are located any significant distance from the common isobase that runs perpendicular to this uplift gradient (Fig. 2). Furthermore, as the uplift has been greater immediately following the retreat of the ice, such adjustments, and thus potential uncertainty, will be more critical further back in time. The resulting SLIPs are most commonly interpreted as representing the isolation of the basins from the highest astronomical tide, which is adjusted to mean sea-level in the compilation of the displacement curves, based on the present-day tidal range. For simplicity, the tidal range is assumed to have been the same throughout the Holocene (Sørensen et al., 2014a:44). The highest astronomical tide in the study area reaches around 30 cm above mean sea-level (30 cm at the standard port Helgeroa in Larvik, Norwegian Mapping Authority, 2021).

As the displacement curves and their trajectory are quite complex constructs and the integrated result of both expert knowledge and more objectively quantifiable parameters, the geologists that have undertaken the studies have not found reason to assign variable uncertainty within the confidence envelopes of the displacement curves (Romundset et al., 2018:187; Sørensen et al., 2014a:44). The reason for this is that the trajectory of the curves is not only based on radiometric dates, the uncertainty of which are well-defined, but are for example also dependent on the interpretation and analysis of sediment cores, the nature and condition of the basin outlets and the adjustment to a common isobase, as well as being based on expert knowledge of regional post-glacial geologic developments and local geomorphology, to name but a few factors (e.g. Romundset et al., 2011, 2018; Svendsen and Mangerud, 1987; for an alternative approach see Creel et al., 2022). For more details and evaluations done for the compilation of each curve, the reader is therefore referred to the individual publications.

The archaeological data compiled for the analysis consists of excavated Stone Age sites with available spatial data from the coastal region between Horten county in the north-east, to Arendal in the south-west (Fig. 2). These number 167 sites, of which 91 are associated with the total of 547 radiocarbon dates. Of these, in turn, 66 sites are related to the 255 radiocarbon date ranges that intersect the Stone Age (9500–1700 BCE), with 95% probability. These sites and ^{14}C-dates form the basis for the analysis. Spatial data in the form of site limits and features, as defined by the excavating archaeologists, were retrieved from local databases at the Museum of Cultural History of the University of Oslo—the institution responsible for archaeological excavations and data curation in the region. In the compiled dataset, each radiocarbon date has been associated with the site features or excavation unit from where they originate, or, where these weren't available, the spatial limit of the entire site. Due to somewhat variable practices between excavations, what available spatial geometry best represents the site limit was decided based on an evaluation of the excavation reports. This means that the limits are variably given as that defined during initial survey, area de-turfed before excavation, area stripped with excavator following the excavation, manually excavated area, or convex hull polygons generated around the site features.

Three of the sites have been associated with agriculture, either directly or in the form building structures. The first is Nordby 1 at which the ^{14}C-dates are associated with a Late Neolithic long-house (Gjerpe and Bukkemoen, 2008). The Middle Neolithic phase at Kvastad A2 (Stokke and Reitan, 2018) and Late Neolithic phase at Nauen A (Persson, 2008) are both directly related to farming activities. Both of these sites also have radiocarbon dates and lithic inventory associated with Mesolithic forager activities. Following from the expected deviance from the settlement patterns that are

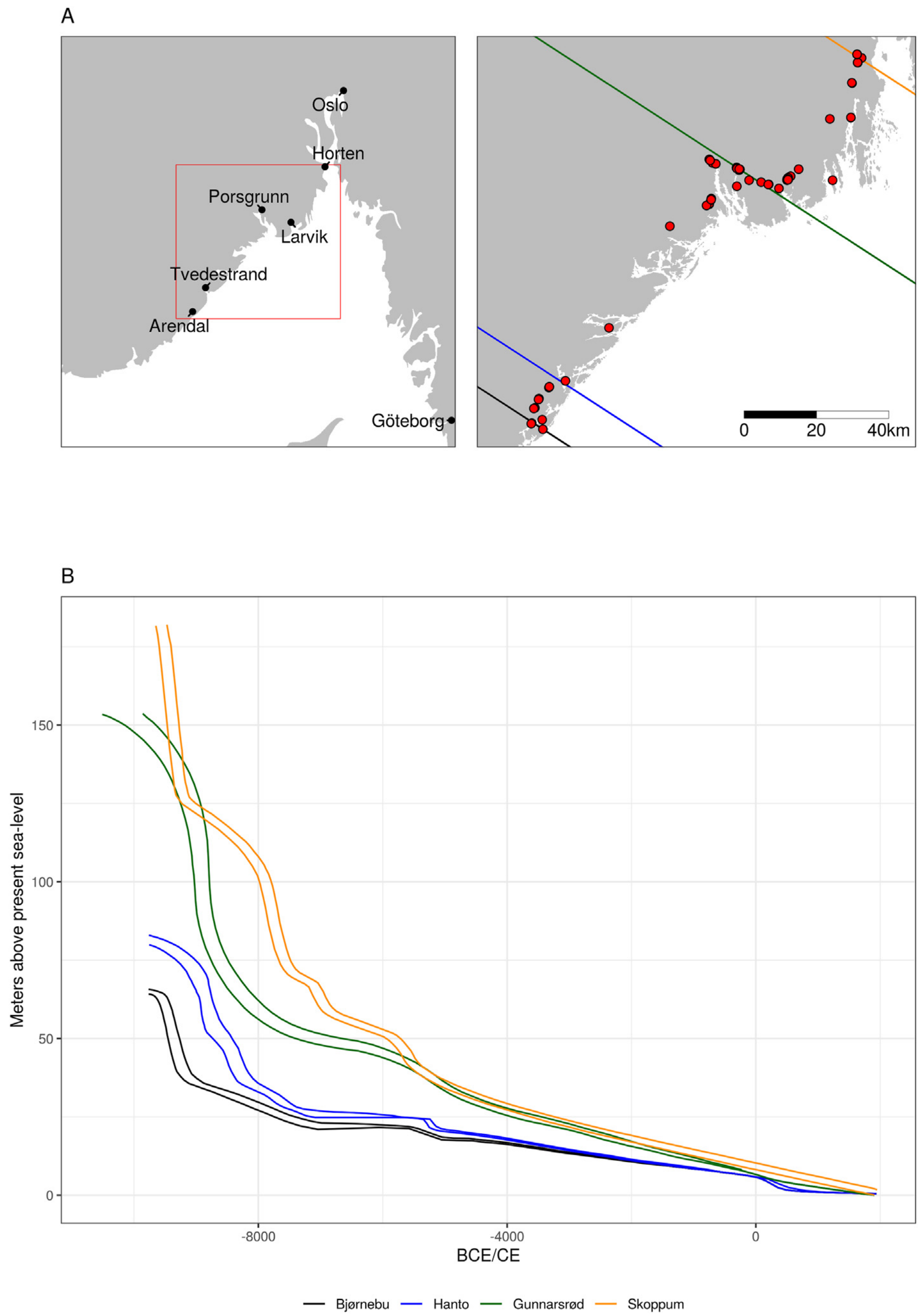

Fig. 2. A) Location of the study area and the distribution of the 66 analysed sites relative to the isobases of the displacement curves. The isobases have a direction of 327° (Romundset et al., 2018, although see Sørensen et al., 2014a). B) Displacement curves. Note the increasing steepness of the curves towards the north-east.

to characterise forager sites, these agricultural phases are highlighted in the analysis below. Finally, Nielsen (2021) has recently suggested that Early and Middle Neolithic features from the otherwise younger sites Bratsberg (Wenn, 2012) and Larønningen (Røberg, 2012) could be related to early agricultural activity in the Oslo fjord region. Due to the uncertain and somewhat speculative nature of this suggestion, these are omitted here.

The elevation data used for the analysis is a digital terrain model (DTM) freely available from the Norwegian Mapping Authority (Norwegian Mapping Authority, 2018; https://hoydedata.no). The 10 m resolution DTM was used rather than the higher-resolution 1 m version, both because this resulted in considerably less processing time and because the higher resolution elevation model is more vulnerable to smaller-scale modern disturbances. The 10 m resolution DTM of the study area is a down-sampled version of the 1 m version and has a height accuracy with a systematic error of 0.1 m (Norwegian Mapping Authority, 2018). All data and R programming code (R Core Team, 2021) required to run the analyses, as well as the derived data are freely available in a version-controlled repository at https://doi.org/10.17605/osf.io/7f9su, organised as a research compendium following Marwick (2017; Marwick et al., 2018).

4. Methods

Shoreline dating is based on the spatial relationship between two phenomena, occupation of sites and shoreline displacement, each associated with temporal uncertainty. The first task was therefore to ascribe a likely date and associated degree of uncertainty to these dimensions. To take account of the gradient in the isostatic rebound, the trajectory of shoreline displacement was first interpolated to each site location based on the distance to the isobases of the displacement curves, using inverse distance weighting (e.g. Conolly, 2020; Conolly and Lake, 2006:94–97). This was done for each year along the entirety of the curves, weighting the interpolation by the squared inverse of the distances. The result of this process is shown for an example site in Fig. 3. For the sites all radiocarbon dates were first individually calibrated using the IntCal20 calibration curve (Reimer et al., 2020) using OxCal v4.4.4 (Bronk Ramsey, 2009) through the oxcAAR package for R (Hinz et al., 2021). Radiocarbon dates associated with each site were then grouped if their date ranges intersected at 99.7% probability, meaning these were effectively taken to be associated with the same occupation event, here termed settlement or site phase. In the case where there are multiple dates believed to belong to a single settlement phase, these were modelled using the Boundary function in OxCal and then summed using the Sum function. Multiple phases at a single site were treated as independent of each other.

The excavation of archaeological sites in Norway typically occur in advance of residential and commercial infrastructure development. As the data collection for the utilised DTM was begun by the Norwegian Mapping Authority in 2016, the area of the DTM immediately surrounding the sites has sometimes been severely impacted by disturbances after the excavation. In addition to employing the 10 m resolution DTM to alleviate some of these issues, this also necessitated some additional editing of the elevation raster. This involved manually defining the extent of problem areas such as railways, highways, quarries and the like. The DTM values on these were then set to missing, and new elevation values were interpolated from the surrounding terrain. This was done using regularised spline interpolation with tension (e.g. Conolly, 2020), using the default settings of r.fillnulls from GRASS GIS (GRASS Development Team, 2017) in R through the package rgrass7 (Bivand, 2021). In addition to code and original spatial data being available in the online repository for the paper, the location and analysis of each individual site is presented in the supplementary material where it has been noted when the area surrounding a site has been edited in this manner.

Armed with a likely date range for the occupation(s) of each site, an estimated trajectory of RSL change at that location, and a DTM edited to remove substantial modern disturbances, the simulations were performed. A single simulation run involved first drawing a single year weighted by the posterior probability distribution of a given occupation phase of a site (Fig. 4). This year then has a corresponding likely elevation range for the contemporaneous shoreline from which an elevation value was drawn uniformly, using intervals of 5 cm. The sea-level was then raised to this elevation on the DTM by defining all elevation values at or below this altitude as missing. Polygons were then created from the resulting areas with missing values. The horizontal distance was then found by measuring the shortest distance between site and sea polygons, and the vertical distance by subtracting the elevation of the sea-level from the lowest elevation of the site polygon. The topographic distance between site and sea was also found by

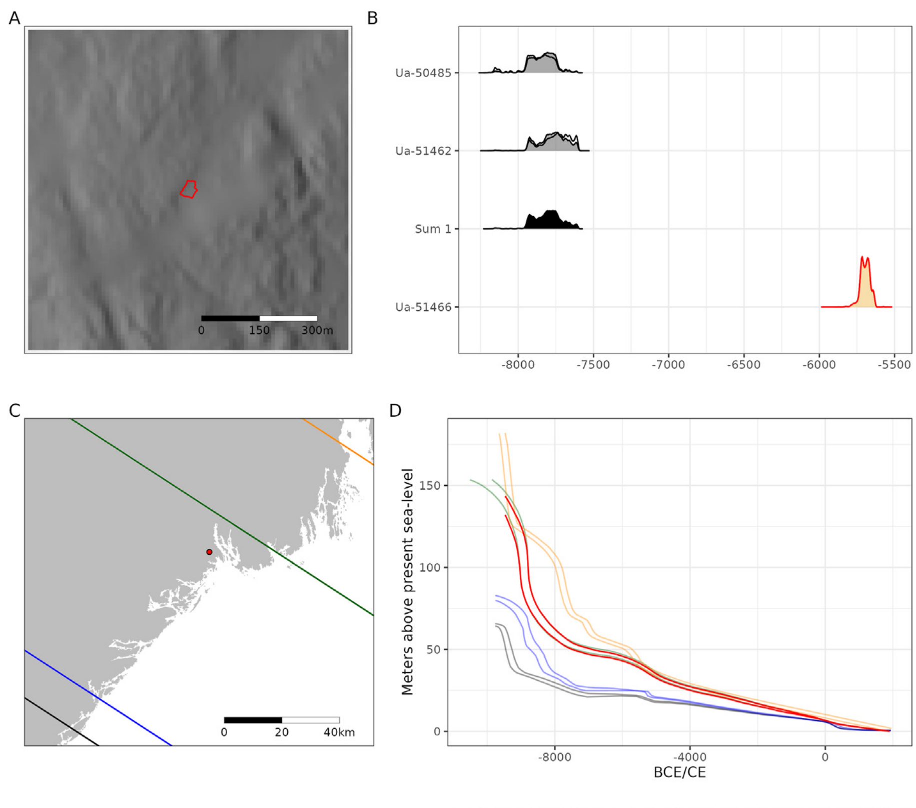

Fig. 3. Example site Hegna vest 1 (Fossum, 2017). A) Location of the site on the edited 10 m resolution DTM. The red outline is the site limit. B) Radiocarbon dates associated with the site. Fill colour indicates what dates are assumed to belong to the same settlement phase. Multiple dates are modelled using the Boundary function in OxCal and then summed. The red outline indicates that the date does not match the typological indicators in the artefact assemblage of the site. C) The location of the site within the study area relative to isobases of the displacement curves. D) Displacement curve interpolated to the site location. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

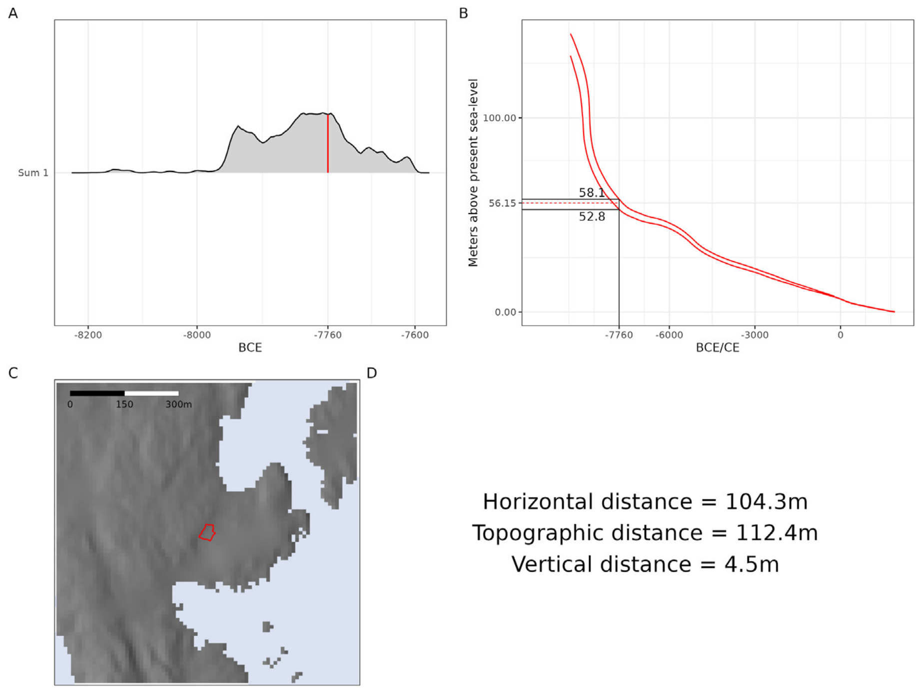

Fig. 4. Example of a single simulation run on the site Hegna vest 1. A) The simulation starts by drawing a single year, weighted by the posterior probability distribution. B) This then corresponds to an elevation range on the interpolated displacement curve. A single elevation is drawn uniformly from this range using 5 cm intervals. C) The sea-level is then adjusted on the DTM to this elevation and the various distance measures are found. D) The numerical result of the simulation run.

measuring the distance while taking into account the slope of the terrain on the DTM. This was done using the topoDistance package for R (Wang, 2019). The topographic distance was measured between the points on the site and sea polygons that were identified as being the closest when measured horizontally. Because it is measured as the shortest topographic path between the horizontally closest points, this means that the distance does not necessarily match the closest topographic distance if the entirety of the polygons had been considered. Not finding the topographically closest points significantly reduced the computational cost of the analysis, and is deemed unlikely to have a considerable impact on the results, given the distances considered. The shortest topographic path was found using the Moore neighbourhood of eight cells (e.g. Conolly and Lake, 2006:253; Herzog, 2013).

In the case where the sea polygons intersect the site polygon, all distance measures were set to zero. In the case that the sea polygons completely contain the site, the horizontal and topographic distance measures were made negative, and the vertical distance was instead measured to the highest point on the site polygon. While it is safe to assume that an archaeological site was not occupied when it was located below sea-level, a negative result can reflect the inherent uncertainty in this procedure, and might also help identify discrepancies in displacement data or radiocarbon dates. Negative values were therefore retained except of for the sites Gunnarsrød 5 and Pjonkerød R1, where the negative values are believed to result from modern disturbances in the DTM rather than the ^{14}C-dates or displacement curves (see supplementary material for more details).

This process was repeated 1000 times for each phase for each site (Fig. 5). The choice of 1000 simulation runs follows from an evaluation of when the mean distances between site and shoreline converged when running 5000 iterations of the simulation on the site Hovland 5 (cf. Crema et al., 2010:1125). This evaluation is presented in the supplementary material. Hovland 5 was chosen for this assessment as it has an imprecise age and is located in area of quite complex topography (Mansrud and Koxvold, 2013).

5. Simulation results

Overall, as is indicated by the measures for central tendency and the almost solid line along the 0 m mark on the y-axes, the simulations show that the sites tend to have been situated close to the shoreline when they were in use (Fig. 6). As is also illustrated by the measures for dispersion, some of the sites are situated considerable distances from the shoreline when the dates believed to be erroneous in the original reports are included (Fig. 6A). However, if one accepts the interpretation that these do not date the main occupation of the sites, as is indicated by the artefact inventories, Fig. 6B gives considerable support to the notion that the sites were in use when they were situated on or close to the contemporaneous shoreline. The distances for the earliest sites appears somewhat high, with the highest vertical distance of the results older than 7500 BCE being 27.9 m. But this can likely be explained as the result of the rapid RSL fall in the earliest part of the Holocene (Fig. 2B), which leads the uncertainty of the ^{14}C-dates to give a wider possible elevation range for the simulated sea-level. This is also indicated by the fact that the median vertical distance for the same simulation results is 6.1 m, and 15 of the 18 sites associated with these results have simulated vertical distances that extend below 5 m.

Another immediately striking result is the apparent deviation from the shoreline towards the end of the Stone Age. Of the results from after 2500 BCE, which are associated with 8 sites, only one has simulation results for vertical distance that includes zero. The highest simulated vertical distance among these is 56.5 m and the median is 12.9 m. Furthermore, some deviation from the shoreline is evident from just after 4000 BCE as well. Of the 21 sites associated with the period between 4000 and 2500 BCE, two sites have all vertical distance results above 25 m. However, the median vertical distance of the results from this period is only 4.3 m, indicating that

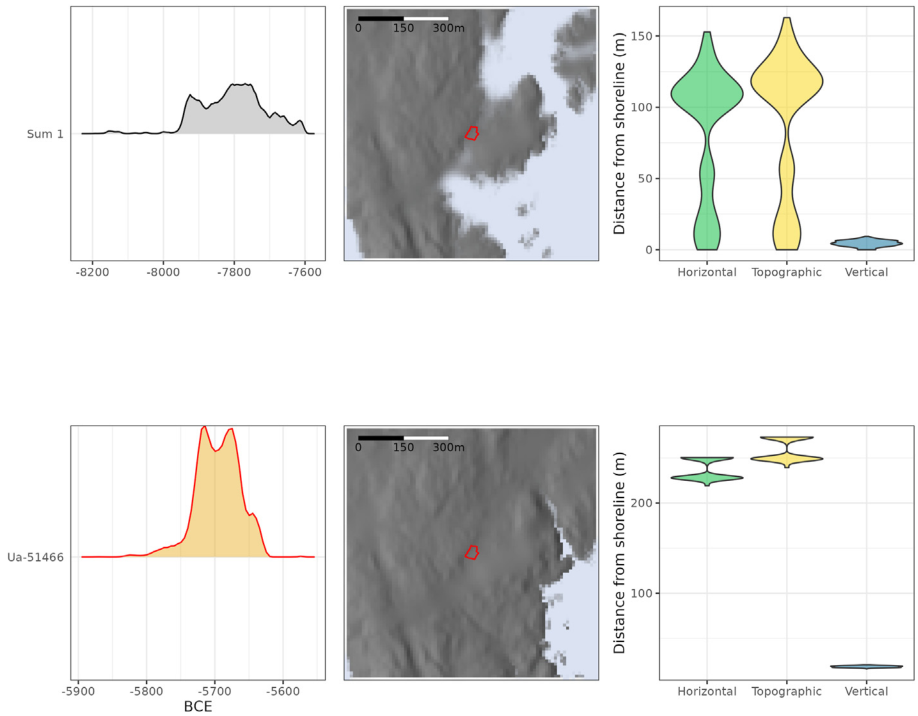

Fig. 5. The result of 1000 simulation runs for each of the two groups of dates on the site Hegna vest 1. The leftmost column of plots shows the calibrated radiocarbon probability distribution from where dates were drawn during simulation. The centre column displays the result of simulating the raised sea-level 1000 times. The more opaque the colour appears, the more times the sea-level was simulated in that location. The rightmost column shows violin plots of the different distance measures across all simulations. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

while some sites have a markedly withdrawn location, most are still situated close to the shoreline. The chronological smearing following from the uncertainty in the ^{14}C-dates means that while the results cannot be used to directly inform discussions that deal with the century scale around these chronological transitions (e.g. Prescott, 2020; Solheim, 2021), the findings are nonetheless in clear agreement with the general chronological developments suggested in the literature.

The negative values around 8000 BCE originate from the sites Løvås 1, 2 and 3. Berg-Hansen et al. (2022:644) made a similar observation in their assessment of the correspondence between shoreline displacement and radiocarbon dates from these sites. The sites are recently excavated, well-dated and are situated in a relatively undisturbed area of the landscape (Berg-Hansen et al., 2022; Reitan and Hårstad, 2022). While there could be a danger of circularity of having archaeological sites inform a reconstruction RSL-change, and, in turn, use these to evaluate the degree of shore-bound settlement, the sites do clearly represent an upper constraining limit for the sea-level, as they would not have been in use when located under water. It therefore seems that the Løvås sites represent a case where the archaeological material indicates a slight discrepancy in the geologic reconstruction of shoreline displacement in the area.

Accepting that shoreline dating appears to lose utility around the transition to the Late Neolithic, as indicated by the clear deviation in site location from the shoreline after this, the results from Fig. 6B are presented again in Fig. 7A, excluding all simulation results younger than 2500 BCE. Furthermore, all negative values have here been set to zero, under the assumption that these result from uncertainty or errors in the data, and not actual site locations. The resulting best point estimate for the vertical distance between sites and shoreline for the pre-Late Neolithic is given by the median distance of 4 m, while 95% of the values fall within the range 0–18 m. That is, for 95% of the cases, the shoreline was simulated to be situated on or less than 18 m below the site location. While these values remain the same when only the Mesolithic dates are included (Fig. 7B), the mean and standard deviation are slightly constrained. Furthermore, while the median for horizontal and topographic distance is only 10 m across all plots in Fig. 7, the relative magnitude of the statistics for dispersion is greater than what it is for vertical distance, illustrating the point that minor variations in vertical distance can have substantial consequences for these distance measures, depending on the surrounding topography.

It is clear that the distributions in Fig. 7 have a severe right skew. Most sites were likely situated less than a meter from the shoreline, and from this there is a sharp decline in density as one moves further along the x-axes. To characterise this relationship, a series of standard models for distributions with a right skew have been fit to the simulation results for vertical distance older than 2500 BCE (Fig. 7A) by means of maximum likelihood estimation (Table 1). As most of the models only accept positive values, a constant of 0.001 was added to avoid values of zero. It was attempted to both remove negative values and force these to zero before adding the constant. As the difference between these two solutions was negligible, and as the assumption here is that negative values in actuality reflect a distance of zero, the latter approach was chosen (a plot displaying the negative values and the compared models is available in the supplementary material).

The performance of the models was then compared by means of the Akaike information criterion (AIC) and the Bayesian (or Schwarz) information criterion (BIC). The AIC and BIC evaluate the degree to which the models fit to the data, while penalising for the number of model parameters to avoid over-fitting (e.g. Burnham and Anderson, 2002; for applications in archaeology see e.g. Eve and Crema, 2014; Timpson et al., 2021). As lower values point to

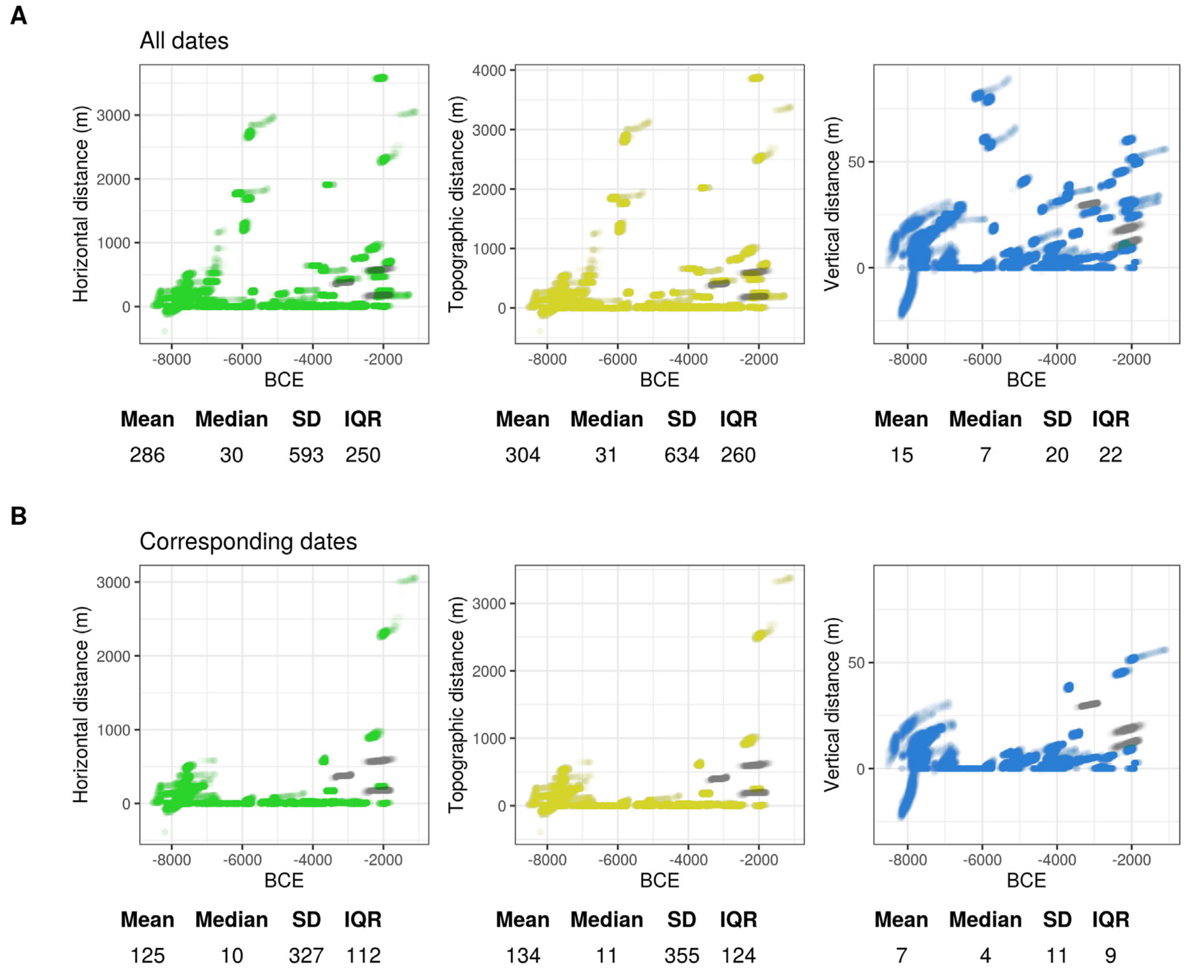

Fig. 6. The result of running the analysis across all sites. Each data point is plotted with some transparency, meaning that the more intense the colour, the more often those values occurred. Results associated with agricultural activities are plotted in grey. The first row A) shows the result of including all dates to the Stone Age, including those seen as otherwise unrelated to the main occupation of the sites (66 sites and 166 site phases). The second row B) shows the result of excluding these (resulting in 51 sites and 69 site phases). The table under each plot lists some corresponding statistics for central tendency and dispersion. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

a better model, it is evident from both the AIC and BIC that the gamma is the best among the candidate models. It is worth noting that this could have benefited from a more sophisticated treatment of the zero-values. This is because these are likely to be a mix of both exact zeros, the case when there is an actual intersection between site and sea, and, although probably to a far lesser extent, zeroes that result from the case when the distance between site and sea is below the detection limit due to the employed methods and the resolution of the spatial data (e.g. Dunn and Smyth, 2005; Helsel, 2005). In conclusion, however, the gamma appears to represent a reasonable approximation of the data. If one accepts this, the probability density function for the gamma distribution can be used to characterise the vertical distance between sites and the shoreline and be used to inform a method for shoreline dating that takes this into account.

6. Shoreline dating

The procedure for shoreline dating to be outlined is aimed at determining the likely age of the occupation of a site based on its altitude above present day sea-level, with reference to shoreline displacement and the likely elevation of the site above the sea-level when it was in use. For simplicity, this is conceptually treated a single event and thus the possibility of multiple or continuous phases of occupation is not treated explicitly. This leads the problem to become similar to that of the calibration of a radiocarbon date (see Fig. 8, Bronk Ramsey, 2009; Stuvier and Reimer, 1989; van der Plicht, 1993). First, finding the elevation of the sea-level at the time the site was in use is dependent on the present-day elevation of the site E and the distance between site and the shoreline D. Based on the simulation results above, the distance from the elevation of the site to the contemporaneous shoreline is defined by the probability density function for the gamma distribution:

$$p(E-D) = \frac{1}{\sigma^{\alpha}\Gamma(\alpha)}(E-D)^{\alpha-1}e^{-(E-D)/\sigma} \quad (1)$$

where α is the shape and σ the scale of the distribution, and $\Gamma(\alpha)$ denotes the gamma function. This can then be coupled with the trajectory of relative sea-level change to find the corresponding calendar date T for the occupation of the site. This is defined by a discrete uniform probability mass function (Ud) on the calendar scale over the range between the lower T_l and upper T_u bounds of the displacement curve that has been interpolated to the site location:

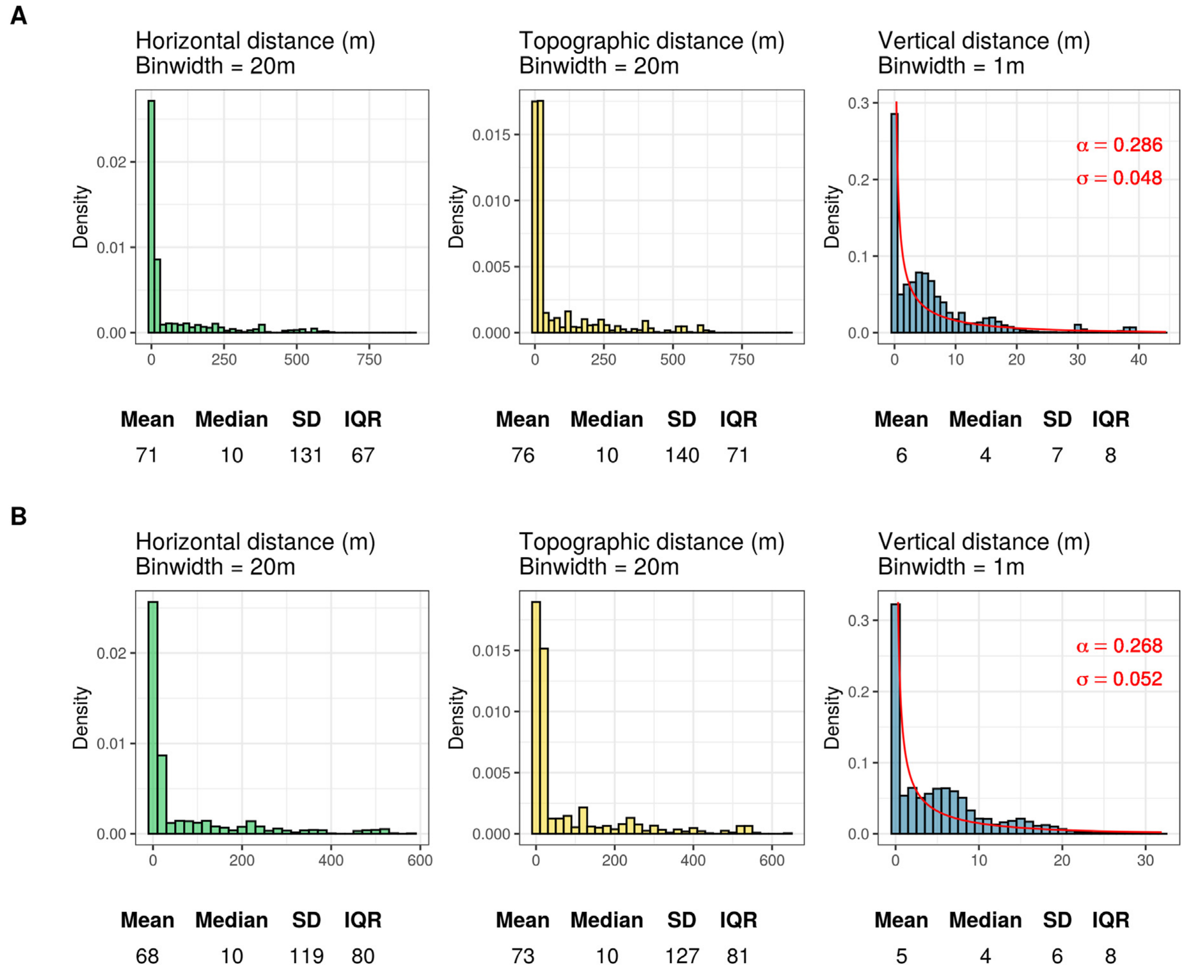

Fig. 7. Histograms showing the simulated distance from the shoreline using radiocarbon dates corresponding to the site inventories. Negative values have been set to zero. A) Simulated results older than 2500 BCE (50 sites and 66 site phases) and B) simulated results older than 4000 BCE (43 sites and 51 site phases). Note that the cut-off is done based on the calendar year associated with each distance value. Consequently, sites and site phases are only completely excluded if the entire posterior probability of the radiocarbon dates falls later than the cut-off. Furthermore, the superimposed gamma distributions have been fit when adding a constant of 0.001 to the distance values and have been cut off on the y-axis for visualisation. The gamma distribution in A forms the basis for the analysis to follow, but a version has also been fit to the vertical distances in B to further illustrate the difference between the distributions.

Table 1
Comparison of models fit to the simulated vertical distances older than 2500 BCE, with negative results set to zero and a constant of 0.001 added to the values. The models are listed in the order of performance. A plot with all of the models is available in the supplementary material.

Model	Parameters	AIC	BIC
Gamma	Shape (α) = 0.286 Scale (σ) = 0.048	230,247	230,229
Log-normal	Mean of the logarithm (μ) = −0.647 SD of the logarithm (σ) = 3.926	268,082	268,064
Power law	Exponent (k) = 1.16	274,052	274,043
Exponential	Rate (λ) = 0.168	348,484	348,475
Logistic	Location (μ) = 4.698 Scale (σ) = 3.558	415,322	415,304

$$p(T|E-D) = Ud\left[T_{l|E-D}, T_{u|E-D}\right] \tag{2}$$

Finding the probability for the date of the site then becomes a matter of transferring the probability of the distance between site and shoreline to calendar dates using the displacement curve:

$$p(T|E-D) = p(T|E-D)p(E-D) \tag{3}$$

We can then get rid of parameter D by summing all possible distances between site and the shoreline. Given its elevation, the probability for the date of the occupation of a site is then:

$$p(T|E) = \sum_D p(T|E-D)p(E-D) \tag{4}$$

An example of an implementation of the outlined approach is given in Fig. 8, where $\alpha = 0.286$ and $\sigma = 0.048$. These are the parameters for the gamma distribution identified when considering all pre-Late Neolithic simulation results (Fig. 7A) and are the parameters used in all applications of the proposed method that follow below. For the numerical implementation, D is here stepped through as a sequence of increments of 0.001 m, which, following from the adjustment of the values for fitting the compared models, starts from 0.001 m. The gamma distribution is stepped through in its cumulative form, where the probability from the previous 0.001 m step is subtracted from the probability at the current step. This probability is then divided equally across the individual calendar years in the range between the lower and the upper limit of the displacement curve at the current 0.001 m step. The probability mass function that is the resulting shoreline date is the sum of performing this procedure on all possible 0.001 m values of D,

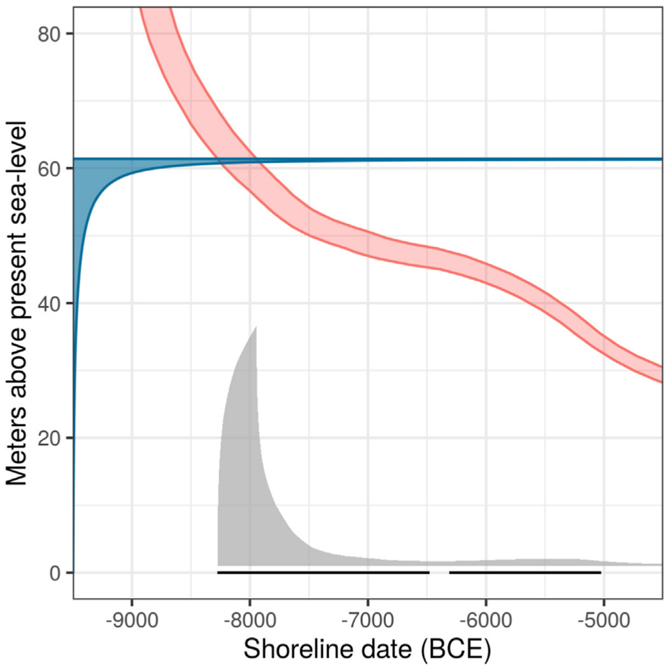

Fig. 8. Shoreline dating of Hegna vest 1. The mean elevation of the site polygon is used to inform E in the dating of the site. The gamma distribution in blue on the y-axis extends the full range of possible values for E − D and has the parameters $\alpha = 0.286$ and $\sigma = 0.048$ (see Fig. 7A). The red envelope marks the shoreline displacement curve interpolated to the site location. The resulting shoreline date in grey is underlined with the 95% HDR in black. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

which, in practice, is down to and including $E - D = 0.001$ or when 99.999% of the gamma distribution has been stepped through.

To evaluate the outlined procedure, it is used to shoreline date the sites from where the method was derived to check if the resulting shoreline dates correspond to the radiocarbon dates associated with the sites (Fig. 9). The Late Neolithic sites are also included here for illustrative purposes, even though these have not informed the gamma parameters in use. Following from having defined the distance between intersecting sea- and site polygons as zero during simulations, the sites were dated using the mean elevation of the site polygons to allow for some variation in elevation over the site limits. The synchroneity between radiocarbon and shoreline dates was then evaluated using the method presented by Parnell et al. (2008). Here, 100,000 age samples drawn from the probability mass function of each shoreline date were subtracted from 100,000 age samples drawn from the corresponding probability mass function of the modelled ^{14}C-dates. The resulting range of the 95% highest density region (HDR, Hyndman, 1996) was then checked to see if it crosses zero, in which case the dates are considered to be in agreement (Fig. 10). When excluding the earliest occupation phase at Gunnarsrød 5, the deviation of which is to be expected based on issues with the DTM (see above), the shoreline date corresponds to the radiocarbon dates in 64 out of 68 cases (93%). Only including dates modelled to be older than 2500 BCE with 95% probability, i.e. older than the Late Neolithic, improves this to 60 out of 62 cases (97%). When only including dates older than 4000 BCE with 95% probability, i.e. only Mesolithic site phases, the success rate is further increased to 49/49 (100%).

7. Re-dating previously shoreline dated sites

To further explore the implementation for shoreline dating presented above, 87 excavated and shoreline dated Stone Age sites within the study area where ^{14}C-dates are not available or these are not believed to date the main occupation of the sites have been subjected to the outlined approach (Fig. 11). The resulting dates are compared to those originally proposed in the excavation reports for the sites (the numerical results are available in the supplementary material). To avoid issues with recent disturbances in the DTM, the sites have been dated based on the mean of the altitudes provided in the report for each site. As all of the included sites have been excavated after the turn of the millennium, and the wide adoption of GNSS technology, the reported elevations should be trustworthy.

This comparison is useful for illustrating both how the method has previously been employed, and for revealing nuances of the implementation that is proposed here. However, the comparison is also unfair to the previously proposed dates for a few reasons. First, the dates provided in the reports are typically stated to be a very rough estimate and are sometimes given as a point estimate with an undefined, but implied or explicit uncertainty range. Secondly, seeing as these reports are from various dates in time, many are based on now outdated data on RSL-change. Thirdly, they are sometimes only meant to indicate a lower bound for when the sites could have been in use. Additionally, the dates are often stated to be the result of also considering artefact typology and characteristics of local topography to inform the likely elevation of the sea when the site was in use—although precisely how these are weighted and used to inform the suggested date is often not as clear.

With a few exceptions, the previously hypothesised dates and the ones achieved here appear to roughly correspond when it comes to the start date for the occupation of the sites. The clearest difference mainly pertains to the fact that the previously proposed date ranges are, almost without exception, more constrained than the 95% HDRs resulting from the proposed method. Considering the right skew of the probability mass functions underlying the 95% HDRs and the general overlap for the start dates, these results could, with some danger of circularity, suggest that shoreline dating has generally been applied with a reasonable degree of success. This also follows from the fact that these dates have typically informed research in an approximate manner (although see e.g. Roalkvam, 2022).

With these considerations in mind, the results also indicate that shoreline dating has at times been applied with an exaggerated degree of precision. While the implications of a more stable RSL-change for shoreline dating are well known, this also appears to be somewhat under-appreciated in the practical implementation of the method. The results indicate that the spatial and temporal contingency of the method is better captured by the implementation suggested here, as is illustrated by the variation in the range of the 95% HDRs for the dates. In some cases the proposed method provides a relatively precise date and in others the HDR offers little more than a *terminus post quem*. This is dependent on the steepness of the displacement curves, leading to the general pattern of older sites situated towards the north-east getting more precise dates (cf. Fig. 2B). However, as some of the 95% HDRs extend well beyond major chronological divisions, even into the Iron Age, it is also clear that some of these could be severely and securely constrained with only cursory reference to typology. While this would be trivial in some cases, the nature and uncertainty inherent to the method still means that this is arguably an exercise that should be explicitly performed. This also points to the possibility of drawing on other temporal data to further improve the precision of the dates that can be achieved with shoreline dating.

Not least following from the fact that relatively few ^{14}C-dates older than c. 8000 BCE associated with anthropogenic activity have been achieved in Norway (Åstveit, 2018; Damlien and Solheim, 2018; Kleppe, 2018), the shoreline dating of the earliest sites is

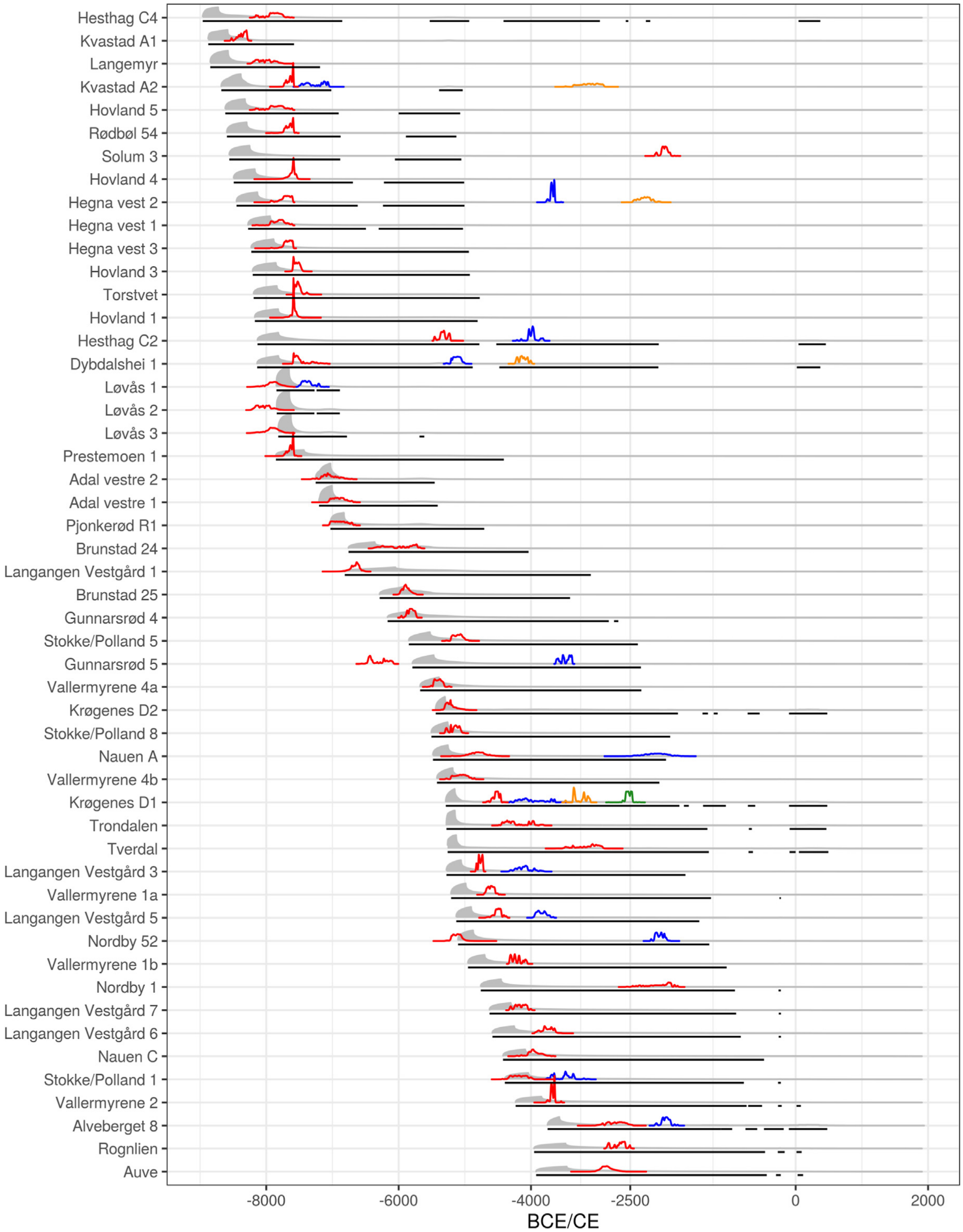

Fig. 9. The result of backwards shoreline dating the 51 sites with radiocarbon dates corresponding to the artefact inventory using the method proposed here. The shoreline dates are plotted in grey and underlined with the 95% HDR in black. These are plotted against the modelled radiocarbon dates, which are given colour from oldest to youngest occupation phase for each site, defined by non-intersecting dates at 99.7% probability. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

essential for understanding the pioneer settlement and the initial colonisation of the Scandinavian peninsula (e.g. Bang-Andersen, 2012; Berg-Hansen, 2018; Breivik, 2014; Fuglestvedt, 2012; Glørstad, 2016). The shoreline dated Preboreal sites from the Brunlanes-project are among the earliest known sites in Norway (Jaksland, 2012a, 2012b; Jaksland and Persson, 2014). These have a distinct Early Mesolithic artefact inventory and are situated in a steep area of the landscape where use of the sites would have been

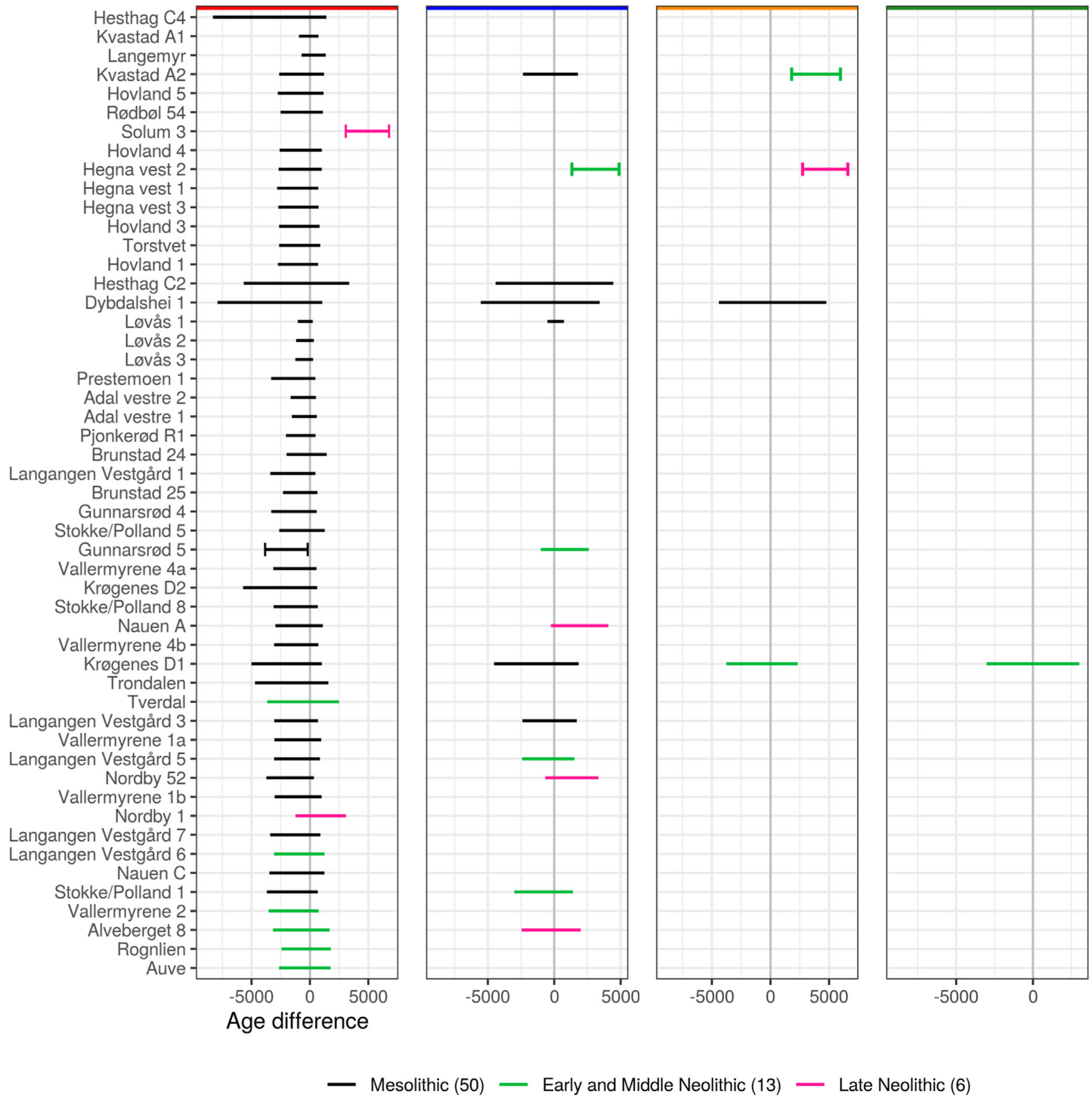

Fig. 10. Evaluation of the agreement between the shoreline dates and radiocarbon dates given in Fig. 9. When the range of the 95% HDR for age difference crosses zero, the shoreline and radiocarbon dates are considered to be in agreement. Line segments with vertical bars indicate that the HDR does not cross zero and that the dates do not correspond. The division and colour coding at the top of the plots reflect the division of site phases given in Fig. 9. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

difficult after the sea retreated any significant distance from their location due to accessibility. In the original publication of the sites, Jaksland (2014) provides a thorough discussion of shoreline dating in general, and as used for the dating of the Brunlanes sites specifically. A comparison of his results and the ones achieved using the above-outlined approach are given in Fig. 12A. The sites have been dated using what Jaksland (2014) gives as the lowest elevation of finds at each site.

The small discrepancies between the achieved results mainly follow from the fact that a slightly updated version of the local displacement curve is applied here (Sørensen et al. in press; cf. Sørensen et al., 2014a). Jaksland's dates are given a flat 200- and 50-year uncertainty range starting from what he gives as the earliest possible date. The 200-year uncertainty range is given if the sites were to be considered in isolation, while his argument for the uncertainty range of only 50 years is based on the location of the sites relative to each other. Since they are located in such a constrained and steep area of the landscape, the difference in elevation between the sites is argued to establish their relative date and thus constrain the uncertainty ranges so that they do not overlap. This information is not integrated in the approach outlined here, but it could justify further reducing the uncertainty ranges. Although their accuracy is of course ultimately dependent on the veracity of the geological reconstruction, the high rate of RSL change in this period does nonetheless result in very precise dates.

Above it was suggested that additional temporal data could be combined with the method to improve its precision. Drawing on Jaksland (2014), this example instead highlights the fact that the spatial nature of the method means that a consideration of the surrounding terrain and other sites can also help to increase the precision of the method if this can be used to exclude certain RSLs as unlikely for when a site was in use. One potential way to do this

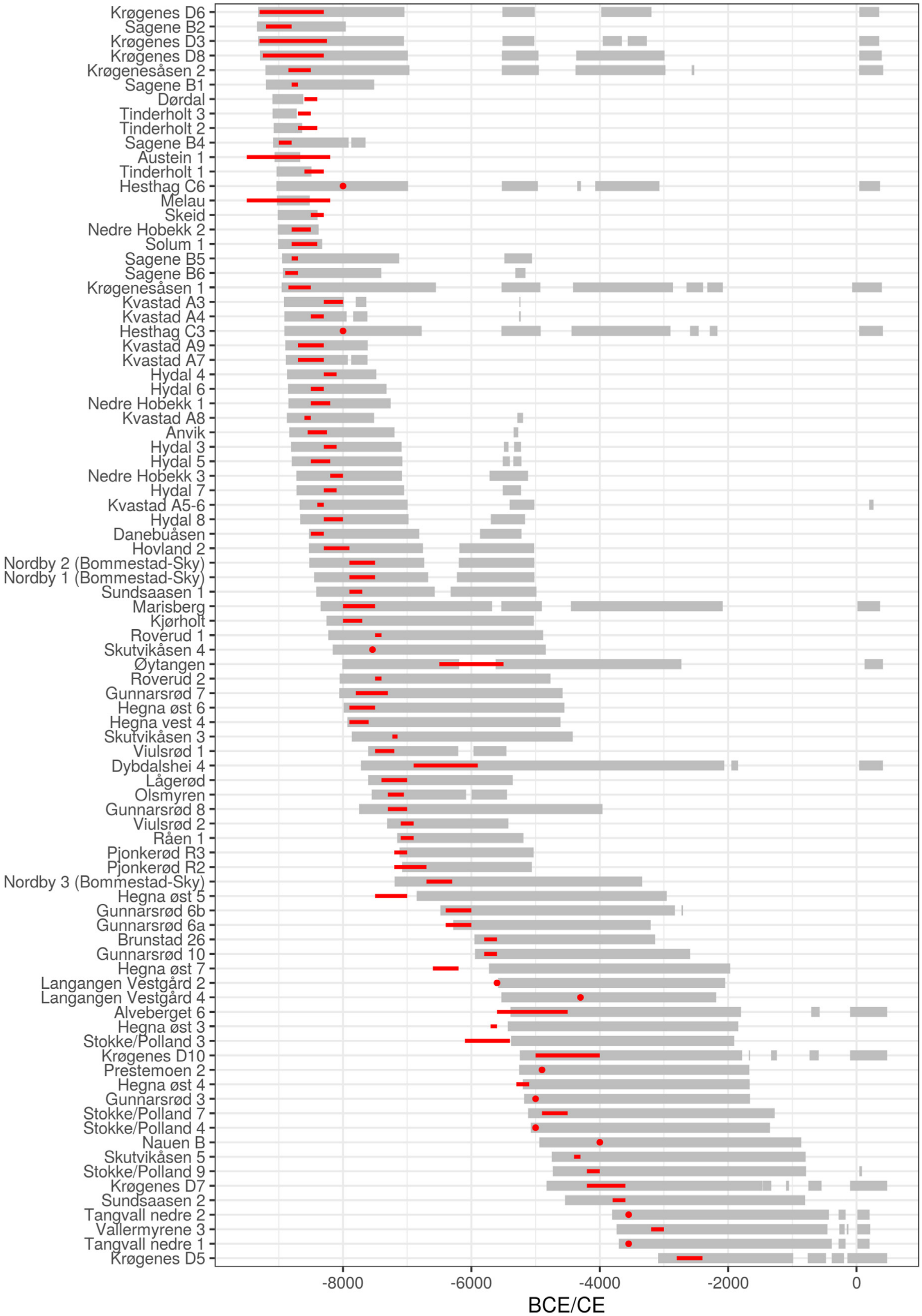

Fig. 11. Re-dating 87 excavated and previously shoreline dated sites in the study area without radiocarbon dates or with radiocarbon dates that do not correspond to the artefact inventories. The 95% HDRs in grey are compared to the dates originally proposed by the excavation reports in red. For clarity in the figure, only the 95% HDRs of the shoreline dates are displayed. However, the reader is asked to keep in mind that these are associated with a probability mass function with a right skew that form a better foundation for any further analysis (see e.g. Telford et al., 2004). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

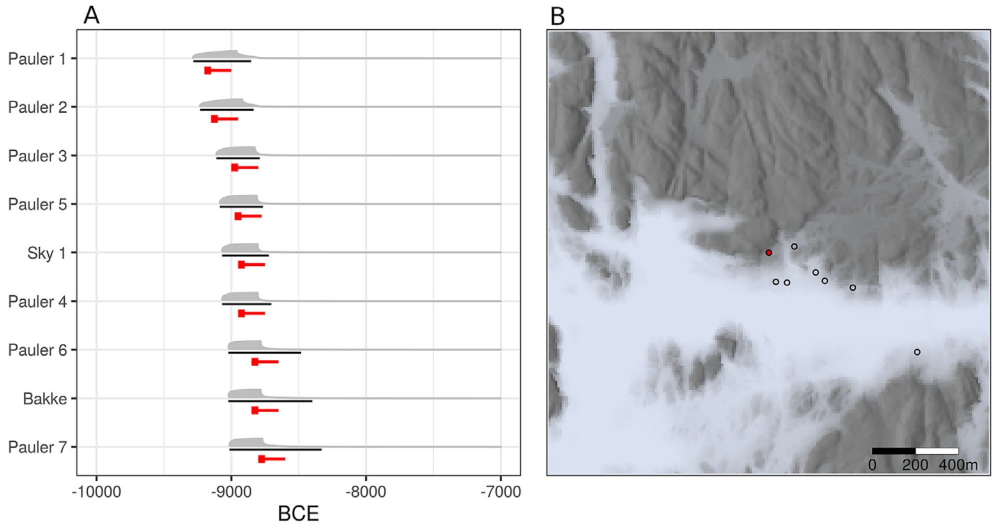

Fig. 12. Shoreline dating of the Brunlanes sites using site altitudes provided by Jaksland (2014:tab.4). A) The result of applying the approach to shoreline dating outlined above. The shoreline date in grey is underlined with the 95% HDR in black. Dates provided by Jaksland (2014) are plotted in red. The box indicates a 50-year uncertainty range which in combination with the red line extends 200 years. B) Map showing the centroids of the Pauler sites and Sky 1. The sea-level has been simulated using the probability distribution associated with the shoreline date for Pauler 1 (see also map in Jaksland, 2014:Fig. 12a). Pauler 1 is the red point. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

could be through the analysis of phosphate concentrations in soils, which has the potential to offer insights on the likely position of the shoreline when a site was in use (Ilves and Darmark, 2011). This has been done in the Baltic Sea region (e.g. Broadbent, 1979; Ilves and Darmark, 2011; Sundström et al., 2006), but has yet to provide reliable results in Norway (e.g. Melvold and Persson, 2014b; Viken, 2018). The identification of other physical traces of shore formation processes and the deposition of beach sediments in relation to archaeological material also holds similar potential (e.g. Bondevik et al., 2019). Finally, another approach could also be to assess the spatial implication of a proposed shoreline date by simulating the adjusted sea-levels, as is done for Pauler 1 in Fig. 12B, followed for example by a visual evaluation of the topography or by evaluating the distance and steepness of the slope to the shoreline. If such methods are developed further, it could conceivably be possible to exclude certain elevations as unlikely for the position of the shoreline when the site was in use. Such approaches would make less of an impact for the Brunlanes sites, where the 95% HDRs are already quite constrained, but could considerably improve the precision of the method in cases where RSL-change has been less severe (cf. Fig. 11).

8. Concluding remarks

The most significant finding of this paper is a confirmation of previous research into the relation between coastal Norwegian Stone Age sites and the prehistoric shoreline. This is indicated by the close proximity of sites and the shoreline until the transition to the Neolithic at c. 4000 BCE, after which a few sites are situated some distance from the sea, followed by a more decisive break at the transition to the Late Neolithic at c. 2500 BCE. This development is in clear agreement with the literature. Furthermore, based on the quantitative nature of these findings, an initial formulation of a refined method for the shoreline dating of pre-Late Neolithic Stone Age sites has been proposed. Apart from taking the distance between sites and the isobases of the displacement curves into consideration when dating the sites, this involves accounting for the distance between the sites and the shoreline. When no other information is available, it can at present be recommended to use the empirically derived gamma distribution with a shape of 0.286 and scale of 0.048 (Fig. 7A) to characterise this relationship. Furthermore, while this remains to be formalised and explored further, it was also demonstrated how the method could potentially be improved by including more information on both the topographic location of the sites and other temporal data. To the degree that making such a distinction is useful, this could be derived from assessments of both a qualitative and quantitative nature, with Bayesian inference forming a natural framework for integrating such considerations (e.g. Buck et al., 1996; Otarola-Castillo et al., 2023). As the precision of the method is both geographically and temporally contingent due to the trajectory of RSL-change, where older sites situated towards the north-east in the study area will get a more precise date, the impact of such additional information will also vary.

Future investigations and radiocarbon dates from Stone Age sites in the region can not only be used to further evaluate and adjust the findings reported here, but a larger sample size could also lay the foundations for refining the method by identifying subsets of sites for which the application of the method could be adjusted. For example, from Fig. 7 it is clear that the Mesolithic sites have generally been located closer to the shoreline than the later sites. It was not attempted to explore this further here, given the constrained sample size and the accuracy that was achieved with the parameters in use. However, the future addition of more data might give justification for using different models or parameter settings when dating sites from certain time intervals. Furthermore, following from its behavioural nature, it is also likely that dimensions such as the nature and purpose of visits to the sites will have implications for how close to the shoreline the sites were located. This is illustrated here by the site phases associated with agricultural activity, marked in Fig. 6, which were all found to be located some distance from the sea. A wide range of different behavioural dimensions could potentially provide nuance to how the method should be applied.

Other factors related to the topographic location of the sites could also be similarly explored. This for example pertains to the exposure of sites to wave action, which is likely to have been of concern (Roalkvam, 2020), and which presumably has implications for how close to the shoreline people settled. This is also related to the fact that while the mean sea-level is used for dating the sites, a consideration of the tidal range and potential impact of storm surges could also have implications for the location of a site relative to the shoreline, depending on the topography (Bondevik et al., 2019; Helskog, 1978). The potential of exploring such dimensions was also hinted at here with the estimation and cursory treatment of the horizontal and topographic distance to the shoreline. If patterns related to such locational patterns can be discerned and unpacked, this will not least be useful for improving the shoreline dating of sites which have only been surveyed and where little information beyond their location is available. A mention should also be made here of the fact that catastrophic events such as tsunamis might also be of relevance (e.g. Blankholm, 2020; Nielsen, 2020; Nyland et al., 2021). Evidence for the impact of tsunamis in the Stone Age has not been identified in south-eastern Norway as of yet (see Romundset et al., 2015:398; cf. Romundset et al., 2018; Sørensen et al., 2014a), and might therefore not be of direct relevance to the coastal settlement in the region. However, the outburst flood resulting from the catastrophic drainage of the glacial lake Nedre Glomsjø around 8500–8000 BCE (Høgaas and Longva, 2019), located in Mid-Norway some 230 km north of present-day Oslo, could have had consequences for how the coast was utilised (Solheim et al., 2020:9).

Some limitations and sources of likely variation and uncertainty that have not been considered should also be mentioned. First, the sample size is limited and the future addition of more sites might alter the picture considerably. Secondly, the validity of the outlined method was evaluated by applying it to the data from where the input parameters were derived. Fitting and evaluating a model using the exact same data will likely exaggerate its performance. Thirdly, the DTM has only been corrected for major modern disturbances. This means that other forms of erosion, although likely not that prevalent, have not been considered. Fourthly, the DTM has a vertical error which could also benefit from being integrated in the analysis (Fisher, 1993; Lewis, 2021). Fifthly, the displacement curves were here interpolated to all site locations without accounting for increased uncertainty as one moves further away from the isobases of the displacement curves—an uncertainty that is likely higher for RSL-change further back in time due to the shoreline gradient. This is also related to the fact that the geologic reconstructions hold uncertainty that is not represented in the displacement curves, relating for example to variation in the methods and quality of the data used for the compilation of the curves, as well as the expert interpretations underlying these. Sixthly, neither the question of how site limits are defined nor the elevation range over which these extend was given much consideration (Mjærum, 2022). Finally, the aggregation and division of settlement phases at each site was here simply done by treating radiocarbon dates not overlapping at 99.7% as representing unrelated occupation events, which were then modelled by use of the Boundary and Sum functions in OxCal. This could also be handled differently (e.g. Bronk Ramsey, 2009, 2015). While each of these factors will have variable impact on the final results, they clearly represent dimensions which would all benefit from further consideration and which means that some of the precision following from the outlined approach is likely to be spurious.

Given that shoreline dating is contingent on regular patterns of human behaviour it should naturally be applied with care. Furthermore, formulating and visualising the method along the lines of how radiocarbon dates are treated, as was done here, does stand the chance of giving a veneer of radiometric accuracy to shoreline dating that is not warranted. That being said, the best chance we have of not throwing away precious temporal data, or exaggerate our handle on it, is arguably to rigorously evaluate the method using independent data such as radiocarbon dates, by offering a precise formulation of how it could be applied, by specifying what sources of uncertainty are accounted for and by making this process transparent through the open dissemination of underlying data and programming code.

As the nature of the relationship between sites and sea is likely to vary temporally and geographically (e.g. Nyland, 2020), the proposed implementation and parametrisation of shoreline dating cannot be expected to be directly applicable elsewhere. When this is combined with the fact that the rate of RSL-change also varies geographically and temporally (e.g. Svendsen and Mangerud, 1987), this means that the accuracy and precision of the method will also vary. However, the methodological framework used to evaluate the relationship between sites and sea is readily extendible to other regions of northern Scandinavia where reliable data on shoreline displacement is available, thus making such extensions feasible. Furthermore, the simulation approach used to integrate multiple sources of spatio-temporal uncertainty was used here to inform the question of the distance between sites and the shoreline. However, this method and general framework can be extended to a wide range of use-cases where one needs to visualise, and quantitatively or qualitatively evaluate the relationship between archaeological phenomena, the prehistoric shoreline, and the uncertainty inherent to this reconstruction.

Contributions

Isak Roalkvam: Conceptualization, Methodology, Software, Formal analysis, Investigation, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data and programming scripts used for the analysis is openly available in a online repository at https://doi.org/10.17605/osf.io/7f9su

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.quascirev.2022.107880.

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Corrigendum to “A simulation-based assessment of the relation between Stone Age sites and relative sea-level change along the Norwegian Skagerrak coast” [Quaternary Science Reviews 299C (2023) 107880]

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When this paper was originally published, there was a notational error in the parameters for the gamma distributions. The gamma can be parametrised with either a ratio or a scale parameter, with the ratio being the inverse of the scale. While the ratio was used for the computations, this was erroneously stated to be the scale in the paper. All places where a value for the scale is provided (Tab. 1, Fig. 7 and pages 10, 11 and 15), this is correct if 1 is divided by the provided value. For the proposed method for shoreline dating, the scale is therefore not 0.048 but 1/0.048, or 20.833 when rounded to the third decimal. This error only occurred in the description of the findings and the proposed method. Code, results and visualisations are unaffected.

The author would like to apologise for any inconvenience caused.

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Paper 3

Exploring the composition of lithic assemblages in Mesolithic south-eastern Norway

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Exploring the composition of lithic assemblages in Mesolithic South-Eastern Norway

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ABSTRACT

This paper leverages multivariate statistics to explore the composition of 54 Mesolithic assemblages located in south-eastern Norway. To provide analytical control pertaining to factors such as variable excavation practices, systems for artefact categorisation and raw-material availability, the sites chosen for analysis have all been excavated relatively recently and have a constrained geographical distribution. The assemblages were explored following two strains of analysis. The first of these entailed the use of artefact categories that are in established use within Norwegian Mesolithic archaeology, while the other involved drawing on measures that have been linked directly to land-use and mobility patterns associated with lithic assemblages more widely. The findings pertaining to the established artefact categories largely reflect the temporal development previously reported in Norwegian Mesolithic research. Furthermore, the chronological trends associated with variables taken from the so-called Whole Assemblage Behavioural Indicators (e.g. Clark and Barton, 2017), originally devised for characterising Palaeolithic assemblages in terms of associated mobility patterns, also align with the development previously proposed in the literature. This provides an initial indication that these measures are applicable in a Norwegian Mesolithic setting as well, setting the stage for a more targeted and rigorous model evaluation outside this exploratory setting. Furthermore, this finding supports the notion that these measures can offer a powerful comparative tool in the analysis of lithic assemblages more generally.

1. Introduction

This study employs multivariate exploratory statistics to analyse lithic assemblages associated with Mesolithic sites located in south-eastern Norway. This is done to identify latent patterns and structure in the relationship between the assemblages, with the ultimate aim of identifying behaviourally induced variation in their composition across time. However, the composition of the assemblages can be expected to be determined by a multitude of factors (e.g. Dibble et al. 2017; Rezek et al. 2020), ranging from the impact of natural formation processes, to various and intermixed behavioural aspects such as purpose, duration, frequency and group sizes at visits to the sites. The assemblages are also likely to be impacted by variation in lithic technology, artefact function, use-life and discard patterns, as well as procurement strategies and access to raw materials. Finally, analytic and methodological dimensions relating to survey, excavation and classification practices are also fundamental to how the assemblages are defined. Consequently, the analysis conducted here is done from an exploratory perspective, where all of these factors should be seen as potential contributors to any observed pattern. In an attempt to limit the influence of some potentially confounding effects, the material chosen for analysis has a constrained geographical distribution, and stems from recent investigations that have employed comparable methods for excavation and classification within larger unified projects.

Even though each individual assemblage can have been impacted by an virtual infinitude of effects that might skew an archaeological interpretation, this does not preclude the applicability of inductive analyses aimed at revealing overarching structure in the data without imposing overly complex analytical frameworks that attempt to account for these particularities (Bevan 2015). Structure that can be revealed from considering all of the assemblages in aggregate can constitute a step in an iterative analytical chain that ultimately aims to tease apart the multitude of factors that have shaped the composition of the assemblages. This would in turn give analytical access to the organisation of lithic technology and variation in past behaviour, adaptation and demographic development (see for example Andrefsky 2009; Barton et al. 2011; Binford 1979; Dibble et al. 2017; Rezek et al. 2020). The most immediate danger of the approach outlined here is rather to be overly naive in the causal significance and cultural importance that is ascribed to any identified pattern. As such, the main aim of this analysis is to compare the results with findings reported in previous literature concerned with the Mesolithic in southern Norway and have the generation of new hypotheses as a possible outcome. To this end, the analysis follows two analytical avenues. The first involves an analysis of

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the assemblages using the classification of the artefacts done for the original excavation reports. The second involves an analysis of the assemblages in light of the so-called Whole Assemblage Behavioural Indicators (e.g. Clark and Barton, 2017) and other factors that have been employed to align properties of lithic assemblages with land-use and mobility patterns.

2. Archaeological context and material

The Early Mesolithic, or Flake Axe Phase, is defined as lasting from c. 9300–8200 BCE (Table 1), and is set to start with the first recorded human presence in Norway (Damlien and Solheim 2018). Previous research has typically proposed that the Early Mesolithic is characterised by a relatively high degree of mobility, and low variation in site types and associated mobility patterns (e.g. Bjerck 2008; Breivik and Callanan 2016; Fuglestvedt 2012; Nærøy 2018; but see Åstveit 2014; Viken 2018). Around the transition to the subsequent Middle Mesolithic or Microlith Phase at c. 8200 BCE, pervasive changes in blade and axe technology occur (Damlien 2016; Eymundsson et al. 2018; Solheim et al. 2020), which in turn has been associated with changes in population genomics and related migration events hailing from the Eurasian steppes (Günther et al. 2018; Manninen et al. 2021). The Microlith Phase is defined as lasting until around 7000 BCE, which is followed by the Pecked Adze Phase, characterised by a more dominating presence of non-flint macro tools and associated production waste in the assemblages (Reitan 2016). The next typological transition at c. 5600 BCE signifies the onset of the Nøstvet Adze Phase. While previously defined as having a slightly longer duration, the Nøstvet Phase has traditionally been seen as representing the onset of more varied settlement systems and stable mobility patterns (e.g. Jaksland 2001; Lindblom 1984). In recent years it has been suggested that the transition to a decrease in mobility and more varied land-use patterns can be traced back to the Middle Mesolithic (Solheim and Persson 2016). The subsequent Transverse Arrowhead Phase (c. 4500–3900 BCE) is characterised by a dramatic decrease in axe finds, and the introduction of new flint projectiles (Reitan 2016). It has recently been suggested that a dispersal of people from southern Scandinavia into southern Norway takes place in this period (Eigeland 2015:379; Nielsen 2021), which could follow after a preceding population decline at c. 4300 BCE (Nielsen 2021; cf. Solheim 2020; Solheim and Persson 2018).

A defining characteristic of the Norwegian Mesolithic is that a clear majority of the known sites are located in coastal areas (e.g. Bjerck 2008). Furthermore, these coastal sites appear to predominantly have been located on or close to the contemporary shoreline when they were in use (Åstveit, 2018; Breivik et al. 2018; Møller 1987; Solheim 2020). In south-eastern Norway, this pattern is combined with a continuous regression of the shoreline, following from isostatic rebound (e.g. Romundset et al. 2018; Sørensen 1979). The fairly rapid shoreline displacement means that the sites tend not to have retained their strategic or ecologically beneficial shore-bound location for long periods of time (cf. Perreault 2019:47). Consequently, the shore-bound settlement, combined with the rapid shoreline displacement has resulted in a relatively high degree of spatial separation of cumulative palimpsests, to follow the terminology of Bailey (2007), while the reconstruction of the trajectory of relative sea-level change allows for a relatively good control of when these accumulation events occurred. In other parts of the world, a higher degree of spatial distribution means that while the physical separation of material can help delineate discrete events, this typically comes at the cost of losing temporal resolution as any stratigraphic relationship between the events is lost (Bailey 2007).

Table 1
Chronological framework. Glørstad's (2010) divison of phases reflects the more traditional framework, to which Reitan (2016) has recently suggested considerable changes.

Glørstad (2010)	
Early Mesolithic, Fosna Phase	9500–8200 BCE
Middle Mesolithic, Tørkop Phase	8200–6300 BCE
Late Mesolithic, Nøstvet Phase	6300–4600 BCE
Late Mesolithic, Kjeøy Phase	4600–3800 BCE
Reitan (2016)	
Flake Axe Phase	9300–8200 BCE
Microlith Phase	8200–7000 BCE
Pecked Adze Phase	7000–5600 BCE
Nøstvet Adze Phase	5600–4500 BCE
Transverse Arrowhead Phase	4500–3900 BCE

The 54 coastal sites chosen for analysis here have a relatively limited geographical distribution (Fig. 1A). The sites were excavated as part of four larger excavation projects that all took place within the last 15 years (Jaksland and Persson 2014; Melvold and Persson 2014; Reitan and Persson 2014; Solheim 2017a; Solheim and Damlien 2013). The sites included in the analysis consist of all Mesolithic sites excavated in conjunction with the projects that have assemblages holding more than 100 artefacts. The institution responsible for these excavations was the Museum of Cultural History in Oslo. This has led to a considerable overlap in the archaeological personnel involved, and comparable excavation practices across the excavations. Furthermore, with these projects, major efforts were made to standardise how lithic artefacts were to be classified at the museum (Koxvold and Fossum 2017; Melvold et al. 2014). As a result, this should reduce the amount of artificial patterning in the data incurred by discrepancies in the employed systems for categorisation (cf. Clark and Riel-Salvatore 2006; Dibble et al. 2017).

The lithic data analysed here is based on the classification of the site assemblages done for the original excavation reports, and consists of 48 debitage and tool types. These represent artefact categories that have been used consistently across the reports. Consequently, sub-categories that have only been used in the classification of some inventories have been omitted. This for example pertains to what blanks have been used for the production of formal tools, which has only been noted in some of the reports. Furthermore, the artefact data have been divided into flint and non-flint materials. Flint does not outcrop naturally in southern Norway, and is only available locally as nodules that have been transported and deposited by retreating and drifting ice (e.g. Berg-Hansen 1999). This means that the distribution and quality of flint has been impacted by a diverse set of climatic and geographical factors (Eigeland 2015:46). Thus, while flint is treated as a unified category here, the variability in quality could have been substantial. Furthermore, the various non-flint raw materials that have been lumped together have quite disparate properties, where fine-grained cryptocrystalline materials are often used as a substitute or supplement to flint, while other, coarser materials are usually associated with the production of axes and other macro tools. Given this differentiated use, these raw-material properties are expected to be reflected in the retained debitage and tool categories. An important benefit of combining all of the non-flint materials is that this reduces the dependency on whether or not these have been correctly and consistently categorised for the reports (cf. Frivold 2017). Finally, while factors such as landscape changes through shoreline displacement can have led to variable raw-material availability at the analysed sites, for example by impacting accessibility by means of watercraft, the relatively constrained geographical distribution of the sites hopefully counteracts some environmentally given sources of variation.

3. The analysis of lithic assemblages

Studies concerned with chronological changes in the composition of lithic assemblages in southern Norway have typically had a focus on morphological variation among artefacts (e.g. Ballin 1999; Bjerck 1986; Reitan 2016) or been concerned with technological processes associated with certain sub-categories of the site inventories, such as the production of blades or axes (e.g. Berg-Hansen 2017; Damlien 2016; Eymundsson et al. 2018; Solheim et al. 2020). Studies that have involved

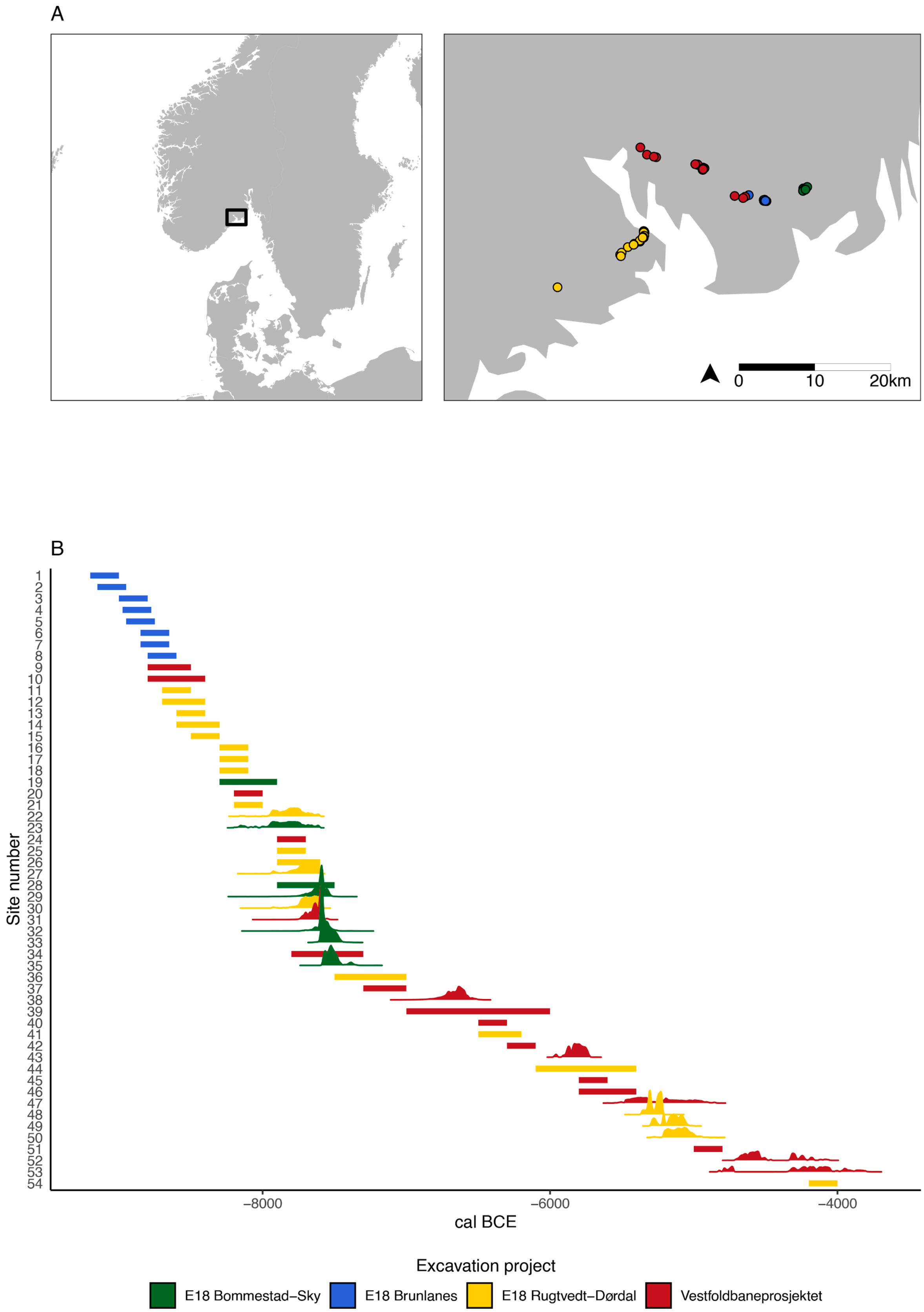

Fig. 1. A) Spatial and B) temporal distribution of the sites chosen for analysis. Radiocarbon age determinations are given as the sum of the posterior density esimates. Solid lines indicate that the site has been dated with reference to relative sea-level change and typological indicators. These follow the original reports. Site numbers match those provided in Table 2.

entire assemblages have either been concerned with general compositional traits such as relative frequency of various tool types and raw-materials (e.g. Breivik 2020; Breivik and Callanan 2016; Reitan 2016; Viken 2018), or involved extremely in-depth studies of technological organisation associated with a handful of assemblages (e.g. Eigeland 2015; Fuglestvedt 2007; Mansrud and Eymundsson 2016). These studies are, however, based on non-quantitative or uni- and bivariate methods, leaving the weighting of the many variables for the final interpretations unclear. To my knowledge, only a single study dealing with the composition of Mesolithic assemblages in southern Norway has involved the use of a multivariate quantitative framework, which was employed to structure the analysis of eight Middle Mesolithic assemblages (Solheim 2013; see Glørstad 2010:145–146 for a spatial application). In sum then, previous studies have typically either been limited to a small number of sites, to a subset of the inventories, to morphological characteristics, or to methods that are difficult to scale and consistently balance in the comparison of a larger number of artefact categories and assemblages.

The aim of the first of part of the analysis conducted here is to evaluate the degree to which the composition of the assemblages align

Fig. 2. Aggregation of variables for the correspondence analysis. The column on the left shows the variables as originally compiled. The column on the right shows how these have been aggregated for the analysis.

with earlier studies that have employed more informal methods. This therefore assumes that the artefact categories employed in Norwegian Stone Age archaeology are, at least to a certain extent, behaviourally meaningful. However, the approach taken is also partially informed by the so-called Frison effect (Jelinek 1976), which pertains to the fact that lithics studied by archaeologists can have had long and complex use-lives in which they took on a multitude of different shapes before they were ultimately discarded. Several scholars have built on this to argue that morphological variation in retouched lithics from the Palaeolithic cannot be assumed to predominantly be the result of the intention of the original knapper to reach some desired end-product, but rather that what is commonly categorised as discrete types of artefacts by archaeologists can instead in large part be related to variable degrees of modification through use and rejuvenation (e.g. Barton 1991; Barton and Clark 2021; Dibble 1995). Artefact categories believed not to be internally consistent and categorically exclusive have therefore been collapsed for the analysis (Fig. 2), as their contribution as discrete analytical units could potentially be misleading. An underlying assumption of the largely intuitively determined aggregation procedure is therefore effectively that the retained categories represent artefact categories that have fulfilled different purposes or are related to different technological processes. While aggregating artefact categories in this manner could subsume important variation, it does also reduce the possibility that any conclusions are not simply the result of employing erroneous units of analysis.

However, for the most part we lack even a most basic understanding of what any individual lithic object in an assemblage has been used for (Dibble et al. 2017). For example, a vast amount of artefacts defined as debitage are likely to have fulfilled the function of tools, and both debitage and formal tool types could have had various different purposes and had a multitude of shapes throughout their use-life. This has major implications that the above-outlined analysis does not take properly into account, rendering it difficult to align any identified pattern with specific behavioural dimensions. As a consequence, the second part of the analysis employs a suite of measures developed for the classification of lithic assemblages with these inferential limitations in mind (Barton et al., 2011; Clark and Barton, 2017, and below). The logic behind these measures are founded on an understanding of technology as being organised along a continuum ranging between curated and expedient (Binford 1973, 1977, 1979). An expedient technological organisation pertains to the situational production of tools to meet immediate needs, with little investment of time and resources in modification and rejuvenation, resulting in high rates of tool replacement. Curated technological organisation, on the other hand, has been related to manufacture and maintenance of tools in anticipation of future use, the transport of these artefacts between places of use, and the modification and rejuvenation of artefacts for different and changing situations.

However, following not least from the ambiguous definition first put forward by Binford (1973), the theoretical definition of curation, its archaeological correlates, and behavioural implications have been widely discussed and disputed (e.g. Bamforth 1986; Nash 1996; Shott 1996; Surovell 2009:9–13). Still, that the distinction can offer a useful analytical point of departure if clearly and explicitly operationalised seems more or less agreed upon, and some dimensions of the concept are generally accepted. For example, although precisely how it is measured may vary, the empirical correspondent to a curated technological organisation is typically defined by high degrees of retouch, as this is commonly seen as a means of realising the potential utility of a tool—or extending its use-life—by the repeated rejuvenation and modification of edges (e.g. Bamforth 1986; Dibble 1995; Shott and Sillitoe 2005).

One concrete operationalisation of the terms has been forwarded by Barton (1998) and collegues (e.g. Barton et al., 1999, 2011, 2013; Barton and Riel-Salvatore, 2014; Clark and Barton, 2017; Riel-Salvatore and Barton, 2004, 2007; Villaverde et al., 1998), who through a series of studies have shown that the relationship between volumetric density of lithics and relative frequency of retouched artefacts in lithic assemblages have a consistent negative relationship across a wide range of chronological and cultural context, ranging from Pleistocene and Holocene assemblages in Europe and Asia, to assemblages associated with both Neanderthals and modern humans (Barton et al. 2011; Riel-Salvatore et al. 2008). This relationship is taken to reflect degree of curation, and is in turn mainly to follow from the accumulated nature of land-use and mobility patterns associated with the assemblages (Barton and Riel-Salvatore 2014). Furthermore, the relationship between curated and expedient technological organisation has been related to the continuum defined by Binford (1980) between residentially mobile foragers and logistically mobile collectors (Clark and Barton, 2017; Riel-Salvatore and Barton, 2004; see also Bamforth 1986; Binford 1977). Residential mobility involves the relatively frequent movement of entire groups between resource patches throughout the year, while logistic mobility entails the use of central base-camps that are moved less often and from where smaller task-groups venture on targeted forays to retrieve specific resources. A higher degree of logistic as opposed to residential mobility thus also involves a wider range of site types and associated mobility patterns (Binford 1980).

Furthermore, in this model, higher degree of mobility would mean a higher dependency on the artefacts and the material people could bring with them, and dimensions such as weight, reliability, repairability, and the degree to which artefacts could be manipulated to fulfil a wide range of tasks are therefore assumed to have been factors of concern. From this it follows that the empirical expectation for short-term camps is a curated technological organisation with higher relative frequency of retouched artefacts, and a lower overall density of lithics (Clark and Barton, 2017). More time spent in a single location, on the other hand, is assumed to lead to better control of raw-material availability and to allow for its accumulation. This should in turn lead to a more expedient technological organisation with reduced necessity for the conservation of lithics and extensive use of retouch. The empirical expectation for lower degree of mobility is therefore relatively high density of lithics, a low relative frequency of retouched artefacts, as well as a higher number of unexhausted cores and unretouched flakes and blades. These variables and underlying logic constitute what has been termed Whole Assemblage Behavioural Indicators (WABI, Clark and Barton, 2017), and is the main framework adopted here.

As these measures are argued to predominantly be determined by land-use and mobility patterns, relative frequency of chips and relative frequency of non-flint material are also included in the analysis, as these measures have also been linked to mobility patterns (e.g. Bicho and Cascalheira 2020; Kitchel et al. 2021) and are of central importance to Norwegian Stone Age archaeology (e.g. Breivik et al. 2016; Reitan 2016)—the use of local non-flint material has been taken to indicate reduced mobility and increased familiarity with local surroundings (Glørstad 2010:181; Jaksland 2001:112).

4. Methodology

The exploratory approach taken here means that a wide range of combinations and transformations of variables has been explored to identify patterning in the data. While only parts of this process can sensibly be reported upon, all data and employed R programming scripts (R Core Team 2020) are freely available as a research compendium at https://osf.io/ehjfc/, following Marwick et al. (2018), allowing readers to explore and scrutinise the data and the final analytical choices made (Marwick 2017).

The 54 analysed sites have been dated by reference to relative sea-level change, typology and/or radiocarbon dates (Table 2). Date ranges for sites based on shoreline displacement and typology are taken from the original reports and follow the evaluation done by the original excavators. Where radiocarbon age determinations believed to be associated with the lithic material are available, these have been calibrated using the IntCal20 calibration curve (Reimer et al. 2020) and

Table 2
Analysed sites. The column for dating method lists whether the sites have been dated with reference to shoreline displacement and typology, or by means of radiocarbon dating. Reported start and end dates are given as years cal BCE.

no	Site name	Dating method	Reported start	Reported end
1	Pauler 1	Shore/typo	9200	9000
2	Pauler 2	Shore/typo	9150	8950
3	Pauler 3	Shore/typo	9000	8800
4	Pauler 5	Shore/typo	8975	8775
5	Pauler 4	Shore/typo	8950	8750
6	Pauler 6	Shore/typo	8850	8650
7	Bakke	Shore/typo	8850	8650
8	Pauler 7	Shore/typo	8800	8600
9	Nedre Hobekk 2	Shore/typo	8800	8500
10	Solum 1	Shore/typo	8800	8400
11	Tinderholt 3	Shore/typo	8700	8500
12	Tinderholt 2	Shore/typo	8700	8400
13	Dørdal	Shore/typo	8600	8400
14	Tinderholt 1	Shore/typo	8600	8300
15	Skeid	Shore/typo	8500	8300
16	Hydal 3	Shore/typo	8300	8100
17	Hydal 4	Shore/typo	8300	8100
18	Hydal 7	Shore/typo	8300	8100
19	Hovland 2	Shore/typo	8300	7900
20	Nedre Hobekk 3	Shore/typo	8200	8000
21	Hydal 8	Shore/typo	8200	8000
22	Hegna vest 1	Radiocarbon	8000	7800
23	Hovland 5	Radiocarbon	8000	7700
24	Sundsaasen 1	Shore/typo	7900	7700
25	Hegna øst 6	Shore/typo	7900	7700
26	Hegna vest 4	Shore/typo	7900	7600
27	Hegna vest 2	Radiocarbon	7900	7550
28	Nordby 2	Shore/typo	7900	7500
29	Hovland 4	Radiocarbon	7900	7500
30	Hegna vest 3	Radiocarbon	7800	7600
31	Prestemoen 1	Radiocarbon	7700	7600
32	Hovland 1	Radiocarbon	7700	7400
33	Hovland 3	Radiocarbon	7650	7450
34	Gunnarsrød 7	Shore/typo	7800	7300
35	Torstvet	Radiocarbon	7500	7100
36	Hegna øst 5	Shore/typo	7500	7000
37	Gunnarsrød 8	Shore/typo	7300	7000
38	Langangen Vestgård 1	Radiocarbon	6800	6600
39	Gunnarsrød 2	Shore/typo	7000	6000
40	Gunnarsrød 6b	Shore/typo	6500	6300
41	Hegna øst 7	Shore/typo	6500	6200
42	Gunnarsrød 6a	Shore/typo	6300	6100
43	Gunnarsrød 4	Radiocarbon	6000	5800
44	Stokke/Polland 3	Shore/typo	6100	5400
45	Gunnarsrød 10	Shore/typo	5800	5600
46	Langangen Vestgård 2	Shore/typo	5800	5400
47	Vallermyrene 4	Radiocarbon	5500	5200
48	Hegna øst 2	Radiocarbon	5350	5200
49	Stokke/Polland 8	Radiocarbon	5300	5200
50	Stokke/Polland 5	Radiocarbon	5300	5000
51	Prestemoen 2	Shore/typo	5000	4800
52	Vallermyrene 1	Radiocarbon	4700	4100
53	Langangen Vestgård 3	Radiocarbon	4350	4000
54	Stokke/Polland 9	Shore/typo	4200	4000

subjected to Bayesian modelling using OxCal v4.4.4 (Bronk Ramsey, 2009) through the oxcAAR package (Hinz et al. 2021) for R. The only constraint imposed for the modelling of the dates was that the dates from each site are assumed to represent a related group of events through the application of the Boundary function (Bronk Ramsey, 2021). The resulting posterior density estimates were then summed for each site.

The first part of the analysis involves employing the method of correspondence analysis (CA), using the lithic count data as classified for the original excavation reports (e.g. Baxter 1994; Shennan 1997). As this part of the analysis partially draws on the above-mentioned Frison effect, several artefact categories have been collapsed for the CA. A version of the CA using the original artefact categories, as well as some additional configurations and ways to aggregate the variables are also available in the supplementary material to the paper.

Following the WABI and other factors associated with mobility patterns, as presented above, the variables employed in the second part of the analysis are relative frequency of secondarily worked lithics (RFSL), defined as the proportion of the assemblages constituted by retouched or ground lithics; volumetric density of lithics (VDL), defined as the total number of artefacts divided by total excavated m^3 as taken from the original reports; relative frequency of chips, defined as the proportion of artefacts with size < 1 mm; relative frequency of cores, the proportion of all artefacts classified as cores in the original reports; relative frequency of blanks, here defined as the proportion of all artefacts classified as flakes, blades, micro-blades or fragments; and finally relative frequency of non-flint material. Following Bicho and Cascalheira (2020), the analysis is done using principal components analysis (PCA), leading to a shift in focus from the relative composition emphasised by the CA, to having more weight placed on patterning in the most abundant occurrences (Baxter 1994:71–77).

A note should also be made on the fact that a few variables that are sometimes invoked for the classification of sites in terms of associated mobility patterns are omitted here (e.g. Bergsvik 1995:116; Bicho and Cascalheira 2020; Breivik et al. 2016). For the assemblage data itself this especially pertains to diversity in tool-types (Canessa 2021), which has been omitted in light of the above-metioned Frison effect. Number of features on the sites has also been disregarded as taphonomic loss is likely to have led to a chronological bias in their preservation. Similarly, the number of activity areas, effectively number of artefact clusters, however defined, has also been disregarded. This follows most notably from the fact that the impact of post-depositional processes at Stone Age sites in Norway is arguably understudied (Jørgensen 2017). This pertains for example to bio-turbation in the form of three-throws, which can have a detrimental effect on the original distribution of artefacts, and which can be expected to have impacted several of the sites treated here (Darmark 2018; Jørgensen 2017).

5. Results

The general impression from the CA is that a chronological dimension accounts for a substantial amount of patterning in the data (Fig. 3). This is indicated by the general transition across the colour scale in the row plot (Fig. 3B), as well as the horseshoe curve or Guttman effect evident in the column plot (Fig. 3A, Baxter 1994:119–120; Lockyear 2000). The fact that the two first dimensions of the CA accounts for as much as 80.53% of the inertia or variance also means that the structure of the data is well-represented in the plots and that these therefore are likely reflect true patterning in the data.

The column plot reveals that the earliest sites are characterised by the flint artefact categories microburins, projectiles, as well as flint macro tools and associated debitage. These assemblages are also to a larger extent characterised by core fragments, both in flint and non-flint materials, rather than cores. The non-flint material on the earliest, or among the earliest sites, appears to be centred around the production of projectiles, as both projectiles and non-flint blades are important constituents of the assemblages at these sites. The first dimension, which is pulling some of the later sites towards the right of the plot, is mainly defined by macro tools and associated debitage in non-flint materials that are negatively correlated with more flint dominated assemblages.

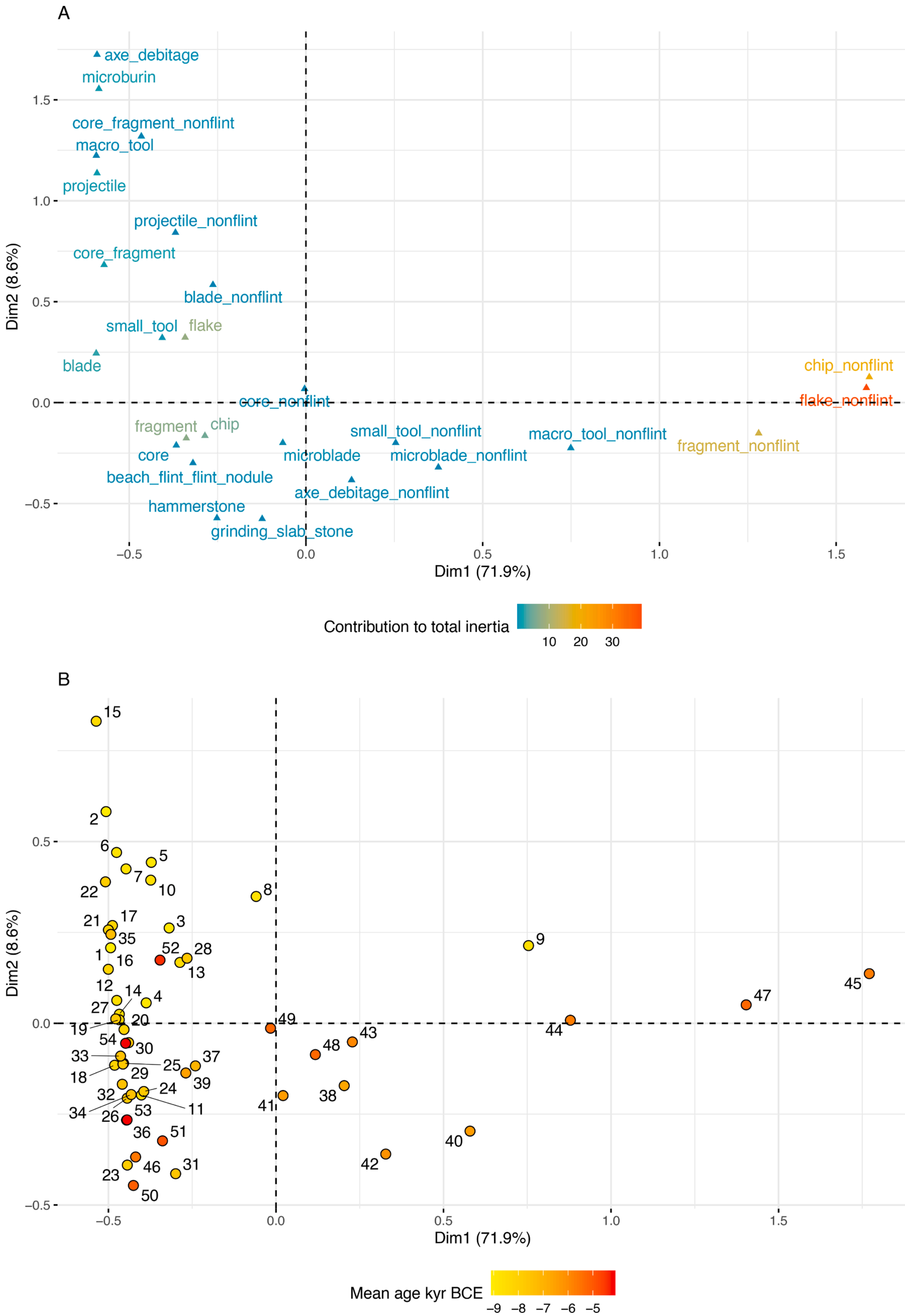

Fig. 3. Correspondence analysis using the artefact count data. A) Column plot (variables), B) Row plot (sites). Points close together are more similar. By evaluating how the variables are distributed on the column plot it is possible to say how these define the two axes, in turn making it possible to relate the distribution of the sites in the row plot to the variables. As these are symmetrical plots, only general statements concerning the interrelation between the rows and the columns across the two plots can be made.

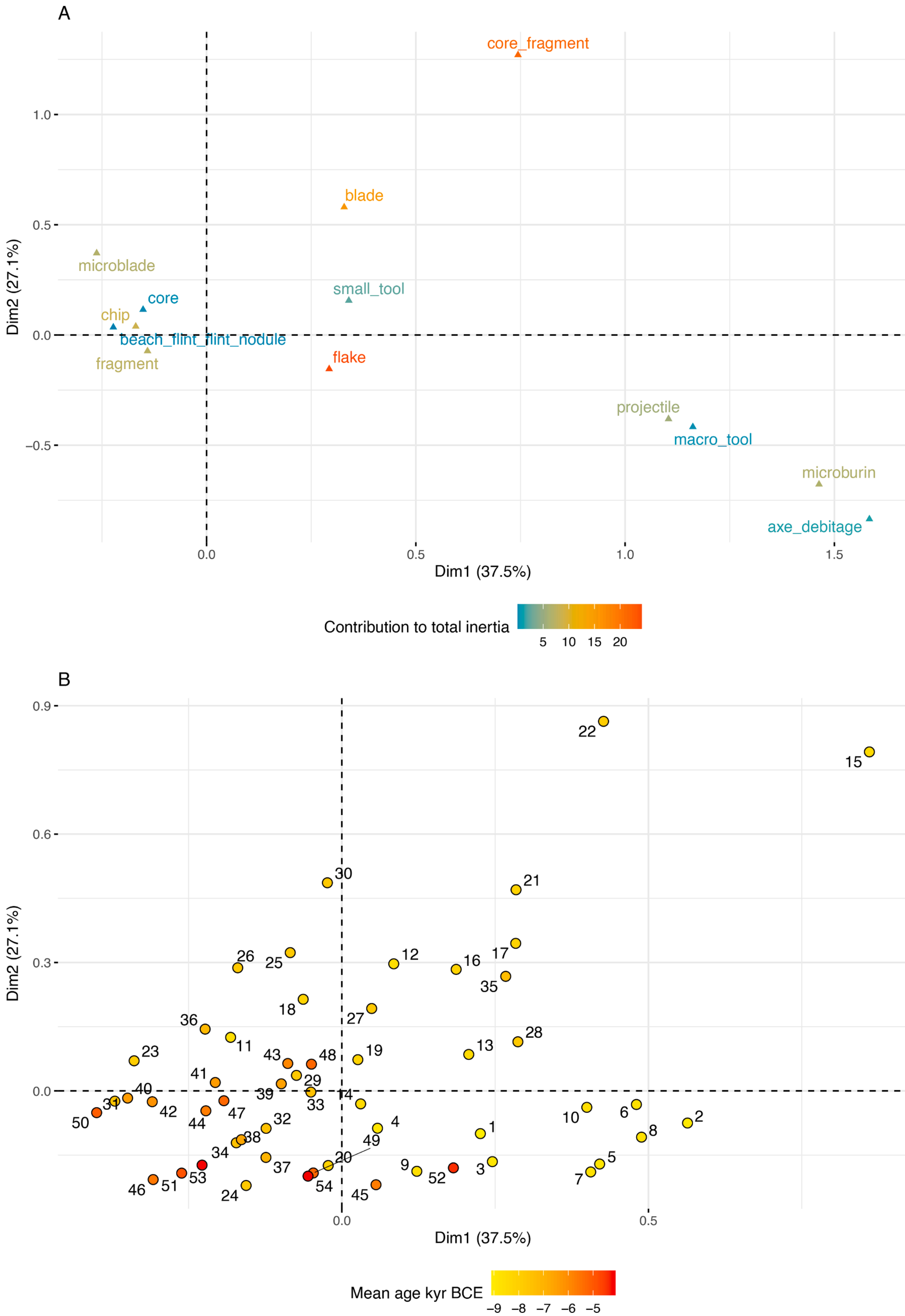

Fig. 4. Correspondence analysis using the flint data. A) Column plot, B) Row plot.

Site number 9, Nedre Hobekk 2, located in the upper right quadrant of the row plot represents a somewhat curious case in that it is an early assemblage characterised by axe production in metarhyolite (Eigeland 2014). However, the site had been quite heavily impacted by modern disturbances that could have impacted the lithic material and which could explain its position as an outlier in the plot. Finally, although the sample size is quite strained and the discussion of finer chronological points might not be warranted, the first dimension does appear to be of of less importance for the absolute latest sites, as indicated by their location to the left of the plot.

As most of the variation in the data is accounted for by the dominating non-flint material in later assemblages, this suppresses and makes it difficult to discern patterns in the flint data. A second CA was therefore performed, excluding the non-flint material (Fig. 4). While not as substantial, there is clear temporal patterning in the flint data as well. This is most marked for the earliest sites which are pulled away from the main cluster, as projectiles, microburins, macro tools and debitage from their production characterises these sites. Slightly younger sites appear more impacted by core fragments and blades. The temporal transition in the main cluster is not as marked, but clearly present, and is driven by a

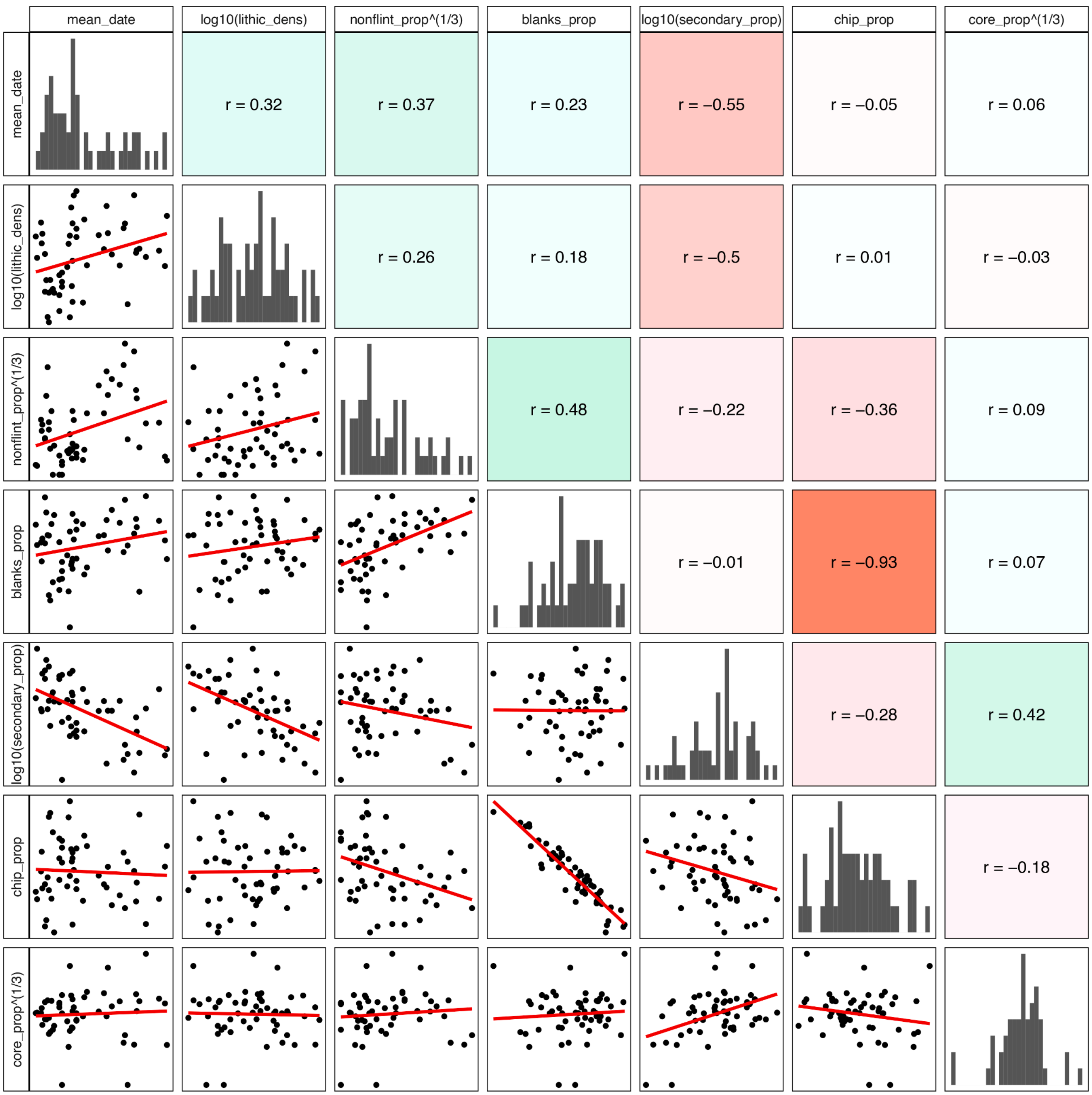

Fig. 5. Correlation matrix showing transformation of skewed variables for the PCA. The mean age of the sites has also been included to visualise overall temporal trends. Cells below the diagonal display the bivariate distributions with a fitted OLS-regression. The cells above the diagonal display and are coloured by the corresponding Pearson's correlation coefficient.

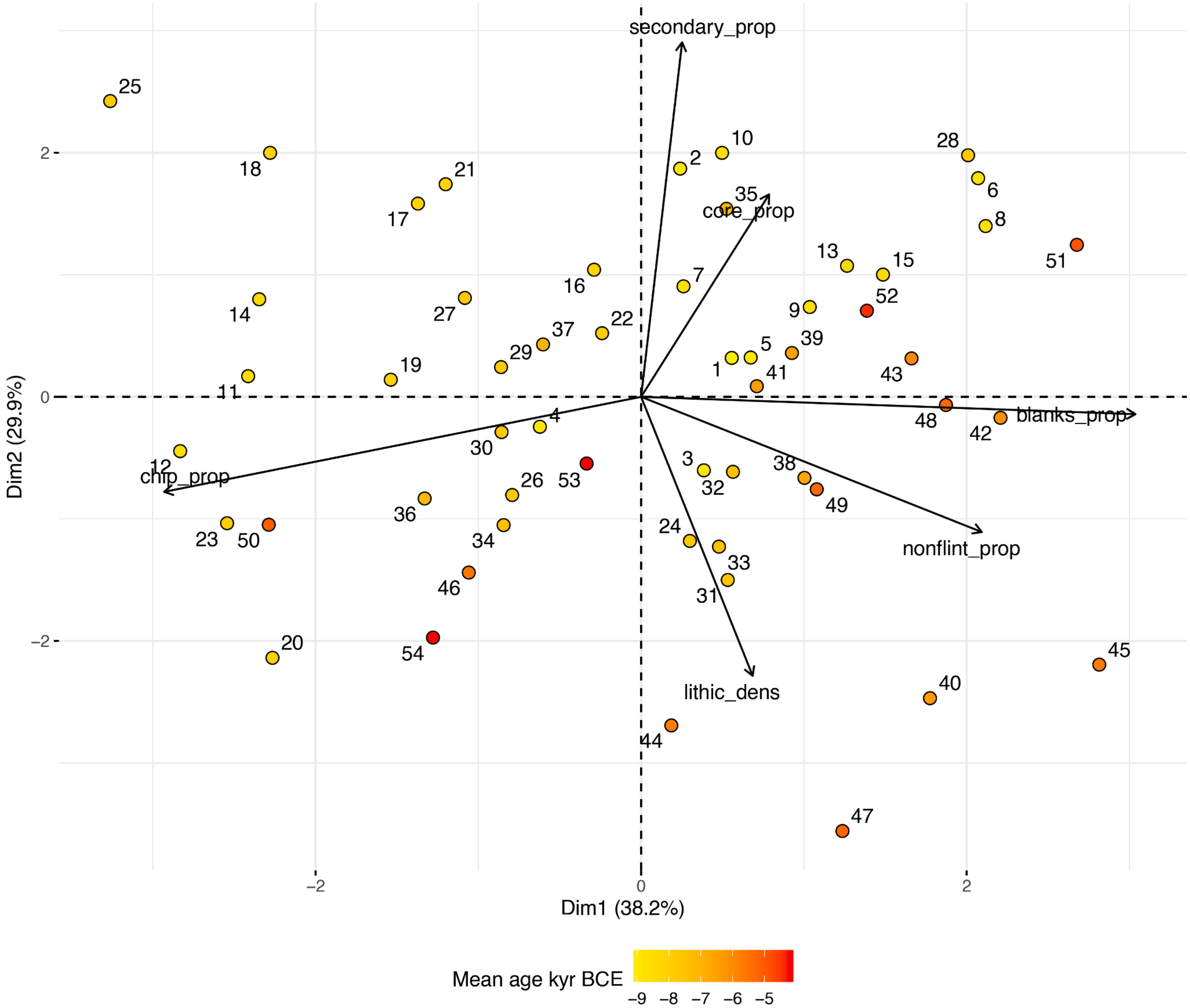

Fig. 6. PCA biplot resulting from analysing variables that have been related to mobility patterns. Note that details on the transformation of the variables has been left out of the plot for clarity, but follow those given in Fig. 5.

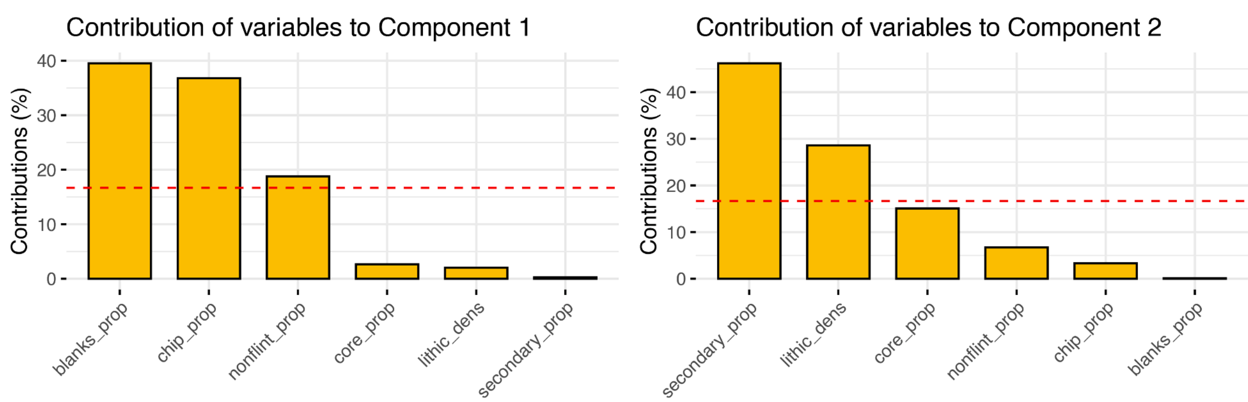

Fig. 7. Contribution of variables to the first two components of the PCA. The dotted red line indicates the expected contribution from each variable given a uniform distribution of impact. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

larger proportion of blades, flakes and small tools in the earliest assemblages of the cluster, which is opposed to chips, fragments and partly micro-blades.

Moving on to the PCA of measures that have been linked to mobility, some of the variables with severely skewed distributions were initially transformed (Fig. 5). Fig. 6 displays the resulting PCA. There is a general temporal transition from the upper left to the bottom right of the plot. The second dimension is mainly defined by a negative correlation between the VDL and RFSL (Fig. 7). Almost orthogonal to this is the strong negative correlation between relative frequency of chips and blanks. While there is a slight tendency for blanks to be more associated with younger sites, frequency of chips appears to be largely independent of time. However, this almost suspiciously strong negative correlation can perhaps have a practical explanation. Seeing as the frequency of non-flint material is positively correlated with blanks and negatively correlated with chips (Fig. 5), one explanation to this pattern could be that smaller non-flint pieces are simply more difficult to identify and separate from naturally fragmented stone during excavation and classification. This could conceivably have led to an over-representation of blanks as compared to chips in assemblages with a high proportion of non-flint material. While this is not necessarily the entire explanation, this does make it difficult to place much analytical weight on this pattern. Relative frequency of cores is not especially impactful in the PCA, and appears to be independent of the temporal dimension as well. That is not to say that cores may not be indicative of or related to mobility patterns, but to get at this may require further analysis beyond their simple classification as cores (Kitchel et al. 2021).

Thus, while the relative frequency of blades and cores does not appear to meet the expectations of the WABI, it is difficult to say to what degree this is caused by idiosyncrasies in the Norwegian system for classification of lithics and properties of the lithic material itself. The relationship between VDL and RFSL does correspond to the model and follows a clear temporal trend that is also correlated with the increased use of local raw material. Thus, if the relationship between VDL and RFSL is accepted as a proxy for curation, and is related to land-use and mobility patterns, these findings would be in line with previous research into the Mesolithic of Norway, indicating that earlier sites are associated with higher degree of mobility than sites from later phases (e.g. Bergsvik 2001; Bjerck 2008; Glørstad 2010; Jaksland 2001). To explore this proposition further, these two variables are subjected to more detailed scrutiny below.

There is a strong negative correlation between the two variables (r = -0.5) and a general tendency for younger sites to be associated with a higher VDL and a lower RFSL than older sites (Fig. 8A). The linear correlation is stronger between the mean site age and RFSL (r = -0.51), than between mean site age and VDL (r = 0.22). Variable non-flint availability and workability has also been suggested to potentially impact these dimensions (cf. Manninen and Knutsson 2014), but while the negative correlation is slightly less marked when only the flint data is considered (r = -0.4), the general pattern is the same (Fig. 8B). The relationship between mean site age and relative frequency of secondarily worked flint is even stronger (r = -0.57), but as indicated by the more spread out distribution along the x-axis, the volumetric density of flint is not temporally contingent (r = 0.1). As was also indicated by the CA, this follows from the fact that non-flint materials make up a higher share of the assemblages for some of the later Mesolithic sites, and is a point returned to below where the temporal dimension of the relationship between VDL and RFSL is explored further.

To get more directly at this temporal trend, a curation index based on VDL and RFSL was devised by first performing a min–max normalisation of the two variables, scaling them to take on values between 0 and 1. The value for artefact density was then made negative to reflect its relationship with degree of curation. The mean was then found for each site on these two normalised values. To account for the temporal uncertainty associated with the dating of the sites, a simulation-based approach was also adopted (e.g. Crema 2012; Orton et al. 2017). A LOESS curve was fit to the curation index and site age for each simulation run, where the age of each site was drawn as a single year from their respective date ranges as provided in Fig. 1. For sites with radiocarbon age determinations the dates were drawn from the summed posterior density estimates, while ages for sites dated with reference to relative sea-level change and typology were drawn uniformly from the associated date range (Fig. 9). This simulation was repeated 1000 times. Disregarding the edge-effects at either end of the plot, the general tendency is a relatively high degree of curation among the earlier sites, followed by a marked drop around 8000 BCE. This has stabilised by around 7000 BCE and remains stable for the rest of the Mesolithic. The variation in degree of curation is also markedly higher after 8000 BCE. Fig. 9B displays the result of running the same procedure on the flint data. The general pattern follows the same trajectory, but the result for some individual sites is noticeably different.

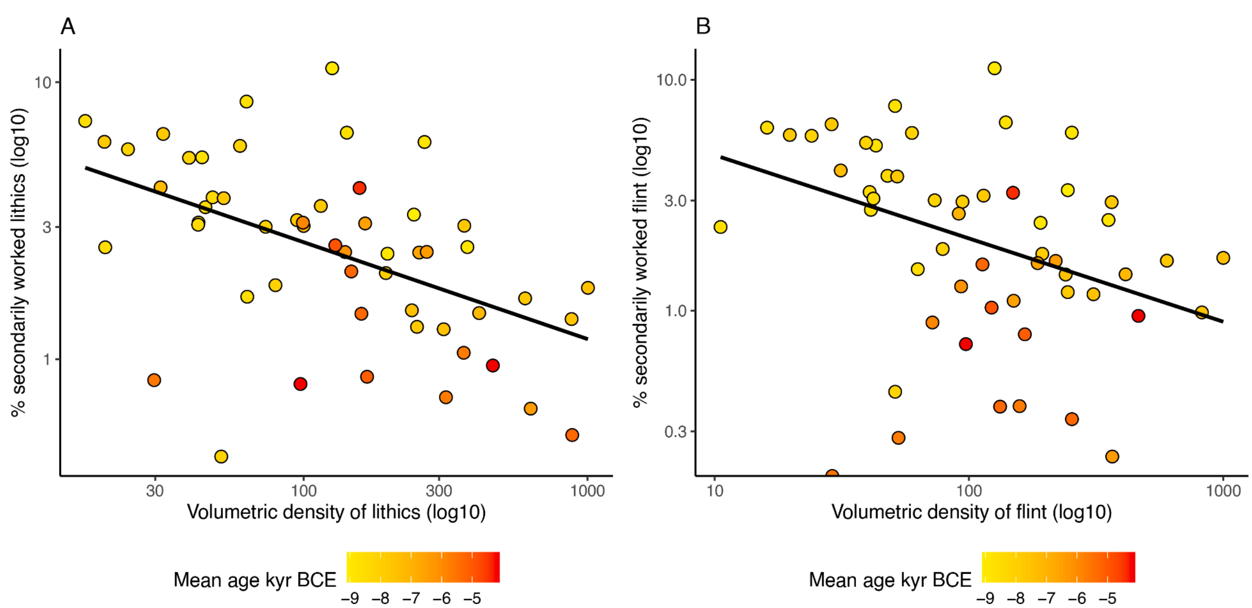

Fig. 8. Relative frequency of secondarily worked lithics plotted against the volumetric density of artefacts for A) All lithics (r = −0.5), B) Flint (r = −0.4). The logarithm is taken to base 10 on all axes.

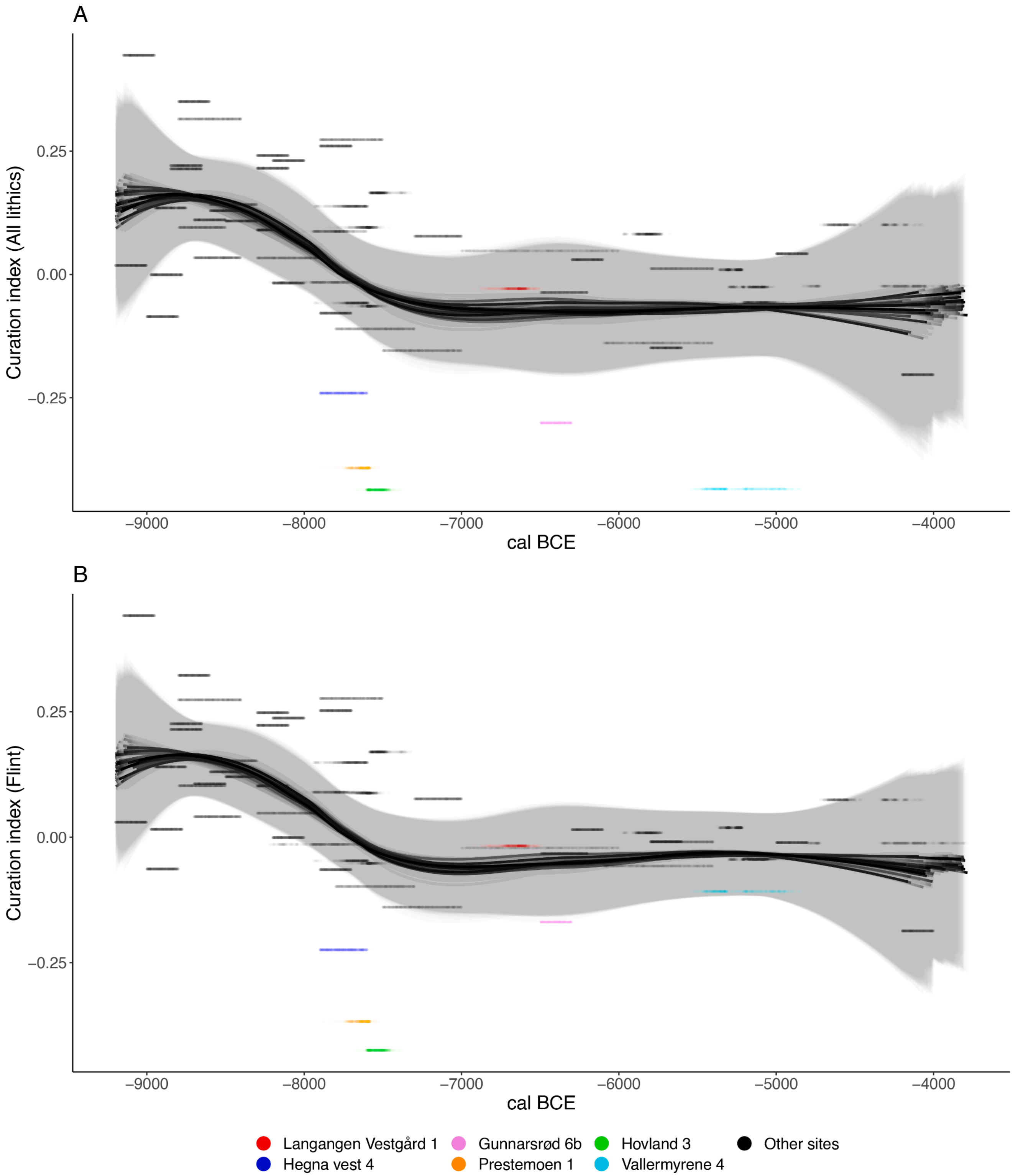

Fig. 9. Temporal variation in the curation index for A) All lithics, and B) Flint. The temporal uncertainty is handled by means of a simulation approach where the site ages are drawn from their respective age determination probability density functions given in Fig. 1B. A LOESS curve has been fit to the distribution for each of the 1000 simulation runs. Each simulation run is plotted with some transparency. Sites mentioned in the text are given colour.

6. Discussion

The results of the CA appear to align well with previous research (e.g. Solheim 2017b, with references). In the flint material the earliest sites are separated from the rest primarily based on the presence of macro tools, microburins, projectiles, and, for slightly younger sites, core fragments and blades (cf. Bjerck 2017; Breivik et al. 2018; Damlien and Solheim 2018; Fuglestvedt 2009; Jaksland and Fossum 2014). The importance of the latter two can be associated with the blade technology that is introduced with the Middle Mesolithic, characterised by blade production from conical and sub-conical cores with faceted platforms that involves the removal of core tablets and rejuvenation flakes

(Damlien 2016). When it comes to the non-flint material, projectiles are to a larger extent a property of the earlier sites than later ones. The use of metarhyolite for the production of axes is present at some earlier sites in addition to the previously mentioned Nedre Hobekk 2, and the production of non-flint hatchets and core axes is introduced in the Microlith Phase (Eymundsson et al. 2018; Jaksland and Fossum 2014; Reitan 2016). However, in agreement with the literature, this is evidently not as prominent a part of these assemblages.

The flint material of the later sites is to a larger extent characterised by micro-blades, which corresponds to the transition to micro-blade production from handle cores (e.g. Solheim et al. 2020). A more fragmented flint material, as indicated by the relative importance of flint chips and fragments, is also a previously noted property of some later Mesolithic, as well as early Neolithic sites (e.g. Fossum 2017; Stokke and Reitan 2018). The most defining material for the later sites, however, is non-flint macro tools and associated debitage, which is dominating some of these assemblages. It was noted above that this material does not seem to impact the latest sites, which would indicate that specialised axe production sites disappear towards the end of the Mesolithic, a notion that would be in line with previous suggestions (e.g. Glørstad 2011; Reitan 2016).

One implication of the fact that the employed artefact categories are so clearly capturing a temporal component could be that the aggregation of artefact categories might have been overly conservative. However, it is also evidently clear, in the words of Kruskal (1971:22), that 'time is not the only dimension.' The results of the CA do most certainly correspond to more pervasive cultural change than a purely typo-chronological development of artefact morphology, which is also made evident by some significant deviances from the overall pattern. Unpicking and aligning these patterns with any specific behavioural and technological dimensions using the coarse CA results is, however, another task entirely. This follows most clearly from the fact that for the most part we do not know what individual lithic objects in the assemblages have been used for, leaving the behavioural and social significance of the employed units of analysis unclear. The results of the CA can, however, be used in conjunction with the part of the analysis that has attempted to get at more specific behavioural dimensions to nuance or explain discrepancies in this data.

The curation index has relatively high values until some time before 8000 BCE, before it drops and stabilises around 7000 BCE. This pattern is evident in both the flint data and when all lithics are treated in aggregate. Furthermore, the increased variation in degree of curation after around 8000 BCE could indicate that these sites were associated with a more varied mobility pattern. The five sites that have values on the curation index below c. -0.25 could in this perspective have predominantly functioned as base-camps within a logistic settlement pattern. That these assemblages reflect stays of a longer duration was suggested for all five sites in the original reports (Carrasco et al., 2014; Eigeland and Fossum, 2017; Persson, 2014; Solheim and Olsen, 2013), with the exception of for Vallermyrene 4, which was argued to be a specialised axe production site, not necessarily associated with lower degrees of mobility (Eigeland and Fossum 2014). This highlights a possible issue pertaining to raw-material variability, as the coarse non-flint material used for the production of axes generally results in a relatively large amount of waste per produced tool, possibly skewing the curation index when compared to assemblages dominated by flint. Referring back to the CA, the difference is most marked for the sites in the later part of the Mesolithic where non-flint material become more dominating parts of the assemblages. As can be seen in Fig. 9B, the degree of curation is markedly higher for both Gunnarsrød 6b and Vallermyrene 4 when the non-flint material is excluded, although they remain more expedient than that of contemporary assemblages. Thus, the degree of expediency for assemblages dominated by non-flint might be somewhat exaggerated when the non-flint material is included, while its exclusion would likely lead to its underestimation. One possible approach could be to weigh the curation index by the proportion of non-flint material in the assemblages. This is not explored further here, however, as the overall tendencies appear robust to this effect.

Another case also worth commenting on is Langangen Vestgård 1, which, on the grounds of an overall large number of artefacts and the possible presence of a dwelling structure was argued to reflect a more permanent site location in the original report (Melvold and Eigeland 2014). However, the relatively high value on the curation index could mean that the site reflects the aggregation of stays which predominantly have been of a comparable duration to those on contemporary sites, while the possible dwelling structure, if taken as an indication of longer stays, could in this perspective represent a remnant from one or a few visits of longer duration that constitute a smaller fraction of the use-life of the site as a whole (cf. Barton and Riel-Salvatore 2014).

While there are certainly nuances in the material that might lead one to question the applicability of the VDL and RFSL measures for any individual site, the overall pattern for curation does appear robust. The curation index is relatively high and uniform until some time before 8000 BCE. This corresponds well with the view that the Early Mesolithic is characterised by a high and uniform degree of mobility. This is followed by a marked increase in expedience, which has stabilised by around 7000 BCE. Again, this corresponds well with the employed chronological framework. Referring back to the demographic changes that are to take place around this transition, the Microlith phase could thus represent a period where migrating people and new living practices were propagating through societies in south-eastern Norway—a process that in light of the curation data would have concluded around 7000 BCE.

The curation index then remains stable for the rest of the Mesolithic. This suggests that the transition to mobility patterns traditionally ascribed to the Nøstvet Phase can indeed be traced back to the Microlith Phase (cf. Solheim and Persson 2016). The continued stability of the curation index could also indicate that the demographic changes suggested to take place in the Transverse Arrowhead Phase are not related to major shifts in land-use and mobility patterns. However, it is worth highlighting the strained sample size for the later parts of the Mesolithic, which could mean that the effect is simply missed.

As it stands, the main hypotheses resulting from the present analysis would be that settlement patterns in the earliest parts of the Mesolithic were characterised by relatively high and uniform degrees of mobility, which then drop before levelling off at around 7000 BCE. These then remain stable throughout the rest of the period, despite variation pertaining to other aspects of the lithic inventories, as evidenced by the CA. The fall in curation levels and parallel increase in variation would seem to correlate well with a transition from a predominantly residential to logistical settlement system (Binford 1980). This indicates, in turn, that the measures represent an empirical link between technological organisation and economic behaviour and mobility patterns (Riel-Salvatore and Barton, 2004).

7. Conclusion

The results of the CA align well with results of previous research in south-eastern Norway, indicating that meaningful chronological patterning is associated with the employed artefact categories. These tendencies are already well-established when it comes to the formal tool types and some debitage categories, but have been given less focus in light of entire assemblages. Precisely what behavioural implication the development in the occurrences of the tool and debitage categories have are less clear, but appears to follow a different and more complex development over time than that of curation, as operationalised here.

The temporal trends associated with the curation index corresponds surprisingly well with trajectories of cultural development previously suggested in the literature, and does therefore, in my view, suggest that shifts in land-use and mobility patterns are the main drivers behind this empirical pattern—in line with the framework of Barton et al. (2011). Another perspective would be that this is not surprising at all (cf. Kuhn and Clark 2015:14), and that the previously demonstrated relevance of these measures across a wide range of contexts points to their pervasive relevance for the organisation of lithic technology, and, therefore, that there should be little reason to think Mesolithic south-eastern Norway should be any different. However, the conclusion that these these measures apply to and appear to capture the dimensions of interest in a relatively controlled empirical setting, reached by means of an exploratory analysis can only constitute a first analytical step. As Elster (2015:12) has pointed out, the human mind seems to have a propensity to settle for an explanation that *can* be true, as soon as this has been reached. This, however, can only constitute the absolute minimum of what is required of a proposed explanation. Subsequent steps should be to probe and challenge this explanatory framework, also in light of alternative hypotheses (e.g. Clark 2009:29–30; Perreault 2019:1–22). The empirical relationship does nonetheless hold great potential for large scale comparative studies in Mesolithic Scandinavia and beyond. Furthermore, the curation index was here simply narratively associated with the most immediate chronological trends emphasised in the literature concerned with the Mesolithic of south-eastern Norway. The explicit quantification does, however, offer the possibility to conduct formal comparisons with a wide range of environmental, demographic and cultural dimensions across multiple scales of analysis.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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Appendix

6.1 Appendix, Paper 1

6.2 Appendix, Paper 2

6.3 Appendix, Paper 3