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

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5 **Abstract**

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

22 **Highlights**

- 23 • Simulates the spatial relation between sites and the prehistoric shoreline
24 • Quantification of horizontal, topographic and vertical distance
25 • Confirms close association between sites and the contemporaneous shoreline
26 • Proposes a formalised method for the shoreline dating of pre-Late Neolithic sites

27 Keywords: Shoreline dating; Stone Age; Settlement patterns; Scandinavia; Relative sea-level change

28 **1 Introduction**

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

39 The close association between Stone Age settlements in the northern parts of Scandinavia and shifting
40 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; 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 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 the parameters of 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 Figure 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 it's 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

90 sea-level has been stable over longer periods of time, people have often reused coastal site locations multiple
 91 times and over long time spans, creating a mix of settlement phases that are difficult to disentangle (e.g.
 92 Hagen 1963; Reitan and Berg-Hansen 2009). Transgression phases, on the other hand, can lead to complete
 93 destruction of the sites, bury them in marine sediments, or in the outermost periphery, submerge them
 94 (Bjerck 2008a; Glørstad et al. 2020). Transgression can therefore lead to a hiatus in the archaeological record
 95 for certain sub-phases in the impacted areas despite the fact that there were likely coastal settlements during
 96 the inferred hiatuses. Comparatively, given a continuous and still ongoing shoreline regression from as high
 97 as c. 220m above present sea-level in the inner Oslo fjord, any one location in south-eastern Norway has
 98 only been shore-bound within a relatively limited time span, and the sites have not been impacted by any
 99 transgressions (Hafsten 1957, 1983; Romundset et al. 2018; Sørensen 1979). This makes the region especially
 100 useful for evaluating the assumption of a shore-bound settlement pattern over a long and continuous time
 101 span.

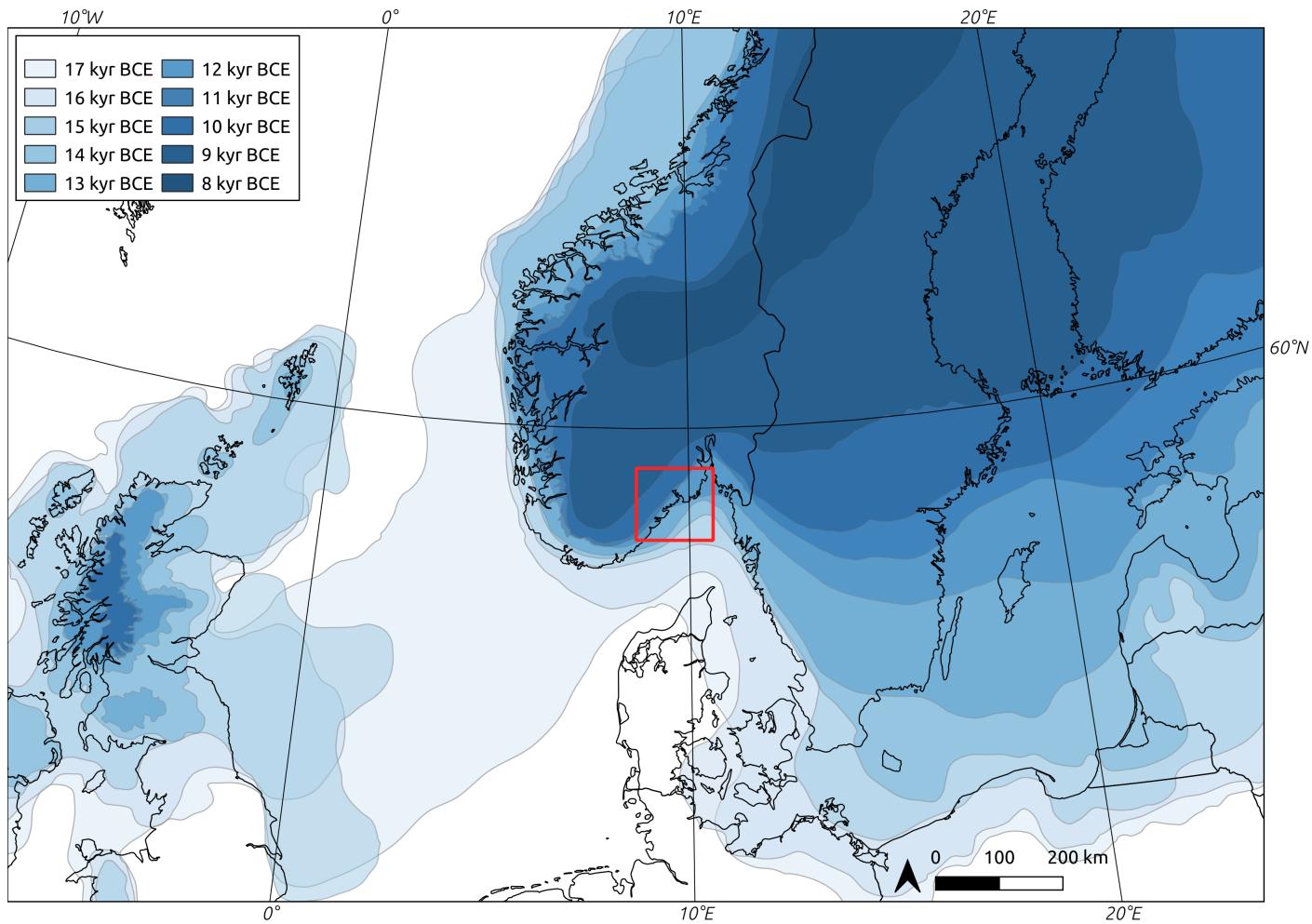


Figure 1: Deglaciation at 1000 year intervals from c. 17–8 thousand years (kyr) BCE. The study area defined later in the text is marked with a red outline (deglaciation data from Hughes et al. 2016, but see also Romundset et al. 2019 in relation to the study area).

102 The method of shoreline dating has been met with scepticism as related to the fundamental premise that
 103 most sites would have been consistently shore-bound, it has been characterised as a relative dating method for
 104 sites located within a constrained geographical area, or it has been argued to offer no more than an earliest
 105 possible date for when a site could have been in use (see review by Nordqvist 1999). The most common
 106 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, 2012a, 2012b; Jaksland and Persson 2014; Melvold and Persson 2014; Reitan and Persson 2014; Reitan and Sundström 2018; Solheim 2017 and below). Recently the method has also been used independently to date a larger number 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). 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 shore-line 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 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

159 for the Larvik area. They found an overlap between the probability distribution of the radiocarbon dates
160 with the shoreline displacement curve for 86.3% of the dates (Solheim 2020:48) . However, where there
161 was a discrepancy, the main occupation of the sites are still believed to have been shore-bound rather than
162 associated with the deviating ^{14}C -dates. This is based on typological and technological characteristics of the
163 assemblages. Whether these mismatches represent later shorter visits that are responsible for the younger
164 radiocarbon dates, or whether these dates are entirely erroneous can be difficult to evaluate (e.g. Persson
165 2008; Schülke 2020). However, this distinction is not deemed critical here, as what is of interest is settlements
166 and tool-production areas as evidenced by artefact inventories or multiple site features. Not remnants of
167 stays as ephemeral to only be discernible by isolated features or dubious ^{14}C -dates. The evaluation of the
168 relevance of radiocarbon dates to settlement activity will here therefore be entirely dependent upon, and
169 follow the discretion of the original excavation reports.

170 Other previous evaluations of the correspondence between radiocarbon- and RSL-informed dates have typically
171 followed the same structure as that of Breivik et al. (2018), involving a visual inspection of radiocarbon
172 probability density functions plotted against local shoreline displacement curves based on the elevation of the
173 site (e.g. Åkerlund et al. 1995; Åstveit 2018; Solheim 2020; see also Bjerck 2008b; Kleppe 1985; Ramstad
174 2009). This approach has a couple of limitations. First, the displacement curves are sometimes applied
175 directly to larger study areas, analogous to what Borreggine et al. (2022) term a bathtub model, with only
176 some studies having taken the variable uplift-rates into account when performing this comparison (e.g. Åstveit
177 2018; Fossum 2020; Møller 1987; Persson 2008). Secondly, with this method, the wider the uncertainty range
178 associated with either radiocarbon date or displacement curve, the higher the probability that the confidence
179 intervals overlap, and the higher the probability that the conclusion supports the hypothesis. This thus
180 leads to an inferential framework that favours uncertainty, which is hardly desirable. In statistical terms this
181 follows from the fact that while one cannot conclude that two dates are different if their confidence intervals
182 overlap, this does not necessarily mean that they are the same. The question thus necessitates a flip from a
183 null-hypothesis of no significant difference, to one of equivalence (e.g. Lakens et al. 2018), as the question
184 of interest is effectively one of synchronicity between events (cf. Parnell et al. 2008). Another limitation of
185 this often-employed method is that it only takes into account the vertical distance between the sites and the
186 sea-level. While this is the main parameter of interest for shoreline dating, the practical implications of a
187 vertical difference in RSL will be highly dependent on local topography and bathymetry. RSL-change can
188 have more dramatic consequences in a landscape characterised by a low relief, as the horizontal displacement
189 of the shoreline will be greater. Taking the spatial nature of the relationship between site and shoreline into
190 account will consequently help get more directly at the behavioural dimension of this relation and help move
191 the analysis beyond a purely instrumental consideration of the applicability of shoreline dating.

192 3 Data

193 To get at the relationship between sites and the contemporaneous shoreline, this analysis was dependent on
194 identifying a study area with good control of the trajectory of prehistoric shoreline displacement. While
195 there is displacement data available for other areas of south-eastern Norway (e.g. Hafsten 1957; Sørensen
196 1979, 1999), considerable methodological developments in recent years means that the most well-established
197 displacement curves are from the region stretching from Horten county in the north-east, to Arendal in the
198 south-west (Figure 2). This area has newly compiled displacement curves for Skoppum in Horten (Romundset
199 2021), Gunnarsrød in Porsgrunn (Sørensen et al. in press; Sørensen, Henningsmoen, et al. 2014; Sørensen,
200 Høeg, et al. 2014), Hanto in Tvedstrand (Romundset 2018; Romundset et al. 2018), and Bjørnebu in
201 Arendal (Romundset 2018).

202 The shoreline displacement data used in this study are based on the so-called isolation basin method (e.g.
203 Kjemperud 1986; Romundset et al. 2011), which involves extracting cores from a series of basins situated on
204 bedrock at different elevations beneath the marine limit, and dating the transition from marine to lacustrine
205 sediments. Each basin thus represents a high precision sea-level index point (SLIP) which are combined
206 in a continuous time series for RSL-change adjusted to a common shoreline isobase. The isobases are here
207 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 (Figure 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, Henningsmoen, et al. 2014:44). The highest astronomical tide in the study area reaches around 30cm above mean sea-level (30cm at the standard port Helgeroa in Larvik, Norwegian Mapping Authority 2021). Furthermore, the confidence bands of the displacement curves and their trajectory are quite complex constructs as they are the integrated result of both expert knowledge and more objectively quantifiable parameters. The reason for this is that the curves do not only contain uncertainty as related to radiometric dates, which are well defined, but they 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 (Figure 2). These number 167 sites of which 91 sites are associated with a total of 547 radiocarbon dates. Of these, in turn, 67 sites are related to the 259 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 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 10m resolution DTM was used rather than the higher-resolution 1m 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 10m resolution DTM of the study area is a down-sampled version of the 1m version and has a height accuracy with a systematic error of 0.1m (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 an online repository at <https://osf.io/7f9su/>, organised as a research compendium following

261 **4 Methods**

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

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

288 Armed with a likely date range for the occupation(s) of each site, an estimated trajectory of RSL change at
289 that location, and a DTM edited to remove substantial modern disturbances, the simulations were performed.
290 A single simulation run involved first drawing a single year from the posterior density estimate of a given
291 occupation phase of a site (Figure 4). This year then has a corresponding likely elevation range for the
292 contemporaneous shoreline from which an elevation value was drawn uniformly, using intervals of 5cm. The
293 sea-level was then raised to this elevation on the DTM by defining all elevation values at or below this
294 altitude as missing. Polygons were then created from the resulting areas with missing values. The horizontal
295 distance was then found by measuring the shortest distance between site and sea polygons, and the vertical
296 distance by subtracting the elevation of the sea-level from the lowest elevation of the site polygon. The topographic
297 distance between site and sea was also found by measuring the distance while taking into account
298 the slope of the terrain on the DTM. This was done using the topoDistance package for R (Wang 2019).
299 The topographic distance was measured between the site polygon and the horizontally closest point on the
300 shoreline. This means that the distance is not necessarily measured as the closest topographic distance to the
301 shoreline, but rather as the shortest topographic path to the horizontally closest point on the shoreline. Not
302 finding the topographically closest point significantly reduced the computational cost of the analysis, and is
303 deemed unlikely to have a considerable impact on the results given the distances considered. The shortest
304 topographic path was found using the Moore neighbourhood of eight cells (e.g. Conolly and Lake 2006:253;
305 Herzog 2013). In the case where the sea polygons intersect the site polygon, all distance measures were set to
306 zero. In the case that the sea polygons completely contain the site, the horizontal and topographic distance
307 measures were made negative, and the vertical distance was instead measured to the highest point on the site
308 polygon. While it is safe to assume that an archaeological site was not occupied when it was located beneath

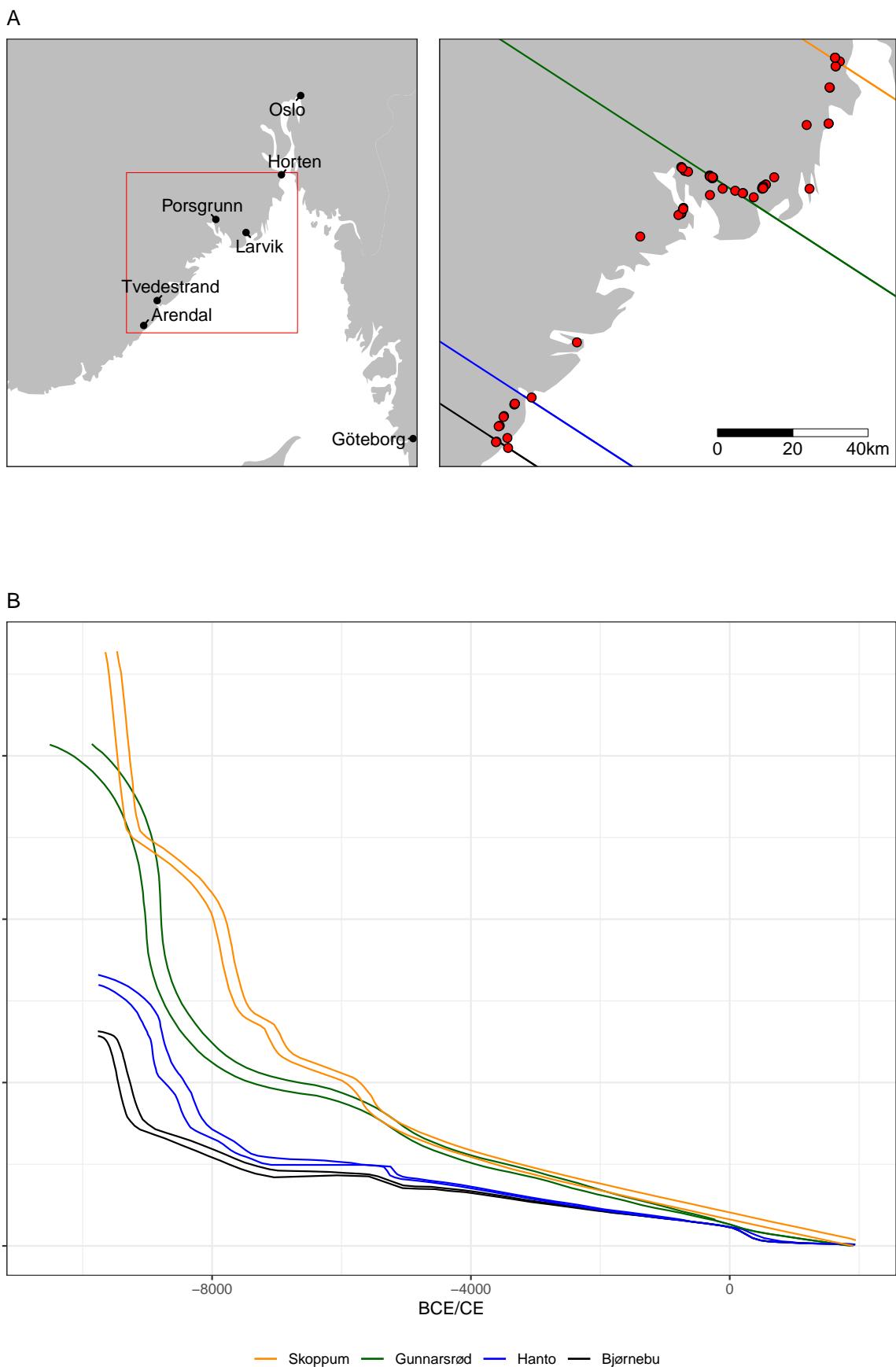


Figure 2: A) Location of the study area and the distribution of the 67 analysed sites relative to the isobases of the displacement curves. The isobases have a direction of 327° (Romundset et al. 2018, although see Sørensen et al. 2014), B) Displacement curves. Note the increasing steepness of the curves towards the north-east.

309 sea-level, a negative result can reflect the inherent uncertainty in this procedure, and might also help identify
310 discrepancies in displacement data or radiocarbon dates. Negative values were therefore retained with the
311 exception of the sites of Gunnarsrød 5 and Pjonkerød R1, where the negative values are believed to result
312 from modern disturbances in the DTM rather than the ^{14}C -dates or displacement curves (see supplementary
313 material for more details).

314 This process was repeated 1000 times for each phase for each site. The choice of 1000 simulation runs follows
315 from an evaluation of when the mean distances between site and shoreline converged when running 5000
316 iterations of the simulation on the site Hovland 5, available in the supplementary material (cf. Crema et al.
317 2010:1125). Hovland 5 was chosen for this evaluation as it has an imprecise age and is located in area of
318 quite complex topography.

319 5 Simulation results

320 Overall, as is indicated by the measures for central tendency and the almost solid line along the 0m mark on
321 the y-axes, the simulations show that the sites tend to have been situated close to the shoreline when they
322 were in use (Figure 6). Some of the sites are situated considerable distances from the shoreline when the dates
323 believed to be erroneous in the original reports are included (Figure 6A), but if one accepts the interpretation
324 that these do not date the main occupation of the sites, as is indicated by the artefact inventories, Figure
325 6B gives considerable support to the notion that the sites were in use when they were situated on or close
326 to the contemporaneous shoreline. The distances for some of the earliest sites appears somewhat high, but
327 this can likely be explained as the result of the rapid RSL fall in the earliest part of the Holocene (Figure
328 2B), which leads the uncertainty of the ^{14}C -dates to give a wider possible elevation range for the simulated
329 sea-level. Another immediately striking result is the apparent deviation from the shoreline towards the
330 end of the Stone Age. After around 2500 BCE several sites are situated a considerable distance from the
331 reconstructed shoreline, and while a couple remain horizontally and topographically close, most appear to be
332 considerably elevated above the sea-level, as indicated on the plot for vertical distance. While the sample size
333 is limited, there are also a couple of sites located some distance from the shoreline just after 4000 BCE. The
334 chronological smearing following from the uncertainty in the ^{14}C -dates means that while the results cannot be
335 used to directly inform discussions that deal with the century scale around these chronological transitions (e.g.
336 Prescott 2020; Solheim 2021), the findings are nonetheless in clear agreement with the general chronological
337 framework in the literature.

338 The negative values around 8000 BCE originate from the sites Løvås 1, 2 and 3. These are recently excavated,
339 well-dated sites situated in a relatively undisturbed area of the landscape (Reitan and Hårstad 2022). While
340 there could be a danger of circularity of having archaeological sites inform a reconstruction RSL-change, and,
341 in turn, use these to evaluate the degree of shore-bound settlement, the sites do clearly represent an upper
342 constraining limit for the sea-level, as they would not have been in use when located under water. It therefore
343 seems that the Løvås sites represent a case where the archaeological material indicates a slight discrepancy in
344 the geologic reconstruction of shoreline displacement in the area.

345 Accepting that shoreline dating appears to lose utility around the transition to the Late Neolithic, as indicated
346 by the clear deviation in site location from the shoreline after this, the results from Figure 6B are presented
347 again in Figure 7A, excluding all simulation results younger than 2500 BCE. Furthermore, all negative values
348 have here been set to zero, under the assumption that these result from uncertainty or errors in the data,
349 and not actual site locations. The resulting best point estimate for the vertical distance between sites and
350 shoreline for the pre-Late Neolithic is given by the median distance of 4m, while 95% of the values fall within
351 the range 0–18m. That is, for 95% of the cases, the shoreline was simulated to be situated on or lower than
352 18m below the site location. While these values remain the same when only the Mesolithic dates are included
353 (Figure 7B), the mean and standard deviation are slightly constrained. Furthermore, while the median for
354 horizontal and topographic distance is only 10m across all plots in Figure 7, the variation in the statistics for
355 dispersion is greater, illustrating the point that minor variations in vertical distance can have substantial
356 consequences for these distance measures, depending on the surrounding topography.

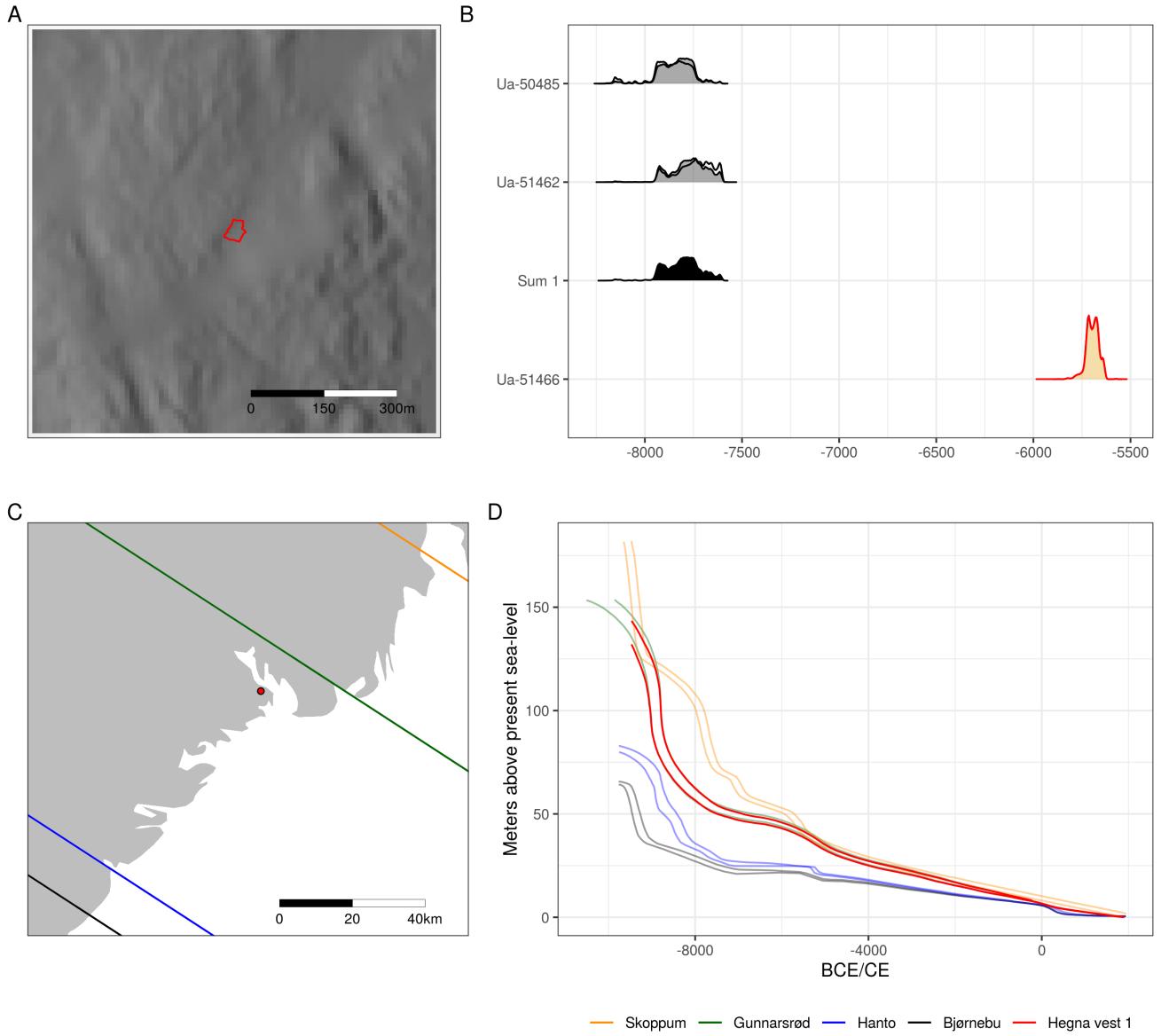


Figure 3: Example site Hegna vest 1 (Fossum 2017). A) Location of the site on the edited 10m resolution DTM. The red outline is the site limit. B) Radiocarbon dates associated with the site. Fill colour indicates what dates are assumed to belong to the same settlement phase. Multiple dates are modelled 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.

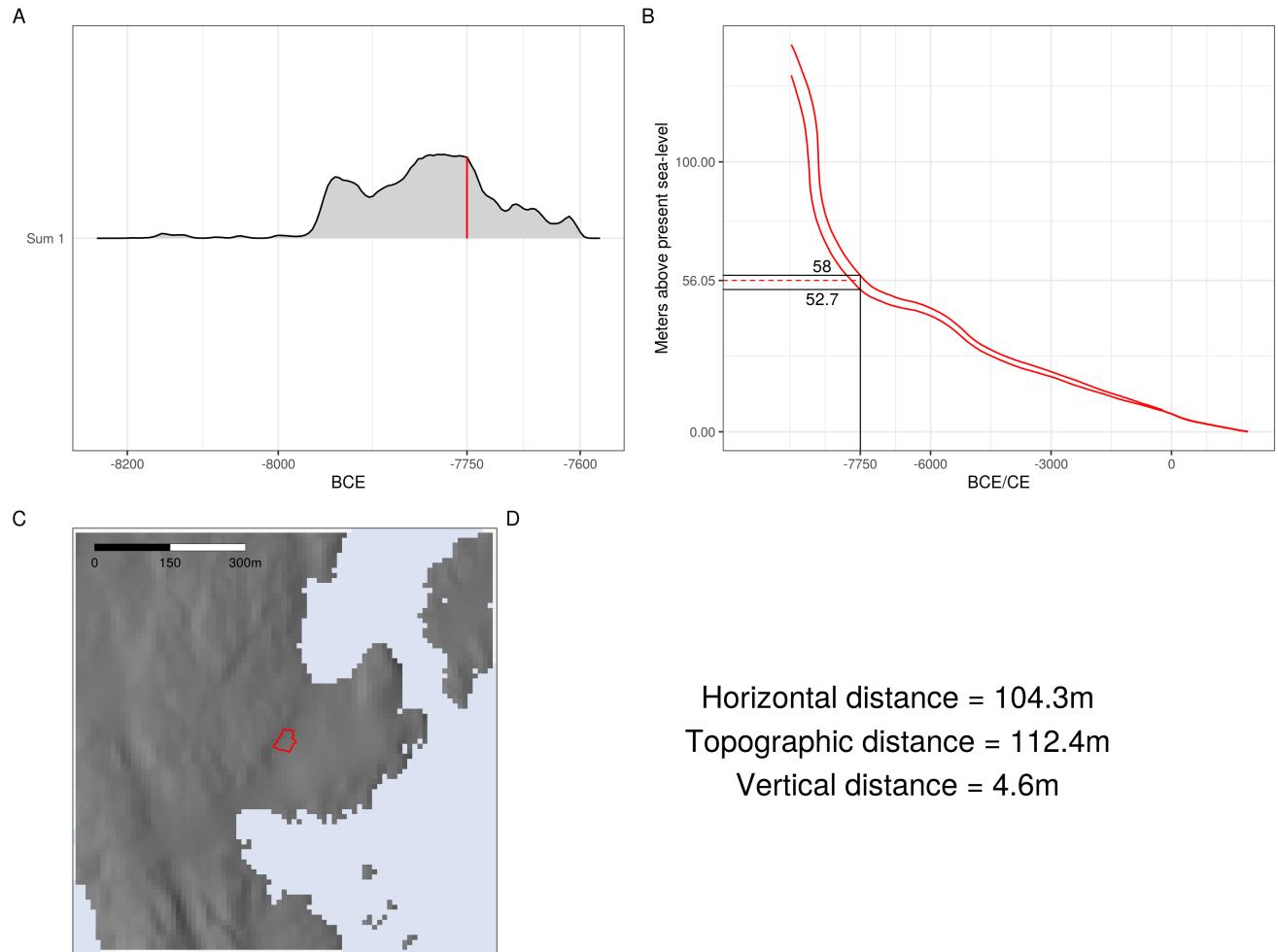


Figure 4: Example of a single simulation run on the site Hegna vest 1. A) The simulation starts by drawing a single year from the posterior density estimate. B) This then corresponds to an elevation range on the interpolated displacement curve. A single elevation is drawn uniformly from this range using 5cm 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.

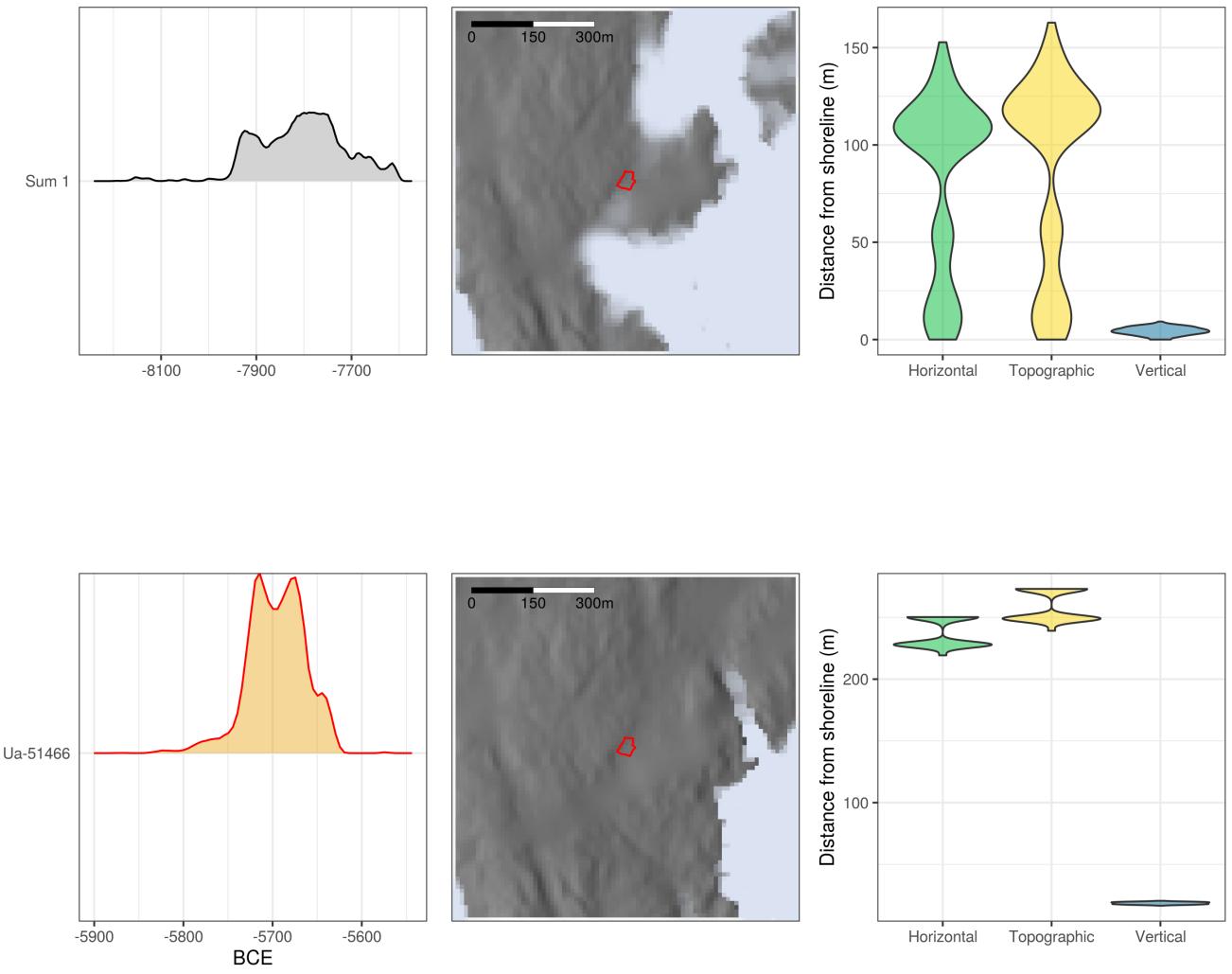


Figure 5: The result of 1000 simulation runs for each of the two groups of dates on the site Hegna vest 1. The leftmost column of plots shows the calibrated radiocarbon probability distribution from where dates were drawn during simulation. The centre column displays the result of simulating the raised 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.

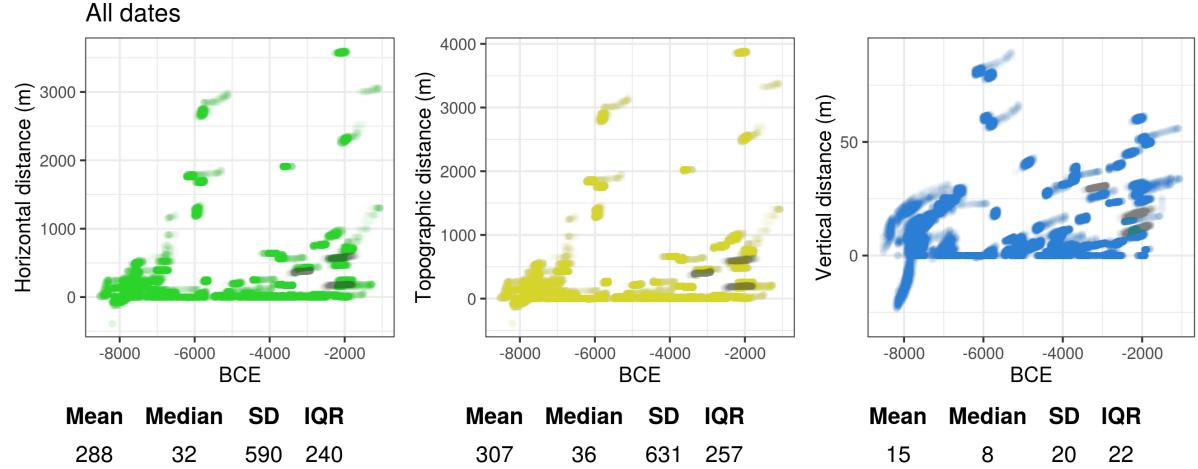
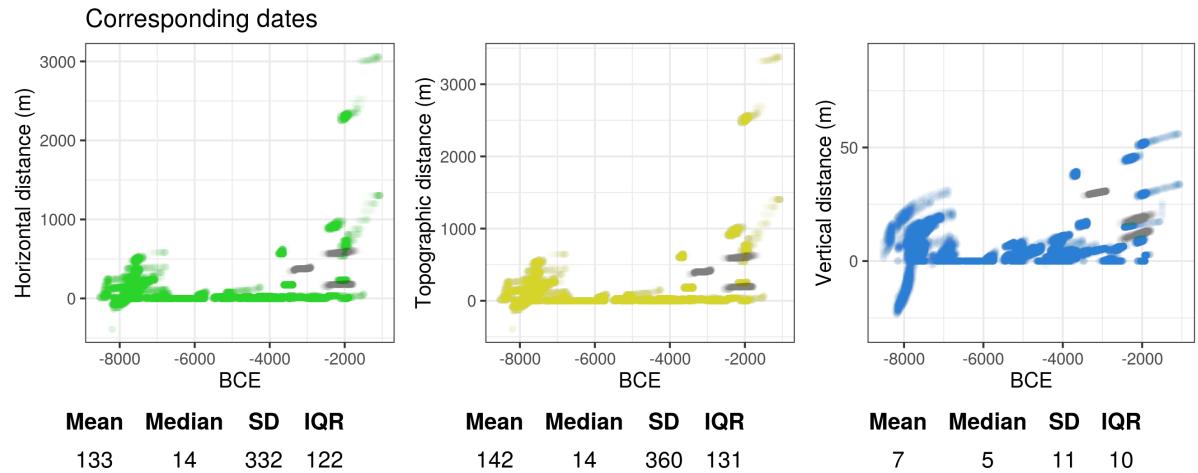
A**B**

Figure 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. The second row B) shows the result of excluding these. The table under each plot lists some corresponding statistics for central tendency and dispersion.

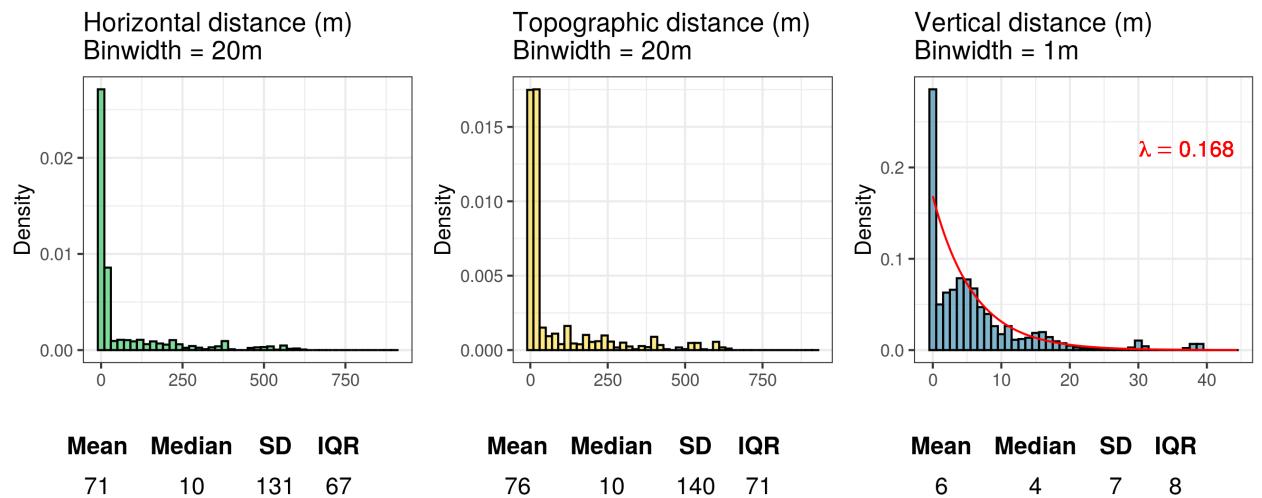
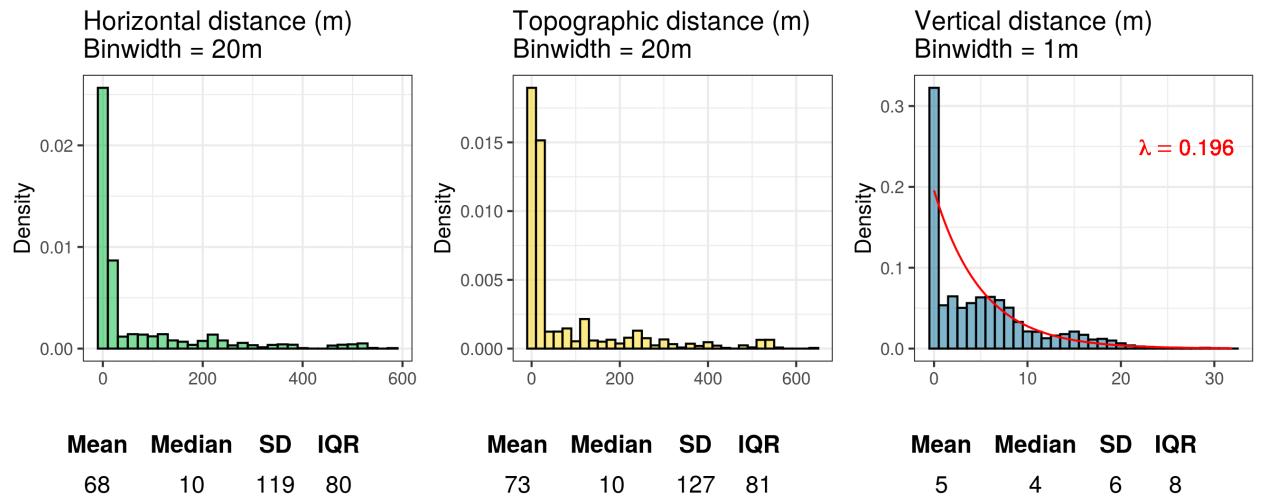
A**B**

Figure 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, and B) simulated results older than 4000 BCE.

357 An exponential function has been fit to the distributions for vertical distance using maximum likelihood
 358 estimation (Figure 7). While it makes theoretical sense that a process of exponential decay explains this
 359 relationship, it is also clear that this does not perfectly match the data. However, this can at least in part be
 360 related to methodological factors, where the accumulation of distance-values on the 0m mark likely follow
 361 from forcing negative values to zero, from the resolution of the spatial data, and from defining intersecting
 362 sea- and site polygon as having a zero distance. If one accepts this, the probability density function for
 363 exponential decay can be used to characterise the vertical distance between sites and the shoreline and be
 364 used to inform a method for shoreline dating that takes this into account.

365 6 Shoreline dating

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

$$p(\alpha - D) = \lambda e^{-\lambda(\alpha - D)} \quad (1)$$

375 where λ is the decay ratio. This can then be coupled with the trajectory of relative sea-level change to find
 376 the corresponding calendar date T for the occupation of the site. This is defined by a uniform probability
 377 density function (U) over the range between the lower T_l and upper T_u bounds of the displacement curve
 378 that has been interpolated to the site location:

$$p(T|\alpha - D) = U[T_l|_{\alpha-D}, T_u|_{\alpha-D}] \quad (2)$$

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

$$p(T|\alpha - D) = p(T|\alpha - D)p(\alpha - D) \quad (3)$$

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

$$p(T|\alpha) = \sum_D p(T|\alpha - D)p(\alpha - D) \quad (4)$$

383 An example of an implementation of the outlined approach is given in Figure 8, where $\lambda = 0.168$. This is
 384 the decay ratio identified when considering all pre-Late Neolithic simulation results (Figure 7A). For the
 385 numerical implementation, D is here stepped through as a sequence of increments of 0.001m, starting from the
 386 site elevation α . The exponential function is stepped through in its cumulative form, where the probability
 387 from the previous 0.001m step is subtracted from the probability at the current step. This probability is then
 388 divided equally across the individual calendar years in the range between the lower and the upper limit of
 389 the displacement curve at the current 0.001m step. The histogram that is the resulting shoreline date is the
 390 sum of performing this procedure on all possible 0.001m values of D , which, in practice, is until $\alpha - D = 0$ or
 391 when 99.999% of the exponential function has been stepped through.

392 To evaluate the outlined procedure it is used to shoreline date the sites from where the method was derived
 393 to check if the resulting shoreline dates correspond to the radiocarbon dates associated with the sites (Figure
 394 9). The Late Neolithic sites are also included here for illustrative purposes, even though these have not
 395 informed the decay ratio in use. Following from having defined the distance between intersecting sea- and
 396 site polygons as zero during simulations, the sites were dated using the mean elevation of the site polygons to
 397 allow for some variation in elevation over the site limits. The synchronicity between radiocarbon and shoreline
 398 dates was then evaluated using the method presented by Parnell et al. (2008). Here, 100,000 age samples
 399 drawn from the probability distribution of each shoreline date were subtracted from 100,000 age samples
 400 drawn from the corresponding modelled ^{14}C -dates. The resulting range of the 95% highest density region
 401 (HDR, Hyndman 1996) was then checked to see if it crosses zero, in which case the dates are considered to
 402 be in agreement (Figure 10). When excluding the earliest occupation phase at Gunnarsrød 5, the deviation
 403 of which is to be expected based on issues with the DTM (see above), the shoreline date corresponds to
 404 the radiocarbon dates in 58 out of 68 cases (84%). Only including dates modelled to be older than 2500
 405 BCE with 95% probability, i.e. older than the Late Neolithic, improves this to 56 out of 62 cases (90%).
 406 When only including dates older than 4000 BCE with 95% probability, i.e. only Mesolithic site phases, the
 407 success rate is further increased to 46/49 (94%). The three failed Mesolithic shoreline dates are from the
 408 early sites Langemyr and Kvastad A2, with the likely implication that a lower decay ratio than what is used
 409 for characterising the distance between site and shoreline for all sites in aggregate should be used for sites
 410 known to be from the earliest part of the Mesolithic (see also Figure 6).

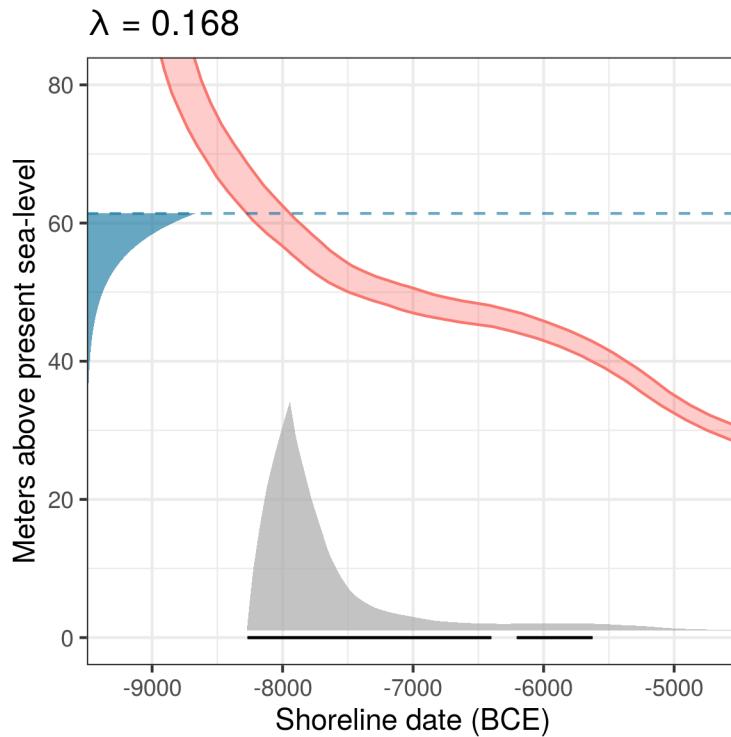


Figure 8: Shoreline dating of Hegna vest 1. The dashed line marks the mean elevation of the site polygon which is used to inform α in the dating of the site. The exponential function decays with ratio λ from Figure 7A. The resulting shoreline date in grey is underlined with the 95% HDR in black.

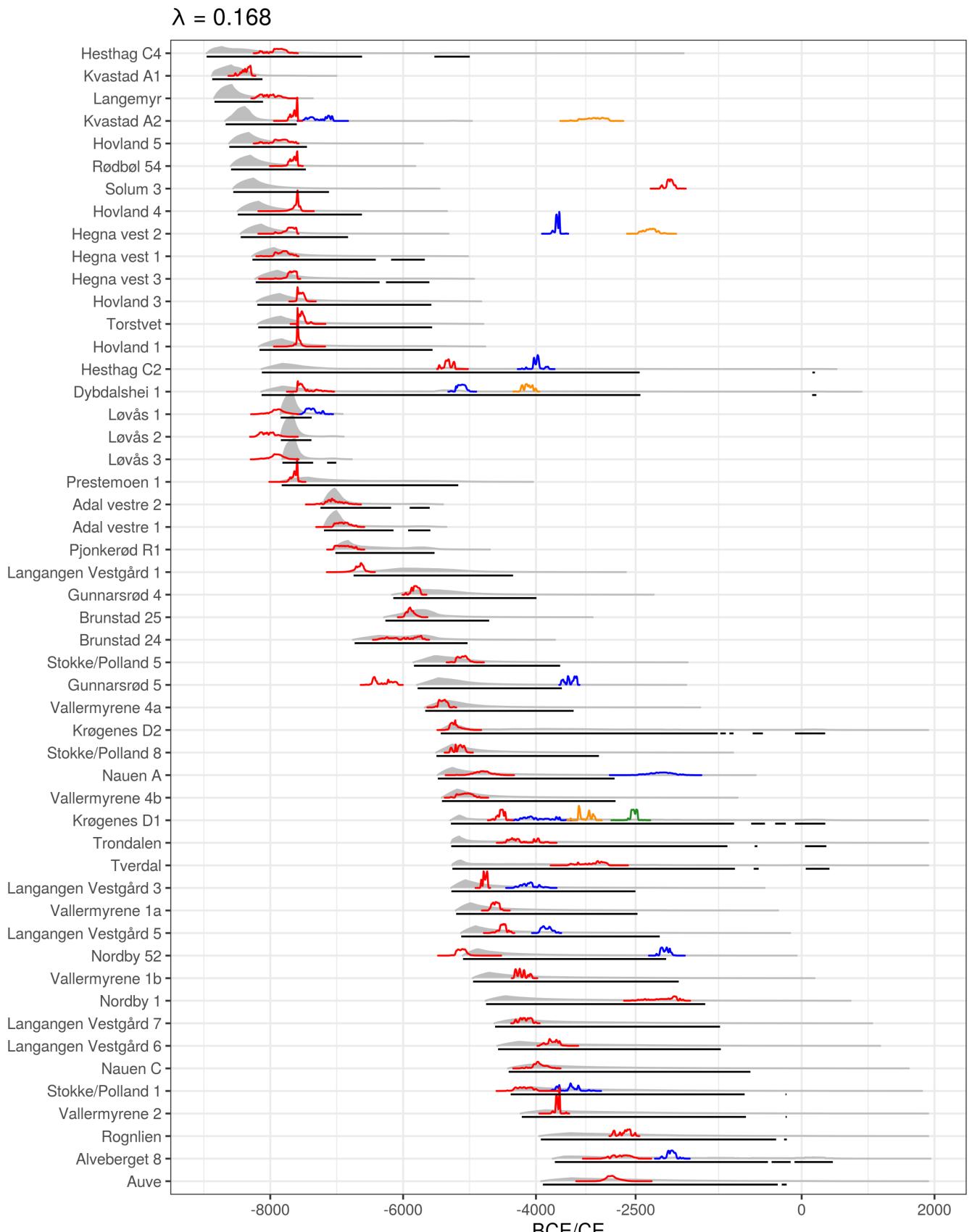


Figure 9: The result of backwards shoreline dating the sites with radiocarbon dates corresponding to the artefact inventory using the method proposed here. The shoreline dates are plotted in grey and underlined¹⁷ with the 95% HDR in black. These are plotted against the modelled radiocarbon dates, which are given colour from oldest to youngest occupation phase for each site, defined by non-intersecting dates at 99.7% probability.

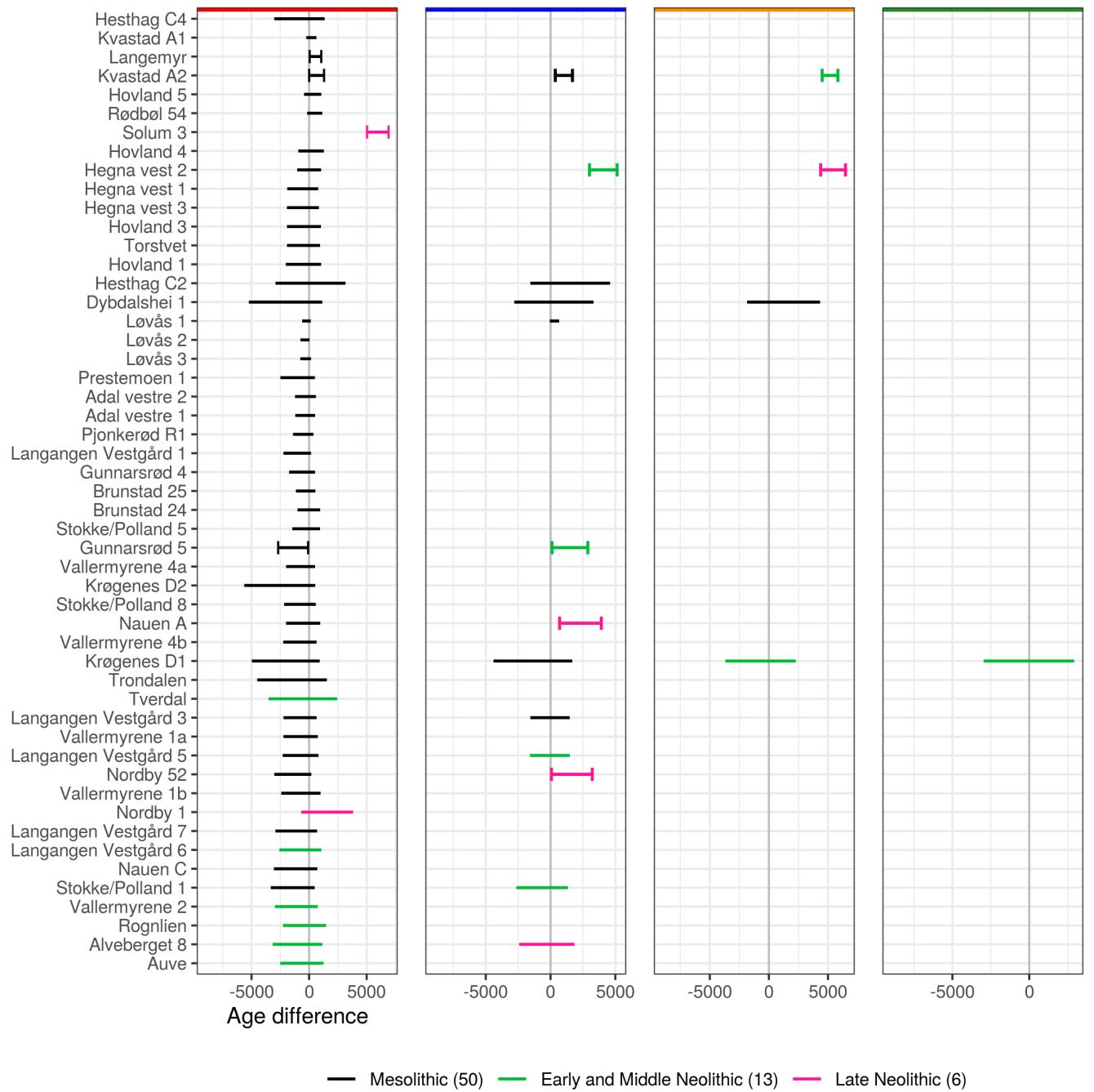


Figure 10: Evaluation of the agreement between the shoreline dates and radiocarbon dates given in Figure 9. When the range of the 95% HDR for age difference crosses zero, the shoreline and radiocarbon dates are considered to be in agreement. Line segments with vertical bars indicate that the HDR does 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 Figure 9.

411 7 Re-dating previously shoreline dated sites

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

420 The comparison with previously reported dates is an illustrative, but unfair exercise for a few reasons. First,
421 the dates provided in the reports are typically stated to be a very rough estimate, and are sometimes given
422 as a point estimate with an undefined, but implied or explicit uncertainty range. Secondly, seeing as these
423 reports are from various dates in time, many are based on now outdated data on RSL-change. Finally, they
424 are sometimes only meant to indicate a lower bound for when the sites could have been in use. Overall, the
425 results could, with some danger of circularity, suggest that shoreline dating has generally been applied with a
426 reasonable degree of success, seeing as these dates have typically been interpreted and informed research in
427 an approximate manner (although see e.g. Roalkvam 2022). With these considerations in mind, the results
428 also indicate that shoreline dating has at times been applied with an exaggerated degree of precision. While
429 the implications of a more stable RSL-change for shoreline dating are well known, this also appears to be
430 somewhat under-appreciated in the practical implementation of the method. The results also highlight the
431 spatial and temporal contingency of the method, illustrated by the variation in the range of the 95% HDRs
432 for the dates. In some cases the method provides a very precise date range and in others it offers little more
433 than a *terminus post quem*. This is dependent on the steepness of the displacement curves, leading to the
434 general pattern of older sites situated towards the north-east getting more precise dates (cf. Figure 2B).
435 Furthermore, as some of the date ranges extend well beyond major chronological divisions, even into the
436 Iron Age, they could be severely and securely constrained with only cursory reference to typology. While
437 this would be trivial in some cases, the nature and uncertainty inherent to the method still means that this
438 is arguably a required exercise that should be explicitly performed. This also points to the possibility of
439 drawing on other temporal data, for example within a Bayesian framework, to further improve the precision
440 of the dates that can be achieved with shoreline dating.

441 Not least following from the fact that relatively few ^{14}C -dates older than c. 8000 BCE associated with
442 anthropogenic activity have been achieved in Norway (Åstveit 2018; Damlien and Solheim 2018; Kleppe
443 2018), the shoreline dating of the earliest sites is essential for understanding the pioneer settlement and the
444 initial colonisation of the Scandinavian peninsula (e.g. Bang-Andersen 2012; Berg-Hansen 2018; Breivik
445 2014; Fuglestvedt 2012; Glørstad 2016). The shoreline dated Preboreal sites from the Brunlanes-project are
446 among the earliest known sites in Norway (Jaksland 2012a, 2012b; Jaksland and Persson 2014). These have a
447 distinct Early Mesolithic artefact inventory and are situated in a steep area of the landscape where use of
448 the sites would have been difficult after the sea retreated any significant distance from their location due
449 to accessibility. In the original publication of the sites, Jaksland (2014) provides a thorough discussion of
450 shoreline dating in general, and as used for the dating of the Brunlanes sites specifically. A comparison of
451 his results and the ones achieved using the above-outlined approach are given in Figure 12A. The sites have
452 been dated using what Jaksland (2014) gives as the lowest elevation of finds at each site, and by employing a
453 exponential decay ratio of 0.13, to allow for more deviance in the distance between site and shoreline. This
454 corresponds to the decay ratio for results older than 7000 BCE in Figure 7.

455 The small discrepancies between the achieved results mainly follow from the fact that a slightly updated
456 version of the local displacement curve is applied here (Sørensen et al. in press; cf. Sørensen, Henningsmoen,
457 et al. 2014). Jaksland's dates are given a flat 200- and 50-year uncertainty range starting from what he
458 gives as the earliest possible date. The 200 year uncertainty range is given if the sites were to be considered
459 in isolation, while his argument for the uncertainty range of only 50 years is based on the location of the
460 sites relative to each other. Since they are located in such a constrained and steep area of the landscape,
461 the difference in elevation between the sites is argued to establish their relative date and thus constrain the

$$\lambda = 0.168$$

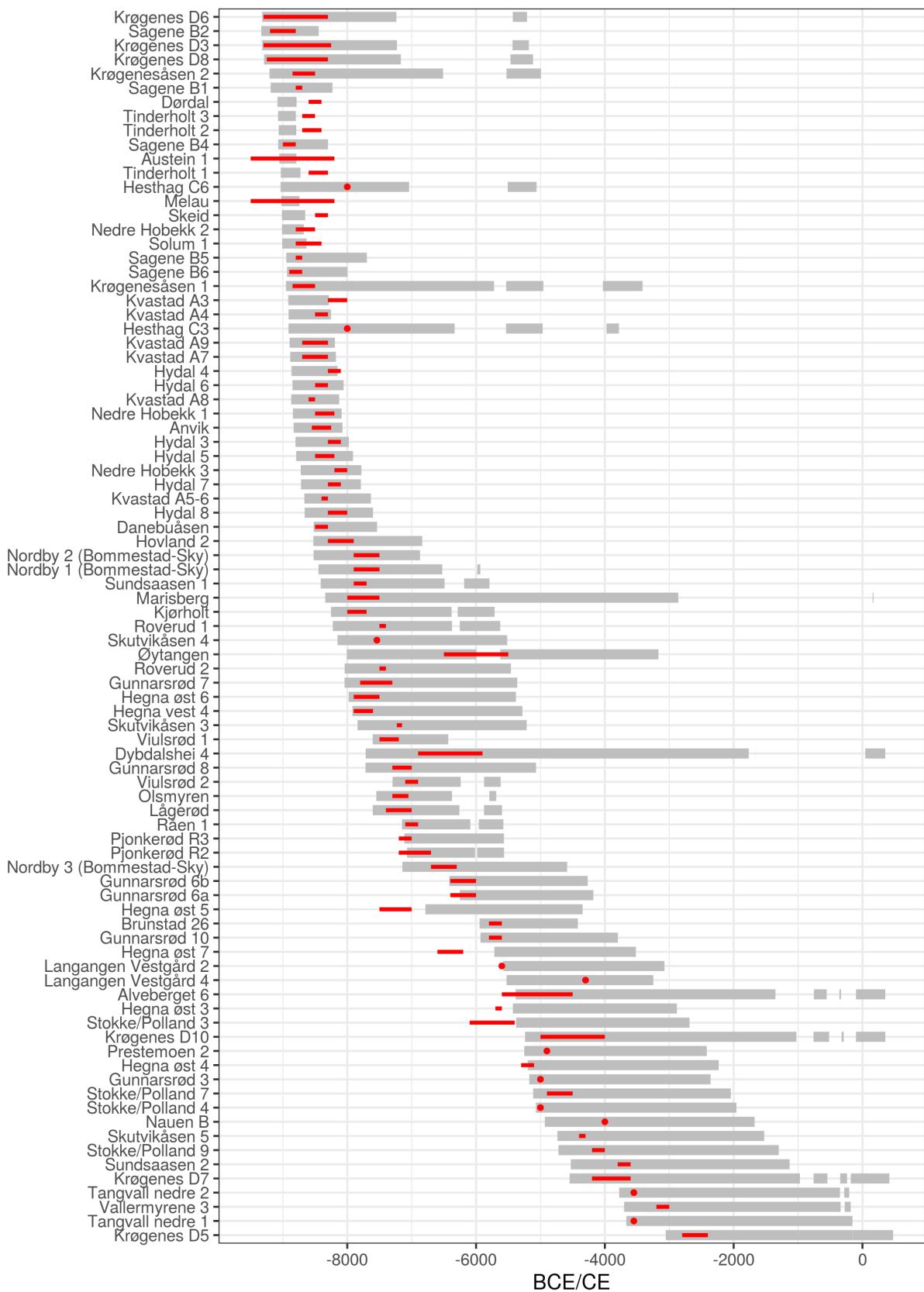


Figure 11: Re-dating excavated and previously shoreline dated sites in the study area without radiocarbon dates or with radiocarbon dates that do not correspond to the artefact inventories. The 95% HDRs in grey²⁰ are compared to the dates originally proposed by the excavation reports in red.

462 uncertainty ranges so that they do not overlap. This information is not integrated in the approach outlined
463 here, but it could justify further reducing the uncertainty ranges.

464 Although their accuracy is of course ultimately dependent on the veracity of the geological reconstruction,
465 the high rate of RSL-change in this period does result in very precise dates. Above it was suggested that
466 additional temporal data could be combined with the method to improve its accuracy and precision. Drawing
467 on Jaksland (2014), this example instead highlights the fact that the spatial nature of the method means
468 that a consideration of the surrounding terrain and other sites can also help to increase the precision of the
469 method if this can be used to exclude certain RSLs as unlikely for when a site was in use. One approach could
470 also be to assess the spatial implication of a proposed shoreline date by simulating the adjusted sea-levels,
471 as is done for Pauker 1 in Figure 12B, followed for example by a visual evaluation of the topography or by
472 evaluating the distance and steepness of the slope to the shoreline. If this method is developed further, it
473 could conceivably be possible to exclude certain elevations as unlikely for the position of the shoreline when
474 the site was in use. Such approaches would make less of an impact for the Brunlanes sites, where the 95%
475 HDR is already quite constrained, but could considerably improve the precision of the method in cases where
476 RSL-change has been less severe (cf. Figure 11).

477 8 Concluding remarks

478 The most significant finding of this paper is a confirmation of previous research into the relation between
479 coastal Norwegian Stone Age sites and the prehistoric shoreline. This is indicated by the close proximity
480 of sites and the shoreline until the transition to the Neolithic at c. 4000 BCE, after which a few sites are
481 situated some distance from the sea, followed by a more decisive break at the transition to the Late Neolithic
482 at c. 2500 BCE. This development is in clear agreement with the literature. Furthermore, based on the
483 quantitative nature of these findings, an initial formulation of a refined method for the shoreline dating of
484 pre-Late Neolithic Stone Age sites has been proposed. Apart from taking the distance between sites and the
485 isobases of the displacement curves into consideration when dating the sites, this involves accounting for the
486 distance between the sites and the shoreline. When no other information is available, it can at present be
487 recommended to use the empirically derived exponential decay ratio of 0.168 (Figure 7A) to characterise
488 this relationship. Furthermore, while this remains to be formalised and explored further, it was also shown
489 how the method can be improved by including more information, both with reference to the topographic
490 location of the sites and other temporal data. As the precision of the method is both geographically and
491 temporally contingent due to the trajectory of RSL-change, where older sites situated towards the north-east
492 in the study area will get a more precise date, the impact of such additional information will also vary.

493 Future investigations and radiocarbon dates from Stone Age sites in the region can not only be used to further
494 evaluate and adjust the findings reported here, but a larger sample size could also lay the foundations for
495 refining the method by identifying subsets of sites for which the application of the method could be adjusted.
496 Given its behavioural nature, it would for example seem likely that dimensions such as the nature and purpose
497 of visits to the sites will have implications for how close to the shoreline they were located. Furthermore,
498 other dimensions related to the topographic location of the sites could be similarly explored. This for example
499 pertains to the exposure of sites to wave action, which is likely to have been of concern (Roalkvam 2020), and
500 which presumably has implications for how close to the shoreline people settled (Blankholm 2020; Helskog
501 1978). This is also related to the fact that while the mean sea-level is used for dating the sites, a consideration
502 of the tidal range could possibly also have implications for the site location relative to the shoreline, depending
503 on the topography (Helskog 1978). The potential of exploring dimensions such as these was also hinted at
504 here with the estimation and cursory treatment of the horizontal and topographic distance to the shoreline.
505 If patterns related to such locational patterns can be discerned and unpacked, this will not least be useful for
506 improving the shoreline dating of sites which have only been surveyed and where little information beyond
507 their location is available.

508 Some limitations and sources of likely variation and uncertainty that have not been considered should also be
509 mentioned. First, the sample size is limited and the future addition of more sites might alter the picture
510 considerably. Secondly, the validity of the outlined method was evaluated by applying it to the data from

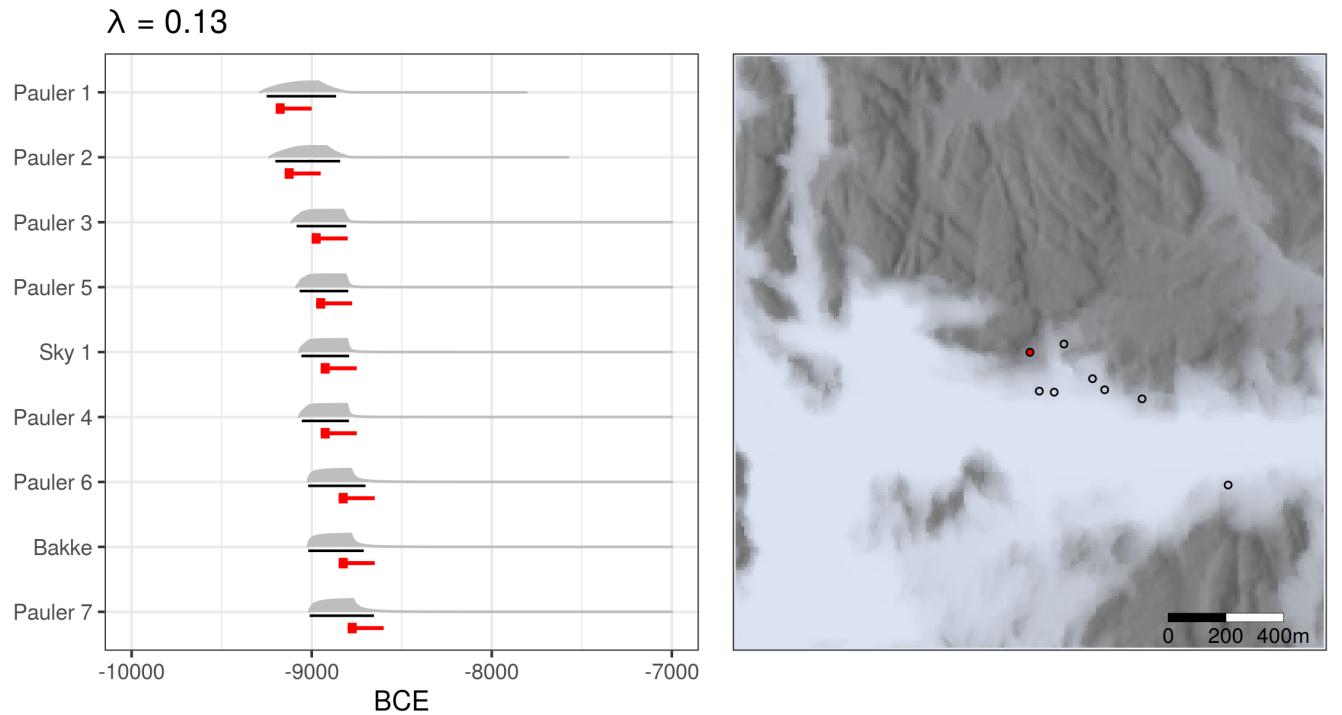


Figure 12: Shoreline dating of the Brunlanes sites using site altitudes provided by Jakobsson (2014:tab.4). A) The result of applying the approach to shoreline dating outlined above. The shoreline date in grey is underlined with the 95% HDR in black. Dates provided by Jakobsson (2014) are plotted in 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 Paurer sites and Sky 1. The sea-level has been simulated using the probability distribution associated with the shoreline date for Paurer 1 (see also map in Jakobsson 2014:fig.12a). Paurer 1 is the red point.

511 where the input parameters were derived. Fitting and evaluating a model using the exact same data will likely
512 exaggerate its performance. Thirdly, the DTM has only been corrected for major modern disturbances. This
513 means that other forms of erosion, although likely not that prevalent, have not been considered. Fourthly, the
514 DTM has a vertical error which could also benefit from being integrated in the analysis (Fisher 1993; Lewis
515 2021). Fifthly, the displacement curves were here interpolated to all site locations without accounting for
516 increased uncertainty as one moves further away from the isobases of the displacement curves—an uncertainty
517 that is likely higher for RSL-change further back in time due to the shoreline gradient. This is also related
518 to the fact that the geologic reconstructions hold uncertainty that is not represented in the displacement
519 curves, relating for example to variation in the methods and quality of the data used for the compilation of
520 the curves, as well as the expert interpretations underlying these. Sixthly, neither the question of how site
521 limits are defined nor the elevation range over which these extend was given much consideration (Mjærum
522 2022). Finally, the aggregation and division of settlement phases at each site was here simply done by treating
523 radiocarbon dates not overlapping at 99.7% as representing unrelated occupation events. This could also be
524 handled differently (e.g. Bronk Ramsey 2009, 2015). While each of these factors will have variable impact on
525 the final results, they clearly represent dimensions which would all benefit from further consideration and
526 which means that some of the precision following from the outlined approach is likely to be spurious.

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

535 Finally, this analysis employed a simulation approach to integrate multiple sources of spatio-temporal
536 uncertainty. Here this was simply used to inform the question of the distance between sites and the shoreline.
537 However, this method and general framework can be extended to a wide range of use-cases where one needs
538 to visualise, and quantitatively or qualitatively evaluate the relationship between archaeological phenomena,
539 the prehistoric shoreline, and the uncertainty inherent to this reconstruction.

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542 History, University of Oslo.

543 References

- 544 Åkerlund, Agneta
545 1996 *Human responses to shore displacement: Living by the sea in Eastern Middle Sweden during the Stone*
546 *Age*. Riksantikvarieämbetet, Stockholm.
- 547 Åkerlund, Agneta, Jan Risberg, Urve Miller, and Per Gustafsson
548 1995 On the applicability of the ^{14}C method to interdisciplinary studies on shore displacement and settlement
549 location. *PACT* 49:53–84.
- 550 Amundsen, Øystein, Stig Knutsen, Axel Mjærum, and Gaute Reitan
551 2006 Nøkleby i Ski – en tidligeolittisk jordbruksboplass? *Primitive tider* 9:85–96.
- 552
- 553 Åstveit, Leif Inge
554 2018 The Early Mesolithic of Western Norway. In *Early Economy and Settlement in Northern Europe. Pioneering, Resource Use, Coping with Change*, edited by Hans Peter Blankholm, pp. 231–274. Equinox, Sheffield.
- 555 Bakka, Egil, and Peter Emil Kaland
556 1971 Early farming in Hordaland, western Norway. Problems and approaches in archaeology and pollen analysis. *Norwegian Archaeological Review* 4:1–17. DOI:10.1080/00293652.1971.9965136.
- 559 Bang-Andersen, Sveinung
560 2012 Colonizing Contrasting Landscapes. The Pioneer Coast Settlement and Inland Utilization in Southern Norway 10,000–9500 Years Before Present. *Oxford Journal of Archaeology* 31:103–120. DOI:10.1111/j.1468-0092.2012.00381.x.
- 561 Berg-Hansen, Inger Marie
562 2009 *Steinalderregistrering. Metodologi og forskningshistorie i Norge 1900–2000 med en feltstudie fra Lista i Vest-Agder*. Museum of Cultural History, University of Oslo, Oslo.
- 565 2018 Continuity and Change in Late- and Post-glacial Social Networks: Knowledge Transmission and Blade Production Methods in Ahrensburgian and Early Mesolithic North West Europe. In *The Early Settlement of Northern Europe. Transmission of Knowledge and Culture*, edited by Kjel Knutsson, Helena Knutsson, Jan Apel, and Håkon Glørstad, pp. 63–98. Equinox, Sheffield.
- 566 Bergsvik, Knut Andreas
568 2009 Caught in the middle: functional and ideological aspects of Mesolithic shores in Norway. In *Mesolithic Horizons: Papers presented at the Seventh International Conference on the Mesolithic in Europe, Belfast 2005*, edited by Sinéad B. McCartan, Rick Schulting, Graeme Warren, and Peter Woodman, pp. 602–609. Oxbow Books, Oxford.
- 570 Bevan, Andrew, Enrico R. Crema, Xiuzhen Li, and Alessio Palmisano
571 2013 Intensities, Interactions, and Uncertainties: Some New Approaches to Archaeological Distributions. In *Computational Approaches to Archaeological Spaces*, edited by Andrew Bevan and Mark Lake, pp. 27–52. Left Coast Press, Walnut Creek.
- 572 Bivand, Roger
574 2021 *rgrass7: Interface Between GRASS 7 Geographical Information System and R*. R package version 0.2-6.
- 576 Bjerck, Hein Bjartmann
577 1990 Mesolithic site types and settlement patterns at Vega, Northern Norway. *Acta Archaeologica* 60:1–32.
- 578
- 579 2005 Strandlinjedatering. In *Norsk arkeologisk leksikon*, edited by Einar Østmo and Lotte Hedeager, pp. 363–364. Pax, Oslo.
- 581 2008a Norwegian Mesolithic Trends: A Review. In *Mesolithic Europe*, edited by Geoff Bailey and Penny Spikins, pp. 60–106. Cambridge University Press, Cambridge.
- 582
- 583 2008b Innledende betraktninger. In *NTNU Vitenskapsmuseets arkeologiske undersøkelser Ormen Lange Nyhamna*, edited by Hein Bjartmann Bjerck, Leif Inge Åstveit, Trond Meling, Jostein Gundersen, Guro Jørgensen, and Staale Normann, pp. 548–551. Tapir Akademisk Forlag, Trondheim.
- 584

- 585 2017 Settlements and Seafaring: Reflections on the Integration of Boats and Settlements Among Marine
586 Foragers in Early Mesolithic Norway and the Yámana of Tierra del Fuego. *The Journal of Island and
Coastal Archaeology* 12(2):276–299. DOI:10.1080/15564894.2016.1190425.
- 587 Blankholm, Hans Peter
588 2020 In the wake of the wake. An investigation of the impact of the Storegga tsunami on the human
settlement of inner Varangerfjord, northern Norway. *Quaternary International* 549:65–73. DOI:<https://doi.org/10.1016/j.quaint.2018.05.050>.
- 589 Borreggine, Marisa, Evelyn Powell, Tamara Pico, Jerry X. Mitrovica, Richard Meadow, and Christian Tryon
590 2022 Not a bathtub: A consideration of sea-level physics for archaeological models of human migration.
591 *Journal of Archaeological Science* 137:105507. DOI:10.1016/j.jas.2021.105507.
- 592 Breivik, Heidi Mjelva
593 2014 Palaeo-oceanographic development and human adaptive strategies in the Pleistocene–Holocene transition:
594 A study from the Norwegian coast. *The Holocene* 24:1478–1490. DOI:10.1177/0959683614544061.
- 595 Breivik, Heidi Mjelva, Guro Fossum, and Steinar Solheim
596 2018 Exploring human responses to climatic fluctuations and environmental diversity: Two stories
597 from Mesolithic Norway. *Quaternary International* 465. Impacts of gradual and abrupt en-
vironmental changes on Late glacial to Middle Holocene cultural changes in Europe:258–275.
598 DOI:10.1016/j.quaint.2016.12.019.
- 599 Breivik, Heidi, and Hein Bjartmann Bjerck
600 2018 Early Mesolithic Central Norway: A Review of Research History, Settlements, and Tool Tradition. In
Early Economy and Settlement in Northern Europe. Pioneering, Resource Use, Coping with Change,
601 edited by Hans Peter Blankholm, pp. 169–206. Equinox, Sheffield.
- 602 Brøgger, Waldemar Christofer
603 1905 *Strandliniens Beliggenhed under Stenalderen i Det Sydøstlige Norge*. Norges geologiske undersøkelse,
604 Kristiania.
- 605 Bronk Ramsey, Christopher
606 2009 Bayesian Analysis of Radiocarbon Dates. *Radiocarbon* 51(1):337–360.
607 DOI:10.1017/S0033822200033865.
- 608 2015 Bayesian Approaches to the Building of Archaeological Chronologies. In *Mathematics and Archaeology*,
609 edited by Juan A. Barcelo and Igor Bogdanovic, pp. 272–292. CRC Press, Boca Raton.
- 610 Conolly, James
611 2020 Spatial interpolation. In *Archaeological Spatial Analysis: A Methodological Guide*, edited by Mark
612 Gillings, Piraye Hacıgüzeller, and Gary Lock, pp. 118–134. Routledge, London & New York.
- 613 Conolly, James, and Mark Lake
614 2006 *Geographical Information Systems in Archaeology*. Cambridge University Press, Cambridge.
- 615 Creel, Roger C., Jacqueline Austermann, Nicole S. Khan, William J. D’Andrea, Nicholas Balascio, Blake
616 Dyer, Erica Ashe, and William Menke
617 2022 Postglacial relative sea level change in Norway. *Quaternary Science Reviews* 282:107422.
618 DOI:10.1016/j.quascirev.2022.107422.
- 619 Crema, Enrico R.
620 2012 Modelling Temporal Uncertainty in Archaeological Analysis. *Journal of Archaeological Method and
Theory* 19(3):440–461. DOI:10.1007/s10816-011-9122-3.
- 621 2015 Time and Probabilistic Reasoning in Settlement Analysis. In *Mathematics and Archaeology*, edited by
622 Juan A. Barcelo and Igor Bogdanovic, pp. 314–334. CRC Press, Boca Raton.
- 623 Crema, Enrico R., Andrew Bevan, and Mark W. Lake
624 2010 A probabilistic framework for assessing spatio-temporal point patterns in the archaeological record.
625 *Journal of Archaeological Science* 37(5):1118–1130. DOI:10.1016/j.jas.2009.12.012.
- 626 Damlien, Hege, and Steinar Solheim

- 629 2018 The Pioneer Settlement of Eastern Norway. In *Early Economy and Settlement in Northern Europe. Pioneering, Resource Use, Coping with Change*, edited by Hans Peter Blankholm, pp. 335–367. Equinox, Sheffield.
- 630
- 631 De Geer, Gerard
- 632 1896 *Om Skandinaviens geografiska utveckling efter Istiden*. P. A. Norstedt & Söner, Stockholm.
- 633
- 634 Eskeland, Knut Fossdal
- 635 2017 *Rapport, arkeologisk registrering. E18 Langangen Rugtvedt, 16/06999, Porsgrunn og Bamble kommune*. Skien.
- 636
- 637 Fisher, Peter F.
- 638 1993 Algorithm and implementation uncertainty in viewshed analysis. *International Journal of Geographical Information Systems* 7(4):331–347. DOI:10.1080/02693799308901965.
- 639
- 640 Fossum, Guro
- 641 2020 Specialists facing climate change. The 8200 cal BP event and its impact on the coastal settlement in the inner Oslo fjord, southeast Norway. In *Coastal Landscapes of the Mesolithic: Human Engagement with the Coast from the Atlantic to the Baltic Sea*, edited by Almut Schülke, pp. 179–201. Routledge, London & New York.
- 642
- 643 Fuglestvedt, Ingrid
- 644 2012 The Pioneer Condition on the Scandinavian Peninsula: the Last Frontier of a ‘Palaeolithic Way’ in Europe. *Norwegian Archaeological Review* 45(1):1–29. DOI:10.1080/00293652.2012.669998.
- 645
- 646 Gjerde, Jan Magne
- 647 2021 The Earliest Boat Depiction in Northern Europe: Newly Discovered Early Mesolithic Rock Art at Valle, Northern Norway. *Oxford Journal of Archaeology* 40:136–152. DOI:10.1111/ojoa.12214.
- 648
- 649 Gjerpe, Lars Erik, and Grethe Bjørkan Bukkemoen
- 650 2008 Nordby 1 – Toskipede hus fra neolitikum-bronsealder og boplasspor fra jernalder. In *E18-prosjektet Vestfold. Bind 3. Hus, boplass- og dyrkningspor*, edited by Lars Erik Gjerpe, pp. 7–38. University of Oslo, Museum of Cultural History, Oslo.
- 651
- 652 Glørstad, Håkon (editor)
- 653 2002 *Svinesundprosjektet. Bind 1. Utgravninger avsluttet i 2001*. University of Oslo, Museum of Cultural History, Oslo.
- 654
- 655 (editor)
- 656 2003 *Svinesundprosjektet . Bind 2. Utgravninger avsluttet i 2002*. University of Oslo, Museum of Cultural History, Oslo.
- 657
- 658 (editor)
- 659 2004 *Svinesundprosjektet. Bind 3. Utgravninger avsluttet i 2003*. University of Oslo, Museum of Cultural History, Oslo.
- 660
- 661 2010 *The Structure and History of the Late Mesolithic Societies in the Oslo Fjord Area 6300–3800 BC*. Bricoleur Press, Lindome.
- 662
- 663 2012 Historical ideal types and the transition to the Late Neolithic in South Norway. In *Becoming European. The transformation of third millennium Northern and Western Europe*, edited by Christopher Prescott and Håkon Glørstad, pp. 82–99. Oxbow Books, Oxford & Oakville.
- 664
- 665 2016 Deglaciation, sea-level change and the Holocene colonization of Norway. *Geological Society, London, Special Publications* 411:9–25. DOI:10.1144/SP411.7.
- 666
- 667 Glørstad, Håkon, Jostein Gundersen, Frode Kvalø, Pål Nymoen, David Simpson, and Birgitte Skar
- 668 2020 Submerged Stone Age from a Norwegian Perspective. In *The Archaeology of Europe’s Drowned Landscapes*, edited by Geoff Bailey, Nena Galanidou, Hans Peeters, Hauke Jöns, and Moritz Mennenga, pp. 125–140. Springer, Cham.
- 669
- 670 GRASS Development Team
- 671 2017 *Geographic Resources Analysis Support System (GRASS) Software, Version 7.2*. Open Source Geospatial Foundation.
- 672
- 673 Gundersen, Jostein

-
- 674 2013 Verken fjord eller fjell – steinalderen i det kystnære innlandet. Gamle og nye funn fra Notodden i
675 Telemark. *Viking* 76:35–62.
- 676 Hafsten, Ulf
- 677 1957 De senkvarterestrandslinje-forskyvningene i Oslofjorden belyst ved pollenanalytiske undersøkelser.
678 *Norwegian Journal of Geography* 16(1-8):74–99. DOI:10.1080/00291955708622137.
- 679 1983 Shore-level changes in South Norway during the last 13,000 years, traced by biostrati-
680 graphical methods and radiometric datings. *Norwegian Journal of Geography* 37(2):63–79.
DOI:10.1080/00291958308552089.
- 681 Hagen, Anders
- 682 1963 Problemkompleks Fosna. Opphav – kontakt med kontinentale grupper – forholdet til Komsa. In
683 *Boplatsproblem vid Kattegat och Skagerack*, pp. 53–59. Göteborg och Bohusläns forminnesförening &
Institutionen för nordisk fornkunskap, Gothenburg University, Gothenburg.
- 684 Helskog, Knut
- 685 1978 Late Holocene sea-level changes seen from prehistoric settlements. *Norwegian Journal of Geography*
686 32:111–119. DOI:10.1080/00291957808552032.
- 687 Herzog, Irmela
- 688 2013 The Potential and Limits of Optimal Path Analysis. In *Computational Approaches to Archaeological
689 Spaces*, edited by Andrew Bevan and Mark Lake, pp. 179–211. Left Coast Press, Walnut Creek.
- 690 Hinsch, Erik
- 691 1955 Traktbegerkultur – Megalitkultur. En studie av Øst-Norges eldste neolitiske gruppe. *Universitetets
692 Oldsaksamling Årbok* 1951/1953:10–177.
- 693 Hinz, Martin, Clemens Schmid, Daniel Knitter, and Carolin Tietze
- 694 2021 *oxcAAR: Interface to 'OxCal' radiocarbon calibration. R package version 1.1.0.*
- 695
- 696 Hollender, Artur
- 697 1901 Om Sveriges nivåförändringar efter människans invandring. *Geologiska Föreningen i Stockholm Förhan-
698 dlingar* 23(4):1118–1130. DOI:10.1080/00293652.1975.9965220.
- 699 Hughes, Anna L. C., Richard Gyllencreutz, Øystein S. Lohne, Jan Mangerud, and John Inge Svendsen
- 700 2016 The last Eurasian ice sheets – a chronological database and time-slice reconstruction, DATED-1.
701 *Boreas* 45(1):1–45. DOI:<https://doi.org/10.1111/bor.12142>.
- 702 Hyndman, Rob J
- 703 1996 Computing and Graphing Highest Density Regions. *The American Statistician* 50(2):120–126.
- 704
- 705 Ilves, Kristin, and Kim Darmark
- 706 2011 Some Critical and Methodological Aspects of Shoreline Determination: Examples from the Baltic Sea
707 Region. *Journal of Archaeological Method and Theory* 18:147–165. DOI:10.1007/s10816-010-9084-x.
- 708 Jakslund, Lasse (editor)
- 709 2001 *Vinterbrolokalitetene – En kronologisk sekvens fra mellom- og senmesolitikum i Ås, Akershus*. University
710 of Oslo, Museum of Cultural History, Oslo.
- 711 (editor)
- 712 2012a *E18 Brunlanesprosjektet. Bind II. Undersøkte lokaliteter fra tidligmesolitikum*. University of Oslo,
713 Museum of Cultural History, Oslo.
- 714 (editor)
- 715 2012b *E18 Brunlanesprosjektet. Bind III. Undersøkte lokaliteter fra tidligmesolitikum og senere*. University
716 of Oslo, Museum of Cultural History, Oslo.
- 717 2014 Kulturhistorisk sammenstilling. In *E18 brunlanesprosjektet. Bind i. Forutsetninger og kulturhistorisk
718 sammenstilling*, edited by Lasse Jakslund and Per Persson, pp. 11–46. University of Oslo, Museum of
Cultural History, Oslo.
- 719 Jakslund, Lasse, and Per Persson (editors)

- 720 2014 *E18 Brunlanesprosjektet. Bind I. Forutsetninger og kulturhistorisk sammenstilling*. University of Oslo,
721 Museum of Cultural History, Oslo.
- 722 Johansen, Erling
- 723 1963 Kyst(fangst)boplassenes strandbundenhet og strandlinjekronologien. In *Boplatsproblem vid Kattegat och Skagerack*, pp. 90–92. Göteborg och Bohusläns fornminnesförening & Institutionen för nordisk fornkunskap, Gothenburg University, Gothenburg.
- 724 1997 Eksperimentelle studier av flint og flint-vandringer i strandsonen. Et forsøk på å vinne ny kunnskap om våre boplasser i steinalderen. *Universitetets Oldsaksamling Årbok* 1995/1996:31–39.
- 725 Jørgensen, Erlend Kirkeng, Petro Pesonen, and Miikka Tallavaara
- 726 2020 Climatic changes cause synchronous population dynamics and adaptive strategies among coastal hunter-gatherers in Holocene northern Europe. *Quaternary Research*:1–16. DOI:10.1017/qua.2019.86.
- 727 Kjemperud, Alfred
- 728 1986 Late Weichselian and Holocene shoreline displacement in the Trondheimsfjord area, central Norway. *Boreas* 15(1):61–82. DOI:10.1111/j.1502-3885.1986.tb00744.x.
- 729 Kleppe, Else Johansen
- 730 1985 *Archaeological Data on Shore Displacements in Norway*. Norges geografiske oppmåling, Hønefoss.
- 731 Kleppe, Jan Ingolf
- 732 2018 The Pioneer Colonization of Northern Norway. In *Early Economy and Settlement in Northern Europe. Pioneering, Resource Use, Coping with Change*, edited by Hans Peter Blankholm, pp. 13–57. Equinox, Sheffield.
- 733 Lakens, Daniël, Anne M. Scheel, and Peder M. Isager
- 734 2018 Equivalence Testing for Psychological Research: A Tutorial. *Advances in Methods and Practices in Psychological Science* 1(2):259–269. DOI:10.1177/2515245918770963.
- 735 Lewis, Joseph
- 736 2021 Probabilistic Modelling for Incorporating Uncertainty in Least Cost Path Results: a Postdictive Roman Road Case Study. *Journal of Archaeological Method and Theory* 28(3):911–924. DOI:10.1007/s10816-021-09522-w.
- 737 Løken, Trond
- 738 1977 Mølen – et arkeologisk dateringsproblem og en historisk identifikasjonsmulighet. *Universitetets Oldsaksamling Årbok* 1975/1976:67–85.
- 739 Marwick, Ben, Carl Boettiger, and Lincoln Mullen
- 740 2018 Packaging Data Analytical Work Reproducibly Using R (and Friends). *The American Statistician* 72(1):80–88. DOI:10.1080/00031305.2017.1375986.
- 741 Melvold, Stine, and Per Persson (editors)
- 742 2014 *Vestfoldbaneprosjektet. Arkeologiske undersøkelser i forbindelse med ny jernbane mellom Larvik og Porsgrunn. Bind 1. Tidlig- Og mellommesolittiske lokaliteter i Vestfold og Telemark*. Portal forlag, Kristiansand.
- 743 Mikkelsen, Egil
- 744 1975a Mesolithic in South-Eastern Norway. *Norwegian Archaeological Review* 8(1):1118–1130. DOI:10.1080/11035890109445866.
- 745 1975b *Frebergsvik. Et mesolitisk boplassområde ved Oslofjorden*. The University Collection of National Antiquities, University of Oslo, Oslo.
- 746 Milne, Glenn A
- 747 2015 Glacial isostatic adjustment. In *Handbook of sea-level research*, edited by Ian Shennan, Antony J Long, and Benjamin P Horton, pp. 421–437. Wiley, Chichester.
- 748 Milne, Glenn A., W. Roland Gehrels, Chris W. Hughes, and Mark E. Tamisiea
- 749 2009 Identifying the causes of sea-level change. *Nature Geoscience* 2(7):471–478. DOI:10.1038/ngeo544.
- 750 Mjærum, Axel

- 766 2018 Hinterland discoveries: Middle Mesolithic woodland utilization and the case of the site Eidsberg,
767 eastern Norway. *Current Swedish Archaeology* 26(1):159–188. DOI:10.37718/CSA.2018.11.
- 768 2022 A Matter of Scale: Responses to Landscape Changes in the Oslo Fjord, Norway, in the Mesolithic.
769 *Open Archaeology* 8(1):62–84. DOI:10.1515/opar-2022-0225.
- 770 Møller, Jakob J
771 1987 Shoreline relation and prehistoric settlement in northern Norway. *Norwegian Journal of Geography*
772 41:45–60. DOI:<http://dx.doi.org/10.1080/00291958708552171>.
- 773 Mörner, Nils-Axel
774 1976 Eustasy and Geoid Changes. *The Journal of Geology* 84(2):123–151. DOI:10.1086/628184.
- 775
776 1979 The Fennoscandian Uplift and Late Cenozoic Geodynamics: Geological Evidence. *GeoJournal* 3(3):287–
777 318. DOI:10.1007/BF00177634.
- 778 Nielsen, Svein Vatsvåg
779 2021 Early farming in Southeastern Norway: New evidence and interpretations. *Journal of Neolithic
780 Archaeology* 23:83–113. DOI:10.12766/jna.2021.4.
- 781 Nielsen, Svein Vatsvåg, Per Persson, and Steinar Solheim
782 2019 De-Neolithisation in southern Norway inferred from statistical modelling of radiocarbon dates. *Journal
783 of Anthropological Archaeology* 53:82–91. DOI:10.1016/j.jaa.2018.11.004.
- 784 Nordqvist, Bengt
785 1995 The Mesolithic settlement of the west coast of Sweden - with special emphasis on chronology and
786 topography of coastal settlements. In *Man and Sea in the Mesolithic. Coastal settlement above and
below present sea level*, edited by Anders Fischer, pp. 185–196. Oxbow Books, Oxford.
- 787 1999 The Chronology of the Western Swedish Mesolithic and Late Paleolithic: Old Answers in Spite of New
788 Methods. In *The Mesolithic of Central Scandinavia*, edited by Joel Boaz, pp. 235–253. University of
Oslo, Oslo.
- 789 Norwegian Mapping Authority
790 2018 *Produktspesifikasjon. Nasjonal modell for høydedata fra laserskanning (FKB-laser)*. FKB-laser_v30.
- 791
792 2021 Tidevannstabeller for den norske kyst med Svalbard samt Dover, England.
- 793
794 Nummedal, Anders
795 1923 Om flintpladsene. *Norwegian Journal of Geography* 7(2):89–141.
- 796
797 Olsen, Asle Bruen, and Sigmund Alsaker
798 1984 Greenstone and diabase utilization in the stone age of western Norway: technological and socio-cultural
799 aspects of axe and adze production and distribution. *Norwegian Archaeological Review* 17(2):71–103.
DOI:10.1080/00293652.1984.9965401.
- 800 Østmo, Einar
801 1988 *Etableringen av jordbrukskultur i Østfold i steinalderen*. The University Collection of National
802 Antiquities, University of Oslo, Oslo.
- 803 2008 *Auve. En fangstboplatt fra yngre steinalder på Vesterøya i Sandefjord. I. Den arkeologiske del*. Museum
804 of Cultural History, University of Oslo, Oslo.
- 805 Parnell, A. C., J. Haslett, J. R. M. Allen, C. E. Buck, and B. Huntley
806 2008 A flexible approach to assessing synchronicity of past events using Bayesian reconstructions of sedimenta-
807 tion history. *Quaternary Science Reviews* 27(19-20):1872–1885. DOI:10.1016/j.quascirev.2008.07.009.
- 808 Persson, Per
809 2008 Nauen 5.2 – Stenåldersboplatser och fossil åkermark. In *E18-prosjektet Vestfold. Bind 2. Steinalderbo-
810 plasser, boplasspor, graver og dyrkningsspor*, edited by Lars Erik Gjerpe, pp. 163–198. University of
Oslo, Museum of Cultural History, Oslo.
- 811 Prescott, Christopher

- 812 2020 Interpreting Complex Diachronic "Neolithic"-Period Data in Norway. In *Farmers at the Frontier – A Pan European Perspective on Neolithisation*, edited by Kurt J. Gron, Lasse Sørensen, and Peter Rowley-Conwy, pp. 381–400. Oxbow Books, Oxford.
- 813
- 814 R Core Team
- 815 2021 *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria.
- 816
- 817 Ramstad, Morten
- 818 2009 Eldre steinalder på Melkøya, representativitet, strandlinjer og transgresjon. In *Undersøkelsene på Melkøya. Melkøyaprosjektet – Kulturhistoriske registreringer og utgravnninger 2001 og 2002*, edited by Anders Hesjedal, Morten Ramstad, and Anja R. Niemi, pp. 491–495. Tromsø museum, Universitetsmuseet, Tromsø.
- 819
- 820 Reimer, Paula J., William E. N. Austin, Edouard Bard, Alex Bayliss, Paul G. Blackwell, Christopher Bronk Ramsey, Martin Butzin, Hai Cheng, R. Lawrence Edwards, Michael Friedrich, Pieter M. Grootes, Thomas P. Guilderson, Irka Hajdas, Timothy J. Heaton, Alan G. Hogg, Konrad A. Hughen, Bernd Kromer, Sturt W. Manning, Raimund Muscheler, Jonathan G. Palmer, Charlotte Pearson, Johannes van der Plicht, Ron W. Reimer, David A. Richards, E. Marian Scott, John R. Southon, Christian S. M. Turney, Lukas Wacker, Florian Adolphi, Ulf Büntgen, Manuela Capano, Simon M. Fahrni, Alexandra Fogtmann-Schulz, Ronny Friedrich, Peter Köhler, Sabrina Kudsk, Fusa Miyake, Jesper Olsen, Frederick Reinig, Minoru Sakamoto, Adam Sookdeo, and Sahra Talamo
- 821
- 822
- 823
- 824
- 825
- 826
- 827
- 828 2020 The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP). *Radiocarbon* 62(4):725–757. DOI:10.1017/RDC.2020.41.
- 829
- 830 Reitan, Gaute, and Inger Marie Berg-Hansen
- 831 2009 *Lundevågenprosjektet, delrapport 1. Sammenfattende rapport. Lunde, 6/1, 6/35 og Skjolnes 7/23, 7/27, Farsund kommune, Vest-Agder*. Oslo.
- 832
- 833 Reitan, Gaute, and Silje Hårstad
- 834 2022 *Løvås, en boplass fra mellommesolitikum, med kulturlag, ildsteder og spor etter mulige hytter. Løvås 47/6, Horten k., Vestfold og Telemark*. University of Oslo, Museum of Cultural History, Oslo.
- 835
- 836 Reitan, Gaute, and Per Persson (editors)
- 837 2014 *Vestfoldbaneprosjektet. Arkeologiske undersøkelser i forbindelse med ny jernbane mellom Larvik og Porsgrunn. Bind 2. Seinmesolittiske, neolittiske og yngre lokaliteter i Vestfold og Telemark*. Portal forlag, Kristiansand.
- 838
- 839 Reitan, Gaute, and Lars Sundström (editors)
- 840 2018 *The Stone Age Coastal Settlement in Aust-Agder, Southeast Norway*. Cappelen Damm Akademisk, Oslo.
- 841
- 842 Roalkvam, Isak
- 843 2020 Algorithmic classification and statistical modelling of coastal settlement patterns in Mesolithic south-eastern Norway. *Journal of Computer Applications in Archaeology* 3(1):288–307. DOI:<https://doi.org/10.5334/jcaa.60>.
- 844
- 845 2022 Exploring the composition of lithic assemblages in Mesolithic south-eastern Norway. *Journal of Archaeological Science: Reports* 42:103371. DOI:10.1016/j.jasrep.2022.103371.
- 846
- 847 Røberg, Frank Halvar N.
- 848 2012 *Bosettings- og aktivitetsspor. Larønningen, 221/2138. Skien, Telemark*. University of Oslo, Museum of Cultural History, Oslo.
- 849
- 850 Romundset, Anders
- 851 2018 Postglacial shoreline displacement in the Tvedstrand-Arendal area. In *The Stone Age Coastal Settlement in Aust-Agder, Southeast Norway*, edited by Gaute Reitan and Lars Sundström, pp. 463–478. Cappelen Damm Akademisk, Oslo.
- 852
- 853 2021 *Resultater fra NGUs undersøkelse av etteristidas strandforskynning nord i Vestfold*. Geological Survey of Norway, Trondheim.
- 854
- 855 Romundset, Anders, Stein Bondevik, and Ole Bennike

- 856 2011 Postglacial uplift and relative sea level changes in Finnmark, northern Norway. *Quaternary Science*
857 *Reviews* 30(19-20):2398–2421. DOI:10.1016/j.quascirev.2011.06.007.
- 858 Romundset, Anders, Ola Fredin, and Fredrik Høgaas
- 859 2015 A Holocene sea-level curve and revised isobase map based on isolation basins from near the southern
860 tip of Norway. *Boreas* 44:383–400. DOI:10.1111/bor.12105.
- 861 Romundset, Anders, Thomas R. Lakeman, and Fredrik Høgaas
- 862 2018 Quantifying variable rates of postglacial relative sea level fall from a cluster of 24 isolation basins in
863 southern Norway. *Quaternary Science Reviews* 197:175–192. DOI:10.1016/j.quascirev.2018.07.041.
- 864 Schmitt, Lou, Stephan Larsson, Jan Burdukiewicz, John Ziker, Krister Svedhage, Jeanette Zamon, and
865 Steffen Holger
- 866 2009 Chronological Insights, Cultural Change, and Resource Exploitation on the West Coast of Sweden
867 During the Late Palaeolithic/Early Mesolithic Transition. *Oxford Journal of Archaeology* 28:1–27.
DOI:10.1111/j.1468-0092.2008.00317.x.
- 868 Schülke, Almut
- 869 2020 First visit or revisit? Motivations of mobility and the use and reuse of sites in the changing coastal
870 areas of Mesolithic southeastern Norway. In *Coastal Landscapes of the Mesolithic: Human Engagement
with the Coast from the Atlantic to the Baltic Sea*, edited by Almut Schülke, pp. 359–393. Routledge,
London & New York.
- 871 Shennan, Ian
- 872 2015 Handbook of sea-level research: Framing research questions. In *Handbook of Sea-Level Research*, edited
873 by Ian Shennan, Antony J Long, and Benjamin P Horton, pp. 3–25. Wiley, Chichester.
- 874 Shetelig, Haakon
- 875 1922 *Primitive Tider i Norge – En oversikt over stenalderen*. John Griegs Forlag, Bergen.
- 876 Simpson, David N
- 877 2009 Automating the extrapolation of sea-level displacement curves: implications for Mesolithic research in
878 western Norway. In *Mesolithic Horizons: Papers presented at the Seventh International Conference
on the Mesolithic in Europe, Belfast 2005*, edited by Sinéad B. McCartan, Rick Schulting, Graeme
Warren, and Peter Woodman, pp. 176–183. Oxbow Books, Oxford.
- 879 Sognnes, Kalle
- 880 2003 On shoreline dating of rock art. *Acta Archaeologica* 74:189–209.
- 881 Solheim, Steinar
- 882 2012 Lokal praksis og fremmed opphav. Arbeidsdeling, sosiale relasjoner og differensiering i østnorsk
883 tidligeolitikum. Unpublished PhD thesis, Oslo.
- 884 (editor)
- 885 2017 *E18 Rugsvedt-Dørdal. Arkeologiske undersøkelser av lokaliteter fra steinalder og jernalder i Bamble
886 kommune, Telemark fylke*. Portal forlag, Kristiansand.
- 887 2020 Mesolithic coastal landscapes. Demography, settlement patterns and subsistence economy in south-
888 eastern Norway. In *Coastal Landscapes of the Mesolithic: Human Engagement with the Coast from the
889 Atlantic to the Baltic Sea*, edited by Almut Schülke. Routledge, London & New York.
- 890 2021 Timing the Emergence and Development of Arable Farming in Southeastern Norway by Using Summed
891 Probability Distribution of Radiocarbon Dates and a Bayesian Age Model. *Radiocarbon* 63(5):1–22.
DOI:10.1017/RDC.2021.80.
- 892 Solheim, Steinar, Hege Damlien, and Guro Fossum
- 893 2020 Technological transitions and human-environment interactions in Mesolithic southeastern Norway, 11
894 500–6000 cal. BP. *Quaternary Science Reviews* 246:106–501. DOI:10.1016/j.quascirev.2020.106501.
- 895 Solheim, Steinar, and Per Persson
- 896 2018 Early and mid-Holocene coastal settlement and demography in southeastern Norway: Comparing dis-
897 tribution of radiocarbon dates and shoreline-dated sites, 8500–2000 cal. BCE. *Journal of Archaeological
898 Science: Reports* 19:334–343. DOI:10.1016/j.jasrep.2018.03.007.

- 899 Sørensen, Rolf
900 1979 Late Weichselian deglaciation in the Oslofjord area, south Norway. *Boreas* 8(2):241–246. DOI:<https://doi.org/10.1111/j.1502-3885.1979.tb00806.x>.
- 901
902 1999 En ^{14}C datert og dendrokronologisk kalibrert strandforksyvningskurve for sørøst-Østfold. Sørøst-Norge. In *Museumslandskap. Artikkelsamling til Kerstin Griffin på 60-årsdagen. Bind A*, edited by Lotte Selsing and Grete Lillehammer, pp. 227–242. AmS-rapport 12A. Museum of Archaeology, Stavanger.
- 903
904 Sørensen, Rolf, Kari E. Henningsmoen, Helge I. Høeg, and Veronika Gälman
905 2014 Holocene landhevningsstudier i sørøst-Vestfold og sørøstre Telemark – Revidert kurve. In *Vestfoldbaneprosjektet. Arkeologiske undersøkelser i forbindelse med ny jernbane mellom Larvik og Porsgrunn. Bind 1*, edited by Stine Melvold and Per Persson, pp. 36–47. Portal, Kristiansand.
- 906
907 Sørensen, Rolf, Kari E. Henningsmoen, Helge I. Høeg, and Veronika Gälman
908 in Holocen vegetasjonshistorie og landhevning i sørøst-Vestfold og sørøstre Telemark. In *The Stone Age in Telemark. Archaeological results and scientific analysis from Vestfoldbaneprosjektet and E18 Rugtvedt-Dørdal*, edited by Per Persson and Steinar Solheim.
- 909
910 Sørensen, Rolf, Helge I. Høeg, Kari E. Henningsmoen, Göran Skog, Solveig F. Labowsky, and Bjørg Stabell
911 2014 Utviklingen av det senglasiale og tidlig preboreale landskapet og vegetasjonen omkring steinalderboplassene ved Pauler. In *E18 Brunlanesprosjektet. Bind 1. Forutsetninger og kulturhistorisk sammenstilling*, edited by Lasse Jakslund and Per Persson, pp. 171–213. University of Oslo, Museum of Cultural History, Oslo.
- 912
913 Stokke, Jo-Simon Frøshaug, and Gaute Reitan
914 2018 Kvastad A2. Lokalitet med funn fra tidlig- og mellommesolitikum og dyrkningsspor fra mellom- og senneolitikum. In *The Stone Age Coastal Settlement in Aust-Agder, Southeast Norway*, edited by Gaute Reitan and Lars Sundström, pp. 375–407. Cappelen Damm Akademisk, Oslo.
- 915
916 Stroeven, Arjen P., Clas Hättestrand, Johan Kleman, Jakob Heyman, Derek Fabel, Ola Fredin, Bradley W. Goodfellow, Jonathan M. Harbor, John D. Jansen, Lars Olsen, Marc W. Caffee, David Fink, Jan Lundqvist, Gunhild C. Rosqvist, Bo Strömborg, and Krister N. Jansson
917 2016 Deglaciation of Fennoscandia. *Quaternary Science Reviews* 147:91–121.
918 DOI:[10.1016/j.quascirev.2015.09.016](https://doi.org/10.1016/j.quascirev.2015.09.016).
- 919
920 Stuvier, Minze, and Paula Reimer
921 1989 Histograms obtained from computerized radiocarbon age calibration. *Radiocarbon* 31(3):817–823.
922 DOI:[10.1017/S0033822200012431](https://doi.org/10.1017/S0033822200012431).
- 923
924 Svendsen, John Inge, and Jan Mangerud
925 1987 Late Weichselian and Holocene sea-level history for a cross-section of western Norway. *Journal of Quaternary Science* 2(2):113–132. DOI:[10.1002/jqs.3390020205](https://doi.org/10.1002/jqs.3390020205).
- 926
927 Tallavaara, Miikka, and Petro Pesonen
928 2020 Human ecodynamics in the north-west coast of Finland 10,000–2000 years ago. *Quaternary International* 549:26–35. DOI:[10.1016/j.quaint.2018.06.032](https://doi.org/10.1016/j.quaint.2018.06.032).
- 929
930 van der Plicht, Johannes
931 1993 The Groningen Radiocarbon Calibration Program. *Radiocarbon* 35(1):231–237.
932 DOI:[10.1017/S0033822200013916](https://doi.org/10.1017/S0033822200013916).
- 933
934 Wang, Ian
935 2019 *topoDistance: Calculating topographic paths and distances. R package version 1.0.1.* [Https://CRAN.R-project.org/package=topoDistance](https://CRAN.R-project.org/package=topoDistance).
- 936
937 Wenn, Camilla Cecilie
938 2012 *Bosetningsspor, produksjonsområde og dyrkningsspor fra Neolitikum til Folkevandringstid. Bratsberg, 63/69, 244. Skien kommune, Telemark.* University of Oslo, Museum of Cultural History, Oslo.
- 939
940 Wikell, Roger, Fredrik Molin, and Mattias Pettersson
941 2009 The Archipelago of Eastern Middle Sweden - Mesolithic Settlement in Comparison with ^{14}C and Shoreline Dating. In *Chronology and Evolution within the Mesolithic of North-West Europe*, edited by Philippe Crombé, Mark van Strydonck, Joris Sergant, Mathieu Boudin, and Machteld Bats, pp. 417–434. Cambridge Scholar Publishing, Brussels.

941

942 Yubero-Gómez, María, Xavier Rubio-Campillo, and Javier López-Cachero

943 2016 The study of spatiotemporal patterns integrating temporal uncertainty in late prehistoric settlements
944 in northeastern Spain. *Archaeological and Anthropological Sciences* 8(3):477–490. DOI:10.1007/s12520-
015-0231-x.