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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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7 **Abstract**

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

23 **Highlights**

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

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

29 **1 Introduction**

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

- <sup>38</sup> Bjerck 2005; Gjerde 2021; Løken 1977; Nordqvist 1995; Schmitt et al. 2009; Sognnes 2003; Tallavaara and Pesonen 2020; Wikell et al. 2009).
- <sup>40</sup> The close association between Stone Age settlements in the northern parts of Scandinavia and shifting prehistoric shorelines was established by 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 1975; Mjærum 2022; Nummedal 1923; Shetelig 1922; 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 amount 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.
- <sup>56</sup> Despite its important role for Norwegian Stone Age 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 is to quantify the degree to which the assumption of shore-bound settlement holds through the Stone Age, and in turn have this inform an improved 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.

## <sup>68</sup> 2 Background

- <sup>69</sup> 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 istostasy. The eustatic sea-level is understood as 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). Istostasy, on the other hand, pertains to adjustments in the crust to regain gravitational equilibrium relative to the underlying viscous mantle. This can be the result of glacial istostasy, which follows from glaciation and de-glaciation and corresponding loading and unloading of weight, as well as from erosion of the crust, which causes its weight to be redistributed. These effects thus causes the lithosphere to either subside due to increased weight, or to rebound and lift upwards due to lower weight (Milne 2015).
- <sup>82</sup> 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 been so severe that most areas of Norway have been subject 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 more severe towards the centre

87 of the ice sheet. Thus, some areas on the outer coast have had a more stable RSL or been subject to marine  
 88 transgression (e.g. Romundset et al. 2015; Svendsen and Mangerud 1987). These conditions are directly  
 89 reflected in the archaeological record. In areas where the sea-level has been stable over longer periods of  
 90 time, people have often reused coastal site locations multiple times and over long time-spans, creating a  
 91 mix of settlement phases that are difficult to disentangle (e.g. Hagen 1963; Reitan and Berg-Hansen 2009).  
 92 Transgression phases, on the other hand, can lead to complete destruction of the sites, bury them in marine  
 93 sediments, or in the outermost periphery, leave them still submerged today (Bjerck 2008a; Glørstad et al.  
 94 2020). This can lead to a hiatus in the archaeological record for certain sub-phases in the impacted areas.  
 95 Comparatively, given a continuous and still ongoing shoreline regression from as high as c. 220m above present  
 96 sea-level in the inner Oslo fjord, any one location in south-eastern Norway has only been shore-bound within  
 97 a relatively limited time-span, and the sites have not been impacted by any transgressions (Hafsten 1957,  
 98 1983; Romundset et al. 2018; Sørensen 1979). This makes the region especially useful for evaluating the  
 99 assumption of a shore-bound settlement pattern over a long and continuous time-span.

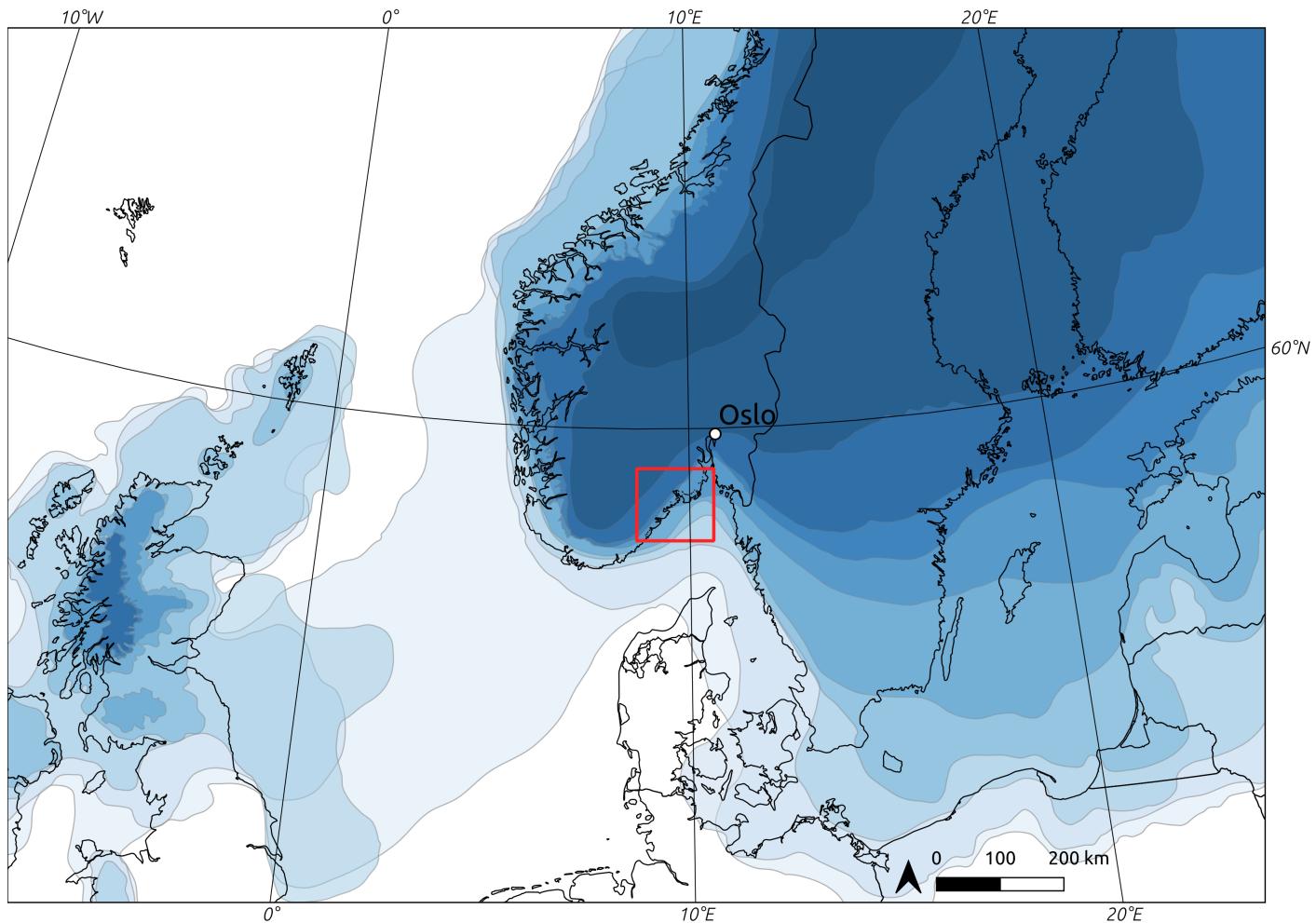


Figure 1: Deglaciation at 1000 year intervals from c. 17–8 kyr BCE. The study area defined later in the text  
 is marked with a red outline (deglaciation data from Hughes et al. 2016, but see also Romundset et al. 2019  
 in relation to the study area).

100 The method of shoreline dating has been met with scepticism as related to the fundamental premise that  
 101 most sites would have been consistently shore-bound, been characterised as a relative dating method for sites  
 102 located at different elevations within a constrained geographical area, or been argued to offer no more than  
 103 an earliest possible date for when a site could have been in use (see review by Nordqvist 1999). The most

common application in Norway has arguably been to use shoreline dating to provide an approximate date for the occupation of the sites, often in combination with other dating methods (see for example chapters in Glørstad 2002, 2003, 2004; Jakslund 2001, 2012a, 2012b; Jakslund 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).

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 hinter- and inland regions, where sites are 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 introduction of the farm 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 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 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 surveys, which are often guided by both a digital and mental reconstruction of past sea-levels (e.g. Berg-Hansen 2009; Eskeland 2017; Nummedal 1923). 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 have been sensible if the site was not shore bound (e.g. Jakslund 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 are sensible and 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 33 Mesolithic sites on the western side of the Oslo fjord to the displacement curve for

156 the Larvik area. They found an overlap between the probability distribution of the radiocarbon dates with  
157 the shoreline displacement curve for 86.5% of the sites. However, where there was a discrepancy, the main  
158 occupation of the sites are still believed to have been shore-bound rather than associated with the deviating  
159  $^{14}\text{C}$ -dates. This is based on typological and technological characteristics of the assemblages. Whether these  
160 mismatches represent later shorter visits that are responsible for the younger radiocarbon dates, or whether  
161 these dates are entirely erroneous can be difficult to evaluate (e.g. Persson 2008; Schülke 2020). However,  
162 this distinction is not deemed critical here, as what is of interest is settlements and tool-production areas as  
163 evidenced by artefact inventories or multiple site features. Not remnants of stays as ephemeral to only be  
164 discernible by isolated features or dubious  $^{14}\text{C}$ -dates. The evaluation of the relevance of radiocarbon dates  
165 to settlement activity will here therefore be entirely dependent on, and follow the discretion of the original  
166 excavation reports.

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

### 189 3 Data

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

198 The employed shoreline displacement data is based on the so-called isolation basin method (e.g. Kjemperud  
199 1986; Romundset et al. 2011), which involves extracting cores from a series of basins situated on bedrock at  
200 different elevations beneath the marine limit, and dating the transition from marine to lacustrine sediments.  
201 Each basin thus represent a high precision sea-level index point (SLIP) which are combined using what has  
202 been termed the isobase method to devise a continuous time series for RSL-change adjusted to a common  
203 isobase. To minimise the impact of variable uplift rates, the cored basins are therefore located in a as  
204 constrained area of the landscape as possible. Following from the morphology of the retreating ice sheet, the

uplift is more severe towards the north-east, meaning that this needs to be adjusted for in the case that any basins are located any significant distance from the common isobase perpendicular to this gradient (Figure 2). The SLIPs indicate 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. This 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 (Norwegian Mapping Authority 2021:30cm at the standard port Helgeroa in Larvik). Furthermore, the confidence bands of the displacement curves and their trajectory are quite complex constructs, and are the integrated result of both expert knowledge and more objectively quantifiable parameters. The reason for this is in part that the curves do not only contain uncertainty as related to radiometric dates, which are well defined, but also hold potential error as related to the interpretation and analysis of sediment cores, the nature and condition of the basin outlets and the adjustment to a common isobase, to name but a few (e.g. Romundset et al. 2011, 2019; for alternative approaches see e.g. Barnett et al. 2020; Cahill et al. 2016; 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 157 sites. Of these, 91 sites are associated with a total of 547 radiocarbon dates. Of these, in turn, 67 sites are related to the 259 radiocarbon dates that fall within the Stone Age (9500–1700 BCE), with 95% probability. These sites and  $^{14}\text{C}$ -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—the institution responsible for archaeological excavations 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  $^{14}\text{C}$ -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 acitivities. 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>). It was here opted for the 10m resolution DTM rather than the higher-resolution 1m version. In addition to resulting in considerably less processing time, the higher resolution elevation model is more vulnerable to smaller-scale modern disturbances that the 10m version is not impacted by. 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 digital research compendium following Marwick et al. (2018).

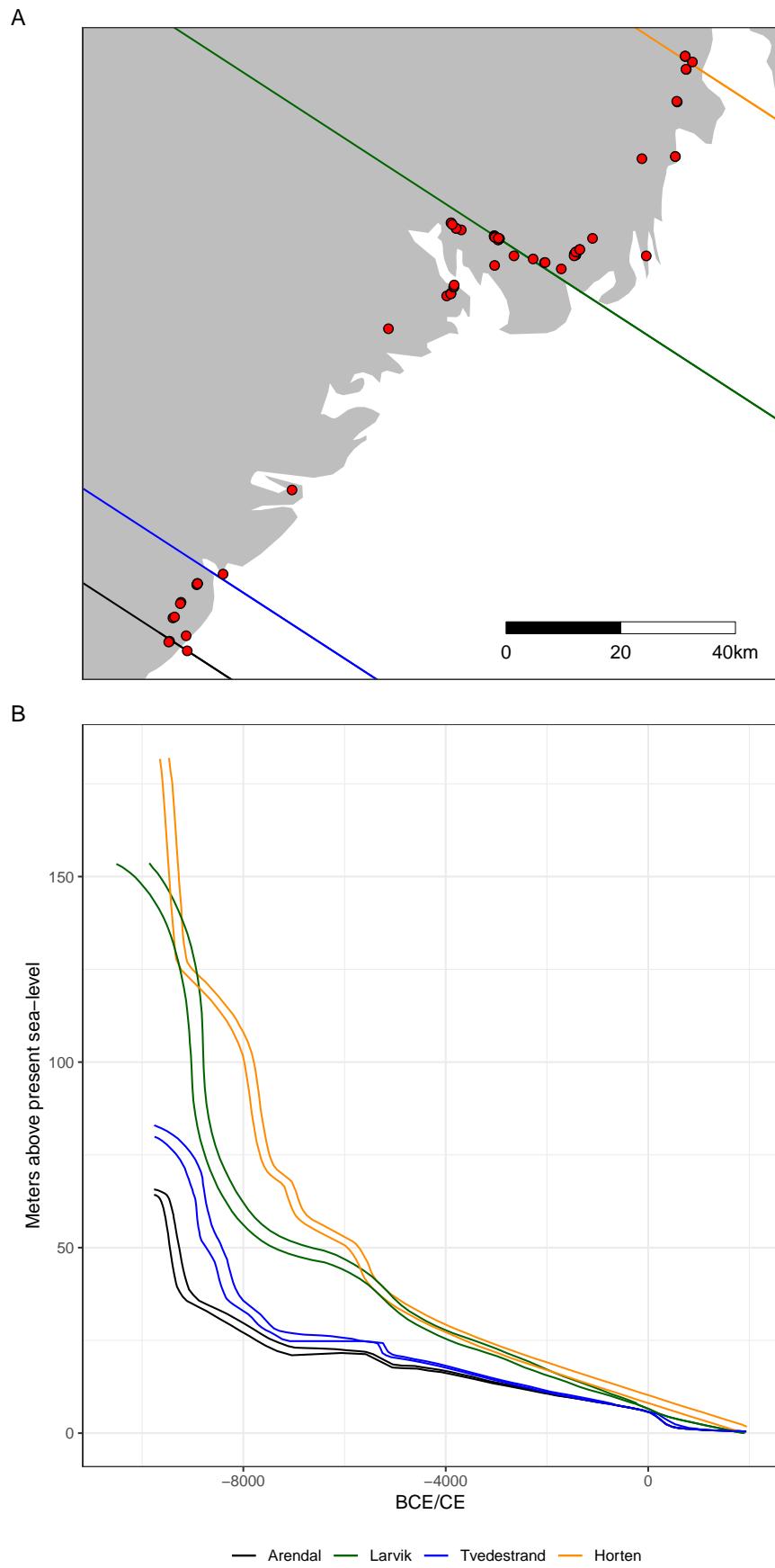


Figure 2: A) Distribution of the 67 analysed sites relative to the isobases of the displacement curves. The isobases have a direction of  $327^\circ$  (Romundset et al. 2018, but see Sørensen et al. 2014), B) Displacement<sup>7</sup> curves. Note the increasing steepness of the curves towards the north-east.

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## 252 4 Methods

253 Shoreline dating is based on the spatial relationship between two phenomena, occupation of sites and shoreline  
254 displacement, each associated with their own range of temporal uncertainty. The first task was therefore to  
255 ascribe likely date ranges and associated uncertainty to these dimensions. To take account of the gradient in  
256 the isostatic rebound, the trajectory of shoreline displacement was first interpolated to each site location based  
257 on the distance to the isobases of the displacement curves, using inverse distance weighting (e.g. Conolly  
258 2020; Conolly and Lake 2006:94–97). This was done for each year along the entirety of the curves, weighting  
259 the interpolation by the squared inverse of the distances. The result of this process is shown for an example  
260 site in Figure 3. For the date ranges associated with the sites, all radiocarbon dates were first individually  
261 calibrated using the IntCal20 calibration curve (Reimer et al. 2020) using OxCal v4.4.4 (Bronk Ramsey 2009)  
262 through the oxcAAR package for R (Hinz et al. 2021). Radiocarbon dates associated with each site were  
263 then grouped if they overlapped with 99.7% probability, meaning these were effectively taken to represent  
264 the same event, here termed settlement or site phase. In the case where there are multiple dates believed to  
265 belong to a single settlement phase, these were modelled using the Boundary function in OxCal and then  
266 summed. Multiple phases at a single site were treated as independent of each other.

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

279 Armed with a likely date range for the occupation(s) of each site, an estimated trajectory of relative sea-level  
280 change at that location, and a DTM edited to remove substantial modern disturbances, the simulations were  
281 performed. A single simulation run involved first drawing a single year from the posterior density estimate of  
282 a given occupation phase of a site (Figure 4). This year then has a corresponding likely elevation range for  
283 the contemporaneous shoreline from which an elevation value was drawn uniformly, using intervals of 5cm.  
284 The sea-level was then raised to this elevation on the DTM by defining all elevation values at or below this  
285 altitude as missing. Polygons were then created from the resulting areas with missing values. The horizontal  
286 distance was then found by measuring the shortest distance between site and sea polygons, and the vertical  
287 distance by subtracting the elevation of the sea-level from the lowest elevation of the site polygon. The topographic  
288 distance between site and sea was also found by measuring the distance while taking into account  
289 the slope of the terrain on the DTM. This was done using the topoDistance package for R (Wang 2019).  
290 The topographic distance was measured between the site polygon and the horizontally closest point on the  
291 shoreline. This means that the distance is not necessarily measured as the closest topographic distance to the  
292 shoreline, but rather as the shortest topographic path to the horizontally closest point on the shoreline. Not  
293 finding the topographically closest point significantly reduced the computational cost of the analysis, and is  
294 deemed unlikely to have a considerable impact on the results given the distances considered. The shortest  
295 topographic path was found using the Moore neighbourhood of eight cells (e.g. Conolly and Lake 2006:253;  
296 Herzog 2013). In the case where the sea polygons intersects the site polygon, all distance measures were  
297 set to zero. In the case that the sea polygons completely contain the site, the horizontal and topographic  
298 distance measures were made negative, and the vertical distance was instead measured to the highest point  
299 on the site polygon. While it is safe to assume that an archaeological site was not occupied when it was  
300 located beneath sea-level, a negative result can reflect the inherent uncertainty in this procedure, and might  
301 also help identify discrepancies in displacement data or radiocarbon dates. Negative values were therefore  
302 retained with the exception of for the sites Gunnarsrød 5 and Pjonkerød R1, where the negative values are  
303 believed to result from modern disturbances in the DTM rather than the  $^{14}\text{C}$ -dates or displacement curves

304 (see supplementary material for more details).

305 This process was repeated 1000 times for each phase for each site. The choice of 1000 simulation runs follows  
306 from an evaluation of when the mean distances between site and shoreline converged when running 5000  
307 iterations of the simulation on the site Hovland 5, available in the supplementary material (cf. Crema et al.  
308 2010:1125). Hovland 5 was chosen for this evaluation as it has a fairly imprecise date and is located in area  
309 of quite complex topography.

## 310 5 Simulation results

311 Overall, as is indicated by the measures for central tendency and the almost solid line along the 0m mark on  
312 the y-axes, the simulations show that the sites tend to have been situated close to the shoreline when they  
313 were in use (Figure 6). Some of the sites are situated considerable distances from the shoreline when the dates  
314 believed to be erroneous in the original reports are included (Figure 6A), but if one accepts the interpretation  
315 that these do not date the main occupation of the sites, as is indicated by the artefact inventories, Figure  
316 6B gives considerable support to the notion that the sites were in use when they were situated on or close  
317 to the contemporaneous shoreline. The distances for some of the earliest sites appears somewhat high, but  
318 this can likely be explained as the result of the steepness of the displacement curves for the earliest part of  
319 the Holocene (Figure 2B), which leads the uncertainty of the  $^{14}\text{C}$ -dates to give a wider possible elevation  
320 range for the simulated sea-level. Another immediately striking result is the apparent deviation from the  
321 shoreline towards the end of the Stone Age. From around 2500 BCE several sites are situated a considerable  
322 distance from the shoreline, and while a couple remain horizontally and topographically close, most appear  
323 to be elevated a considerable distance from the sea-level, as indicated on the plot for vertical distance. While  
324 the sample size is limited, there are also a couple of sites located some distance from the shoreline just after  
325 4000 BCE. That the findings appear to be off from the chronological framework by around a century must be  
326 seen in relation to chronological smearing from the uncertainty in the  $^{14}\text{C}$ -dates, and the findings are thus in  
327 clear agreement with the literature.

328 The negative values around 8000 BCE originate from the sites Løvås 1, 2 and 3. These are recently excavated,  
329 well-dated sites situated in a relatively undisturbed area of the landscape. While there would be a danger of  
330 circularity of having archaeological sites inform a reconstruction RSL-change, and in turn use these to evaluate  
331 the degree of shore-bound settlement, the sites do clearly represent an upper limit for the sea-level, as they  
332 would not have been in use when located under water. It could therefore seem that the Løvås sites represent  
333 a case where the archaeological material indicates a slight discrepancy in the geological reconstruction of  
334 shoreline displacement in the area.

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

347 An exponential function has been fit to the distributions for vertical distance using maximum likelihood  
348 estimation (Figure 7). While it makes theoretical sense that a process of exponential decay explains this  
349 relationship, it is also clear that this does not perfectly match the data. However, this can at least in part be  
350 related to methodological factors, where the accumulation of distance-values on the 0m mark likely follow  
351 from forcing negative values to zero, from the resolution of the spatial data, and from defining intersecting

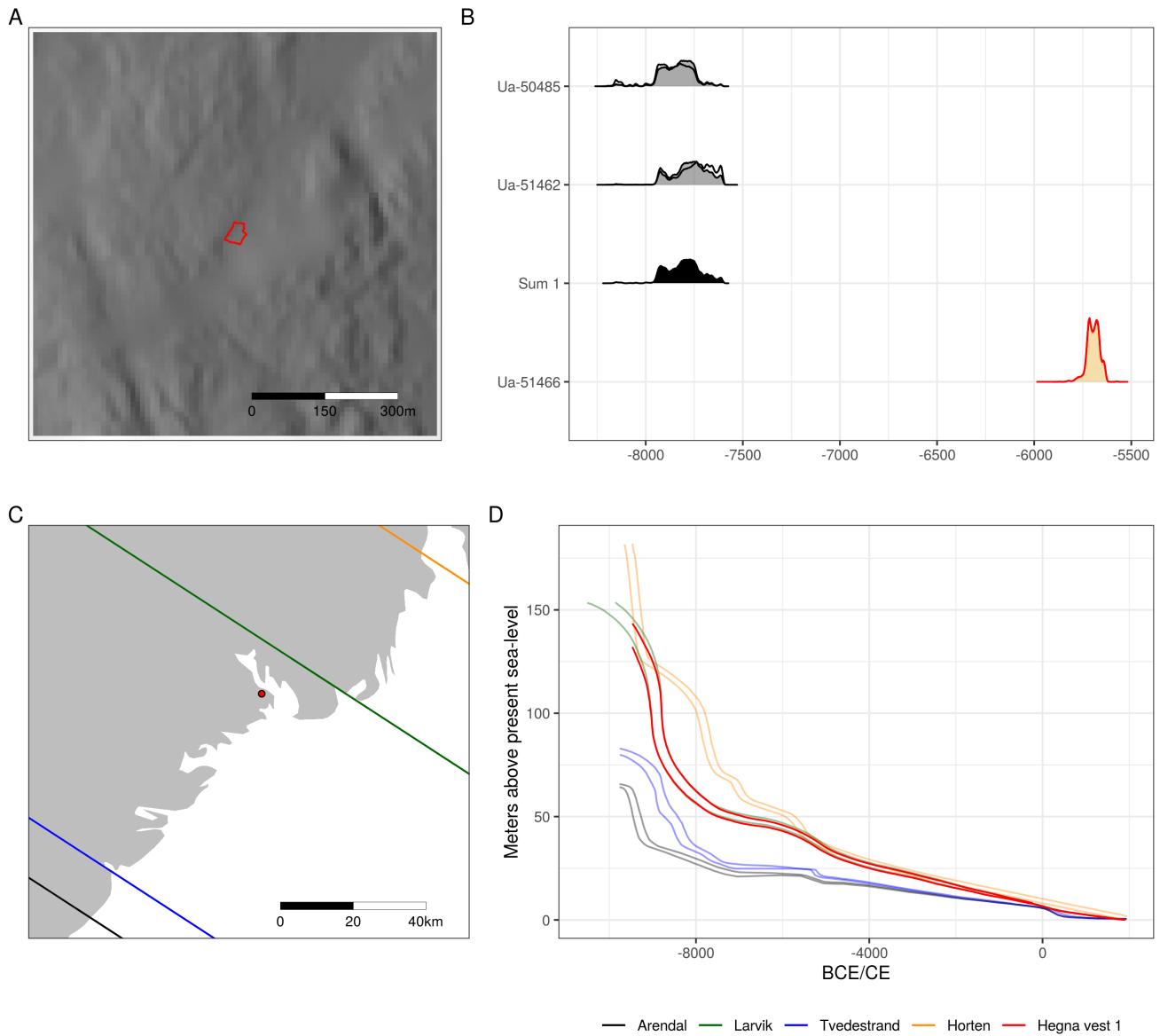


Figure 3: Example site Hegna vest 1 (Fossum 2017). A) Location of the site on the edited 10m resolution DTM. The red outline is the site limit. B) Radiocarbon dates associated with the site. Fill colour indicates what dates are assumed to belong to the same settlement phase. Multiple dates are modelled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

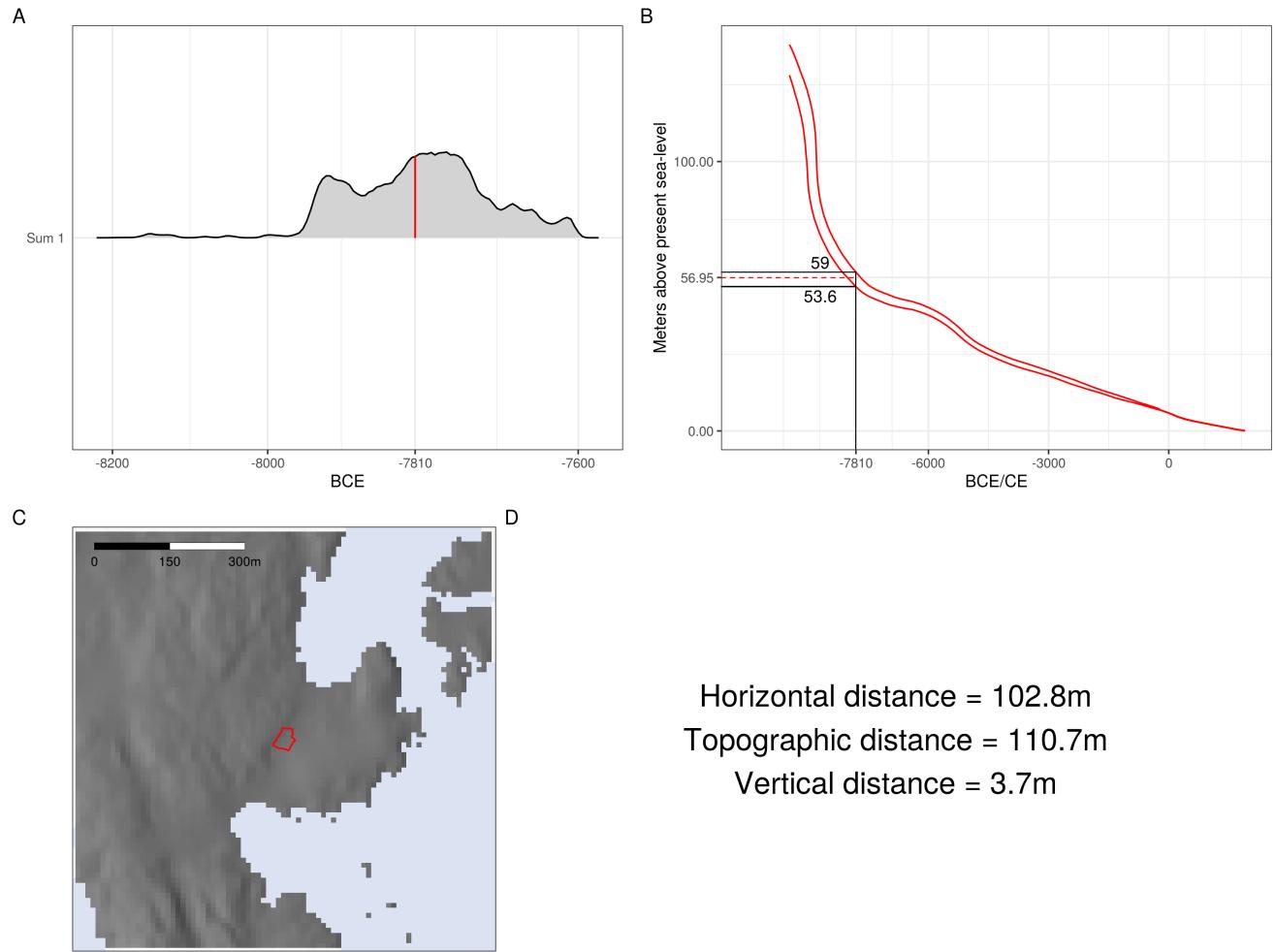


Figure 4: Example of a single simulation run on the site Hegna vest 1. A) The simulation starts by drawing a single year from the posterior density estimate. B) This then corresponds to an elevation range on the interpolated displacement curve. A single elevation is drawn uniformly from this range using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

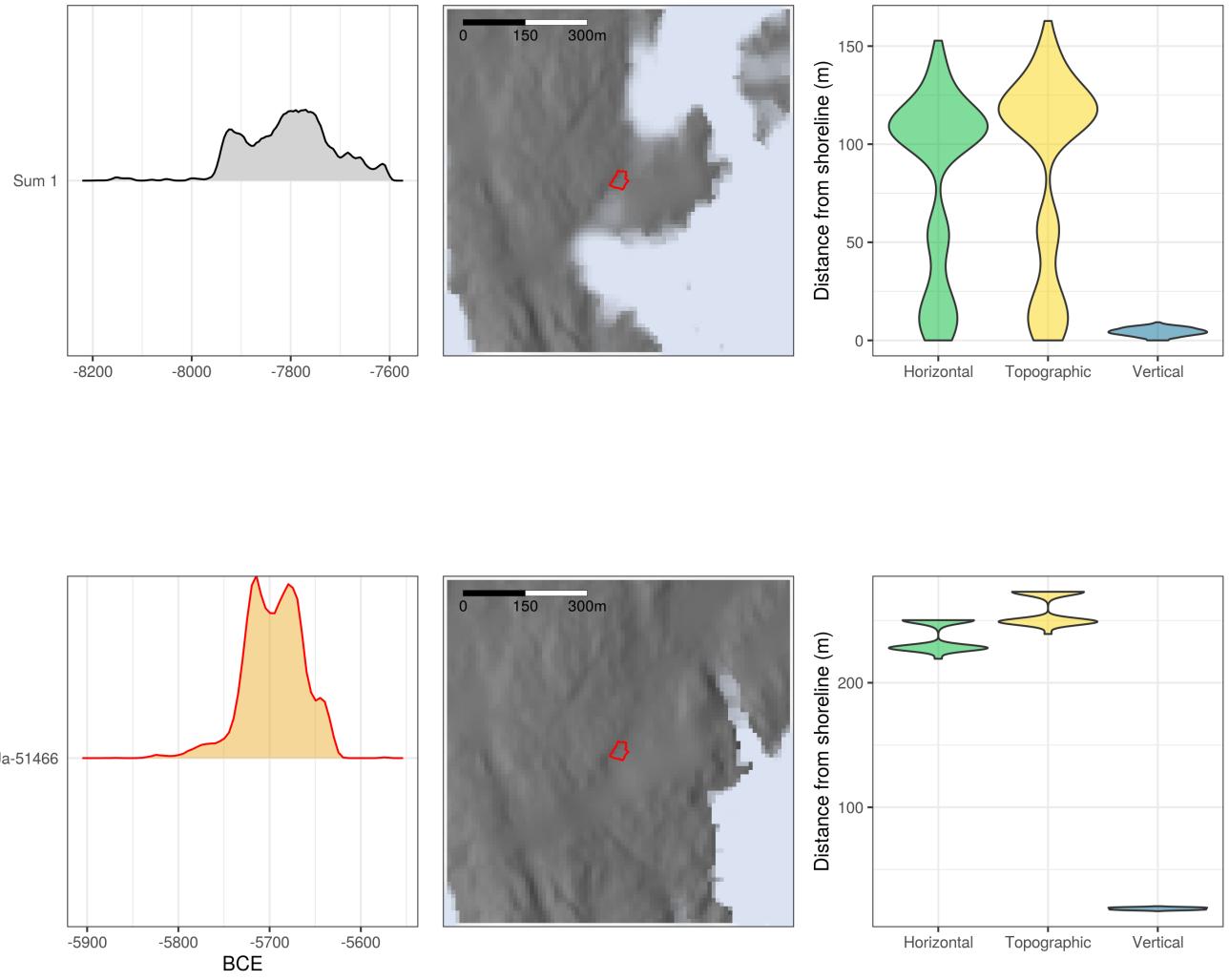


Figure 5: The result of 1000 simulation runs for each of the two groups of dates on the site Hegna vest 1. The first column of plots shows the calibrated radiocarbon probability distribution from where dates were drawn during simulation. The second column displays the result of simulating the raised sea-level 1000 times. The more opaque the colour, the more times the sea-level was simulated to that location. The third column shows violin plots of the different distance measures across all simulations.

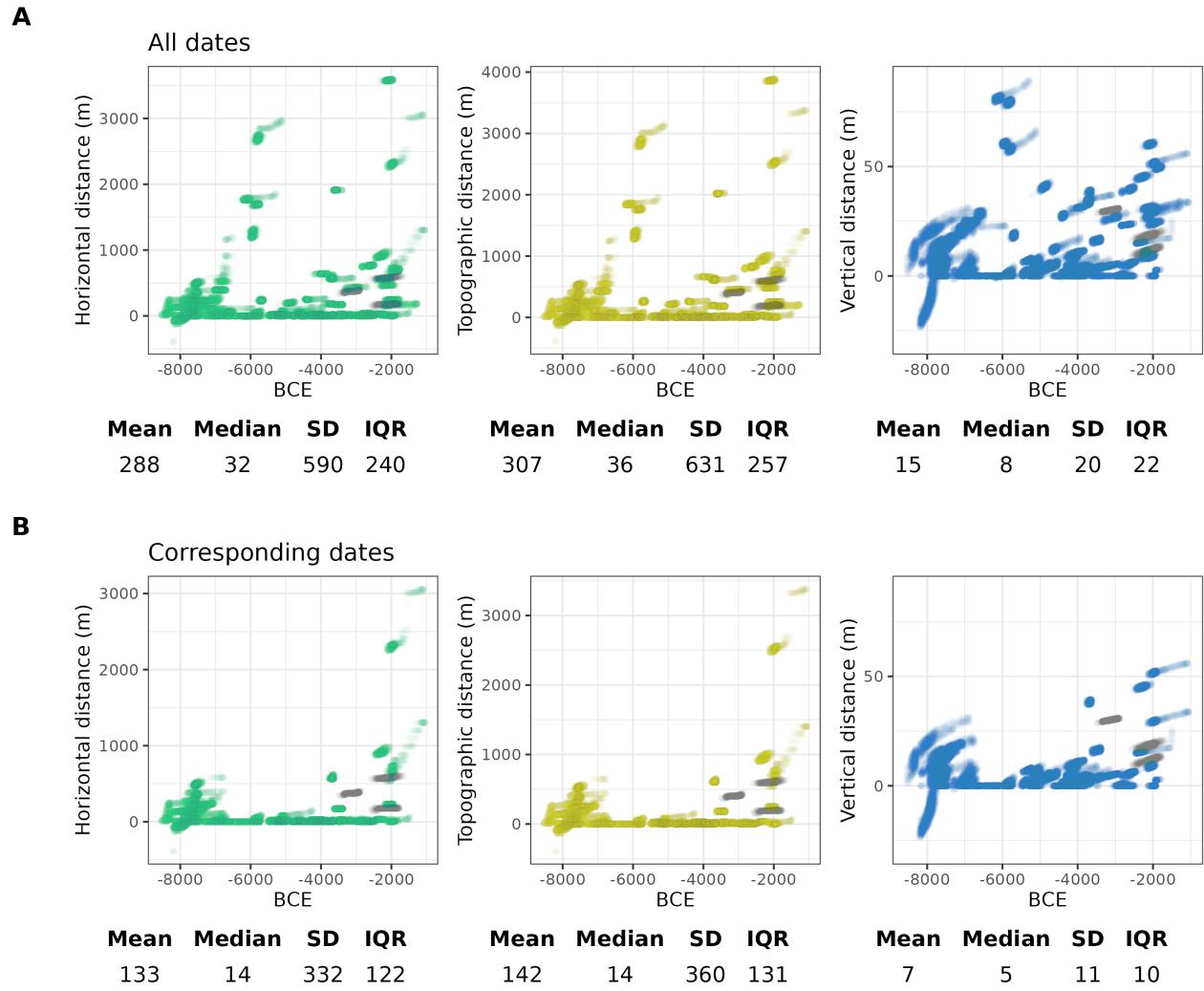
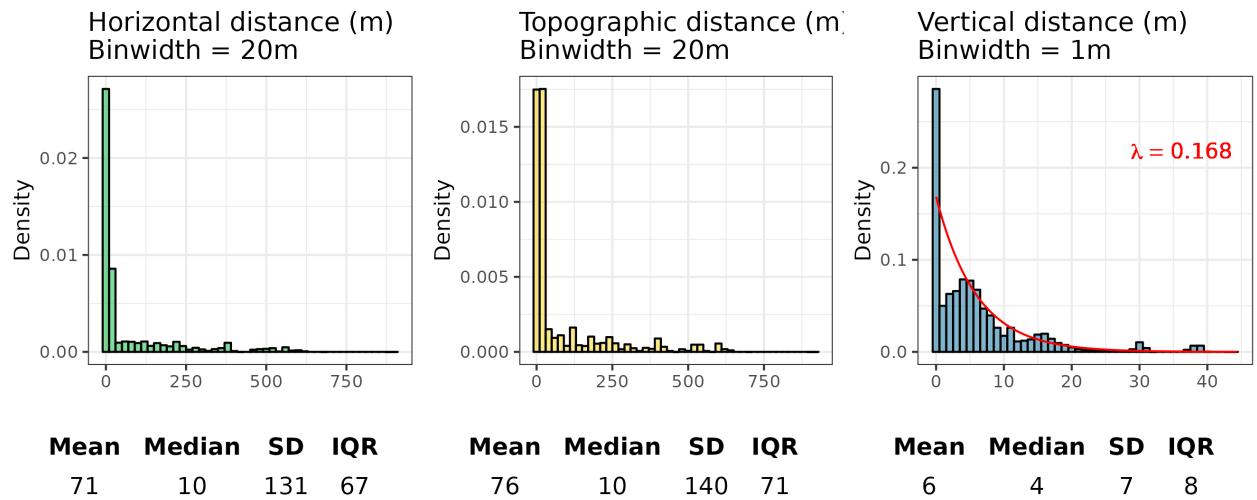


Figure 6: The result of running the analysis across all sites. Each data point is plotted with some transparency, meaning that the more intense the colour, the more often those values occurred. Results associated with agricultural activities are plotted in grey. The first row A) shows the result of including 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**

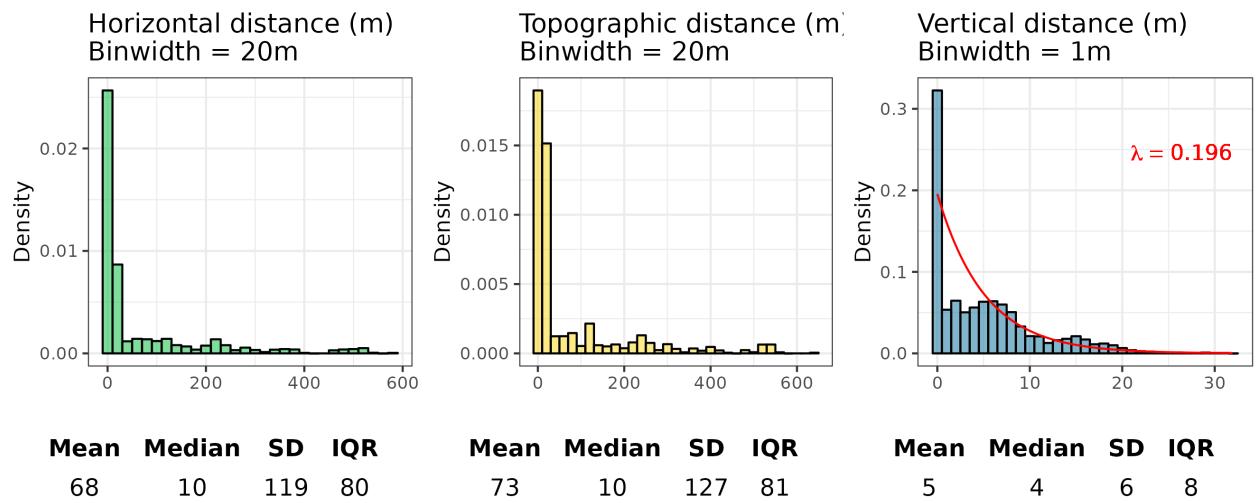


Figure 7: Histograms showing the simulated distance from the shoreline using radiocarbon dates corresponding to the site inventories. Negative values have been set to zero. A) Simulated results older than 2500 BCE, and B) simulated results older than 4000 BCE.

352 sea- and site polygon as having a distance of zero. If one accepts this, the probability density function for  
353 exponential decay can be used to characterise the vertical distance between sites and the shoreline, and be  
354 used to inform a method for shoreline dating that takes this into account.

## 355 6 Shoreline dating

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

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

365 where  $\lambda$  is the decay ratio. This can then be coupled with the trajectory of relative sea-level change to find  
366 the corresponding calendar date  $T$  for the occupation of the site. This is defined by a uniform probability  
367 density function over the range between the lower  $T_l$  and upper  $T_u$  bounds of the displacement curve that  
368 has been interpolated to the site location:

$$p(T|\alpha - D) = U[T_{l|\alpha-D}, T_{u|\alpha-D}] \quad (2)$$

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

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

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

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

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

382 In Figure 9 the outlined procedure is used to shoreline date all of the sites from where this relationship  
383 was derived, with the Late Neolithic sites also included for illustrative purposes. Following from having  
384 defined the distance between intersecting sea- and site polygons as zero during simulations, the sites were  
385 all dated using the mean elevation of the site polygons to allow for some variation in elevation over the site  
386 limits. The synchronicity between radiocarbon and shoreline dates was then evaluated using the method

387 presented by Parnell et al. (2008). Here, 100,000 age samples drawn from the probability distribution of each  
 388 shoreline date were subtracted from 100,000 age samples drawn from the corresponding modelled  $^{14}\text{C}$ -dates.  
 389 The resulting range of the 95% highest density region (HDR, Hyndman 1996) was then checked to see if  
 390 it crosses zero, in which case the dates are considered to be in agreement (Figure 10). When excluding  
 391 the earliest occupation phase at Gunnarsrød 5, the deviation of which is to be expected based on issues  
 392 with the DTM (see above), the shoreline date correspond to the radiocarbon dates in 58 out of 68 cases  
 393 (84%). Only including dates modelled to be older than 2500 BCE with 95% probability, i.e. older than the  
 394 Late Neolithic, improves this to 56 out of 62 cases (90%). When only including dates older than 4000 BCE  
 395 with 95% probability, i.e. only Mesolithic site phases, the success rate is further increased to 46/49 (94%).  
 396 The three failed Mesolithic shoreline dates are from the early sites Langemyr and Kvastad A2, with the  
 397 likely implication that a lower decay ratio than what is used for characterising the distance between site  
 398 and shoreline for all sites in aggregate should be used for sites known to be from the earliest part of the  
 399 Mesolithic (see also Figure 6).

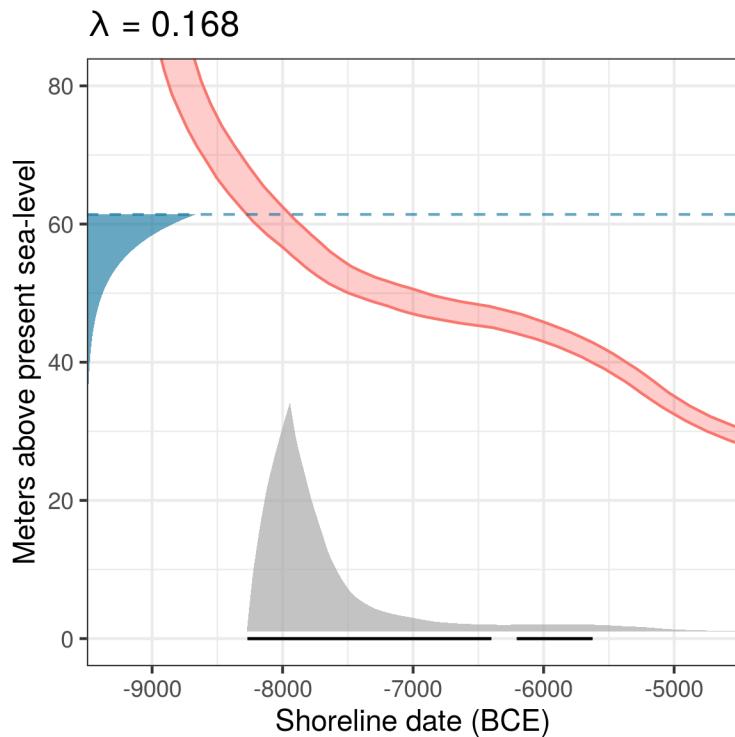


Figure 8: Shoreline dating of Hegna vest 1. The dashed line marks the mean elevation of the site polygon which is used to inform  $\alpha$  in the dating of the site. The exponential function decays with ratio  $\lambda$  from Figure 7A. The resulting shoreline date in grey is underlined with the 95%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

## 400 7 Re-dating previously shoreline dated sites

401 To further explore the implementation for shoreline dating presented above, excavated and shoreline dated  
 402 Stone Age sites within the study area where  $^{14}\text{C}$ -dates are not available or these are not believed to date the  
 403 main occupation of the sites have been subjected to the outlined approach (Figure 11). The resulting dates  
 404 are compared to those originally proposed in the excavation reports for the sites (the numerical results are  
 405 available in the supplementary material). To avoid issues with recent disturbances on the DTM, the sites  
 406 have been dated based on the mean of the altitudes provided in the report for each site.

407 The comparison with previously reported dates is an illustrative, but unfair exercise for a few reasons. First

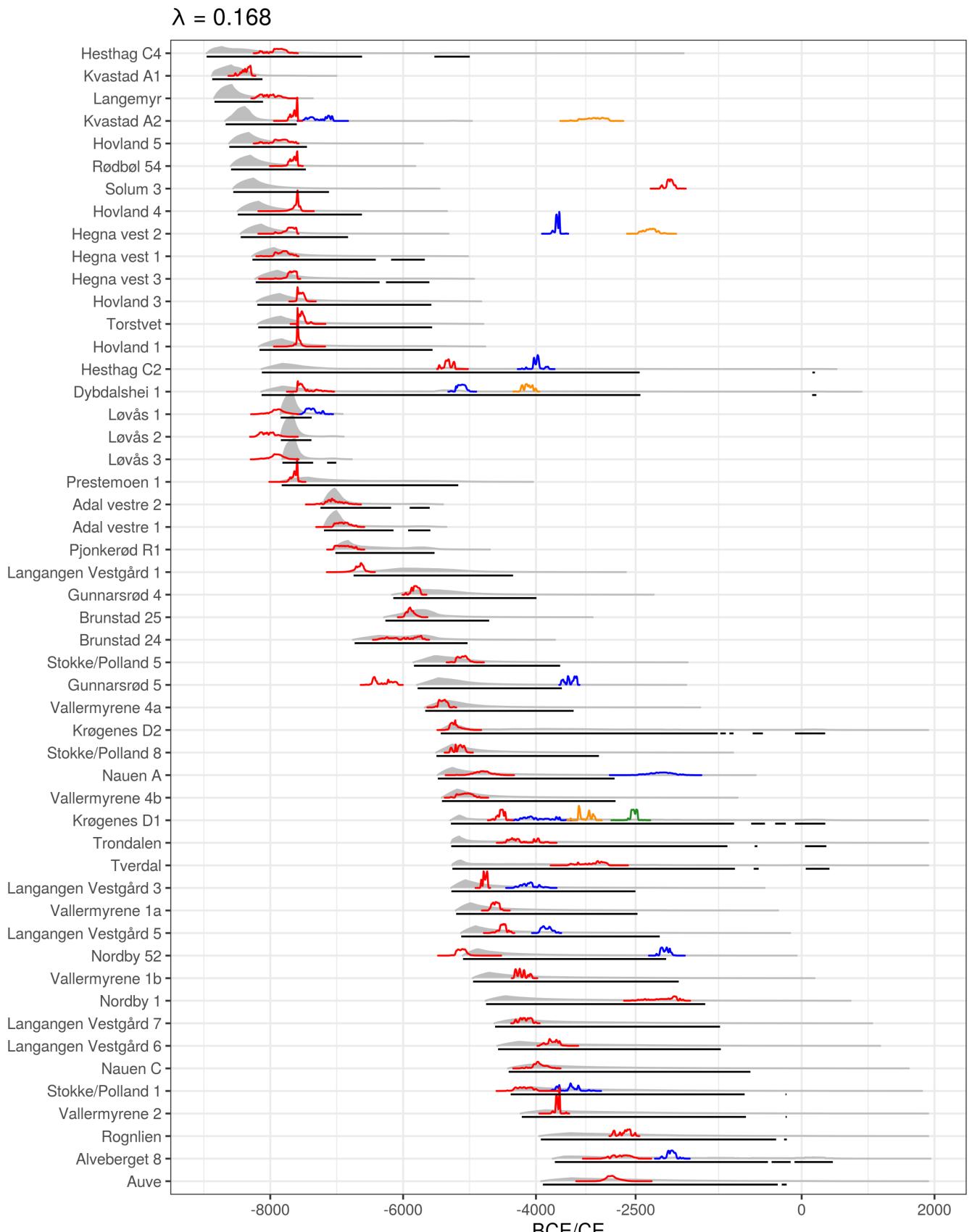


Figure 9: The result of backwards shoreline dating the sites with radiocarbon dates corresponding to the artefact inventory using the method proposed here. The shoreline dates are plotted in grey and underlined<sup>17</sup> with the 95% HDR in black. These are plotted against the modelled radiocarbon dates, which are given colour from oldest to youngest occupation phase for each site, defined by non-overlapping dates at 99.7% probability.

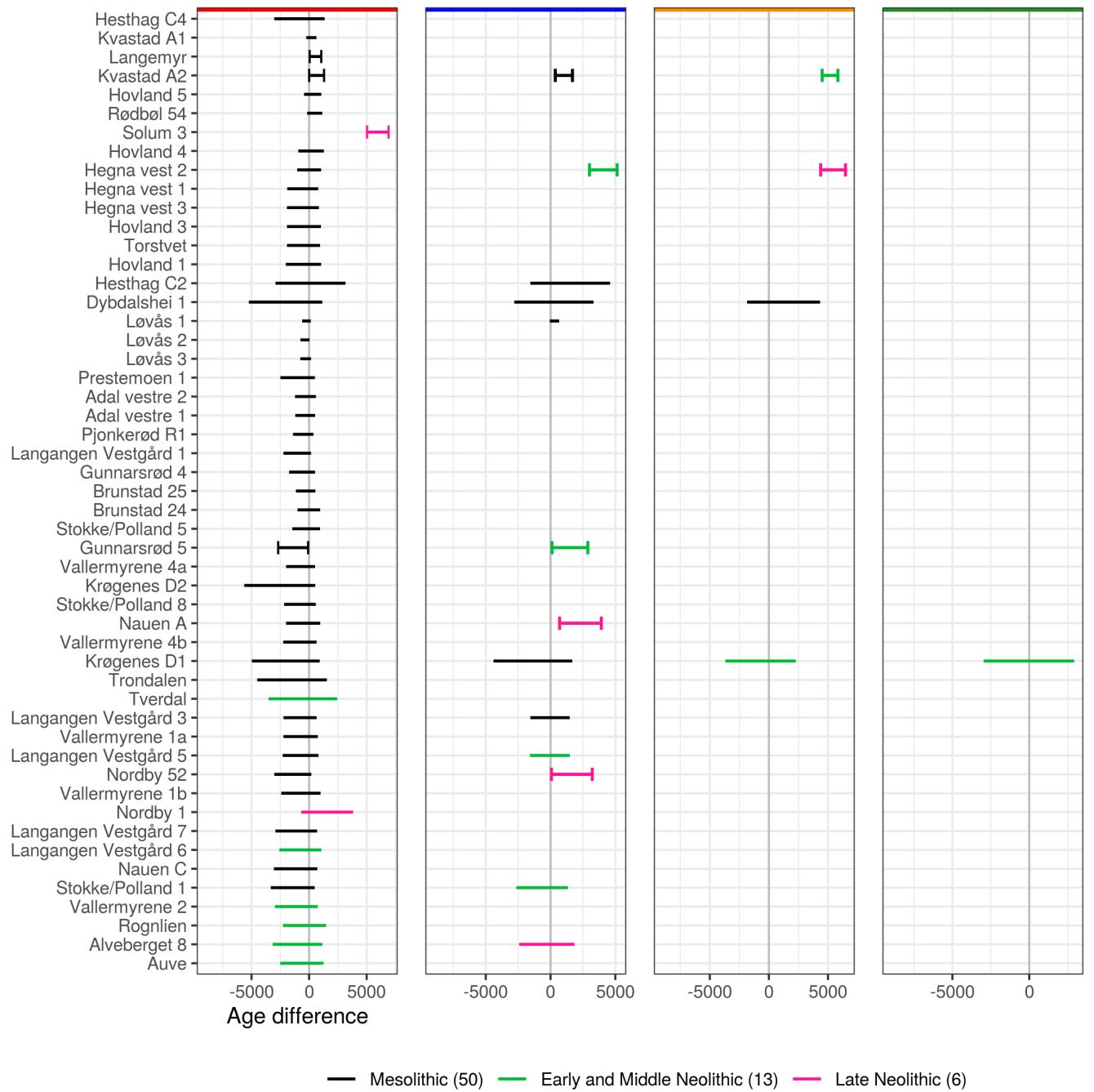


Figure 10: Evaluation of the agreement between the shoreline dates and radiocarbon dates given in Figure 9. When the range of the 95% HDR for age difference crosses zero, the shoreline and radiocarbon dates are considered to be in agreement. Line segments with vertical bars indicate that the HDR does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

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

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

442 The small discrepancies between the achieved results mainly follow from the fact that a slightly updated  
443 version of the local displacement curve is applied here (cf. Sørensen et al. in prep). Jaksland's dates are  
444 given a flat 200 and 50 year uncertainty range starting from what he gives as the earliest possible date. The  
445 200 year uncertainty range is given if the sites were to be considered in isolation, while his argument for the  
446 uncertainty range of only 50 years is based on the location of the sites relative to each other. Since they  
447 are located in such a constrained and steep area of the landscape, the difference in elevation between the  
448 sites is argued to establish their relative date and thus constrain the uncertainty ranges so that they don't  
449 overlap. This information is not integrated in the approach outlined here, but could justify further reducing  
450 the uncertainty ranges.

451 Although their accuracy is of course ultimately dependent on the veracity of the geological reconstruction,  
452 the high rate of RSL-change in this period does result in very precise dates. Above it was suggested that  
453 additional temporal data could be combined with the method to improve its accuracy and precision. Drawing  
454 on Jaksland (2014), this example instead highlights the fact that the spatial nature of the method means  
455 that a consideration of the surrounding terrain and other sites can also help in increasing the precision of  
456 the method if this can be used to exclude certain sea-levels as unlikely for when a site was in use. One  
457 approach could also be to assess the spatial implication of a proposed shoreline date by simulating the  
458 adjusted sea-levels, as is done for Pauker 1 in Figure 12B, followed for example by a visual evaluation of the  
459 topography or by evaluating the distance and steepness of the slope to the shoreline. If this is developed

$$\lambda = 0.168$$

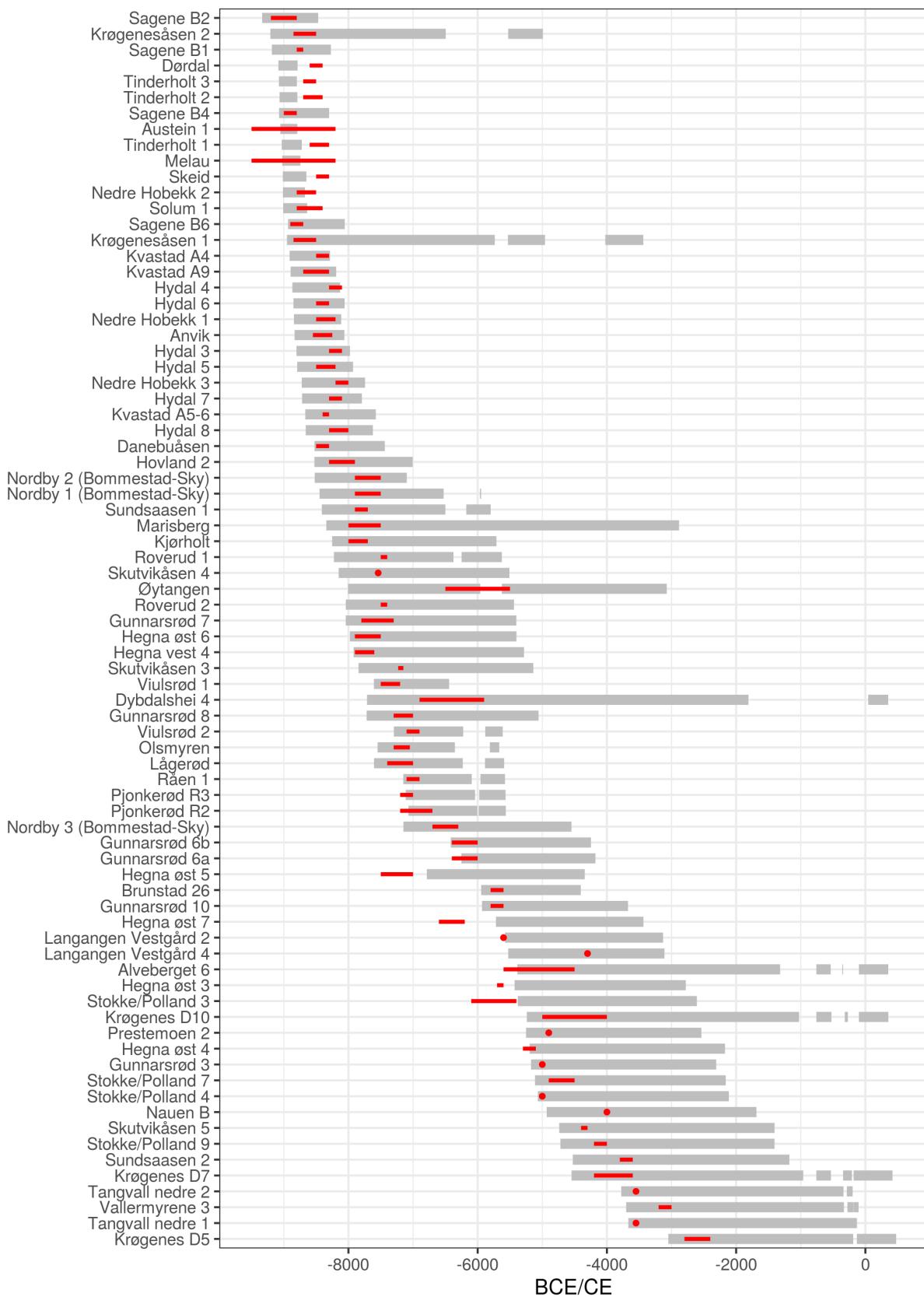


Figure 11: Re-dating excavated and previously shoreline dated sites in the study area without radiocarbon dates or with radiocarbon dates that do not correspond to the artefact inventories. The 95% HDRs in grey<sup>20</sup> are compared to the dates originally proposed by the excavation reports in red.

460 further, it could conceivably be possible to exclude certain elevations as unlikely for the position of the  
 461 shoreline when the site was in use. Such approaches would make less of an impact in this setting, where the  
 462 95% HDR is already quite constrained, but could considerably improve the precision of the method in cases  
 463 where RSL-change has been less severe (cf. Figure 11).

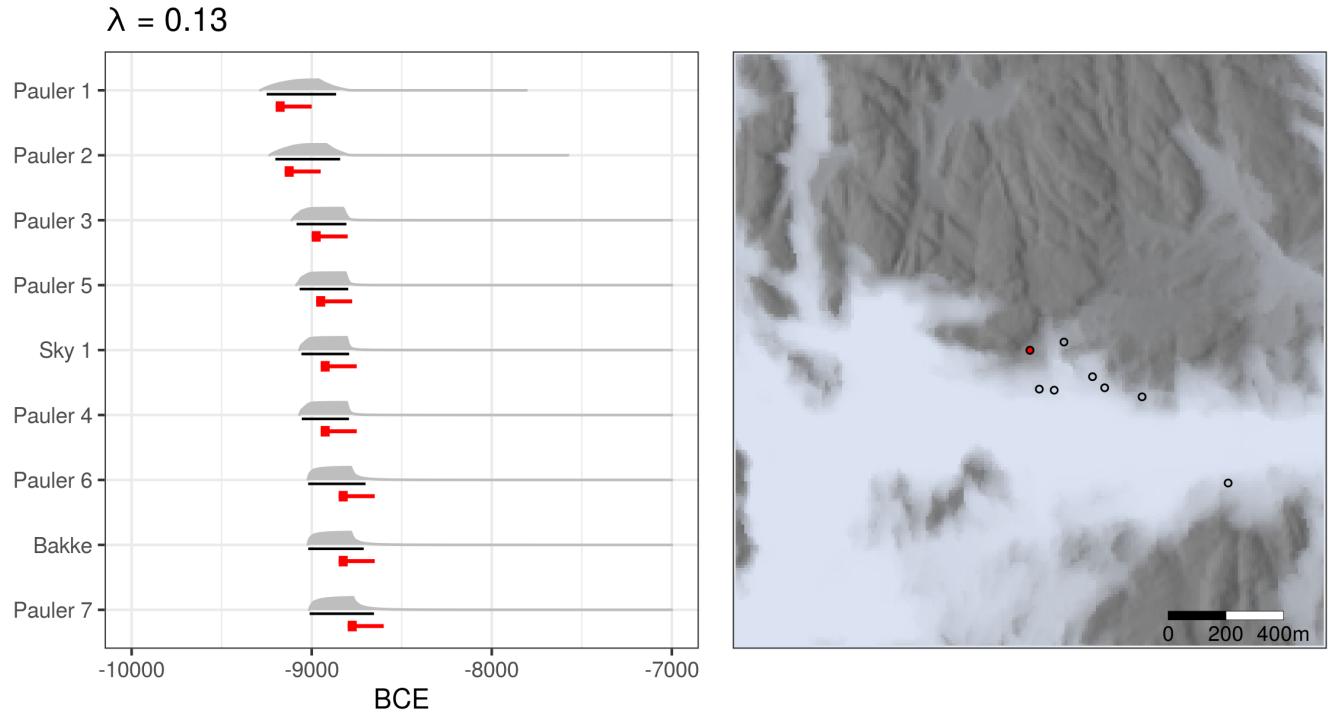


Figure 12: Shoreline dating of the Brunlanes sites using site altitudes provided by Jaksland (2014:tab.4). A) The result of applying the approach to shoreline dating outlined above. The shoreline date in grey is underlined with the 95% HDR in black. Dates provided by Jaksland (2014) are plotted in red. The box indicates a 50 year uncertainty range which in combination with the red line extends 200 years. B) Map showing the centroids of the 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 Jaksland 2014:fig.12a). Paurer 1 is the red point.

## 464 8 Concluding remarks

465 The most immediate contribution of this paper is what must be considered a confirmation of previous research  
 466 into the relation between coastal Norwegian Stone Age sites and the prehistoric shoreline. This is indicated  
 467 by the close relationship between sites and the shoreline up until the transition to the Neolithic at c. 4000

468 BCE, after which a couple of sites become situated some distance from the sea, followed by a more decisive  
469 break at the transition to the Late Neolithic at c. 2500 BCE. This development is in clear agreement with  
470 the literature. Furthermore, based on the quantitative nature of these findings, an initial formulation of  
471 a refined method for the shoreline dating of pre-Late Neolithic Stone Age sites has been proposed. Apart  
472 from taking the distance between sites and the isobases of the displacement curves into consideration when  
473 dating the sites, this involves accounting for the distance between the sites and the shoreline. When no other  
474 information is available, it can at present be recommended to use the empirically derived exponential decay  
475 ratio of 0.168 (Figure 11A) to characterise this relationship. Furthermore, while this remains to be formalised  
476 and explored further, it was also showed how the method can be improved by including more information,  
477 both with reference to the topographic location of the sites and other temporal data. As the precision of  
478 the method is both geographically and temporally contingent due to the trajectory of RSL-change, where  
479 older sites situated towards the north-east in the study area will get a more precise date, the impact of such  
480 additional information will also vary.

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

496 Some limitations and sources of likely variation and uncertainty that have not been considered should also  
497 be mentioned. First of all the sample size is strained and the future addition of more sites might alter the  
498 picture considerably. Secondly, the validity of the outlined method was evaluated by applying it to the data  
499 from where the input parameters were derived. Fitting and evaluating a model using the exact same data will  
500 likely exaggerate its performance. Thirdly, the DTM has only been corrected for major modern disturbances.  
501 This means that other forms of erosion, although likely not that prevalent, has not been taken into account.  
502 Fourthly, the DTM has a vertical error which could also benefit from being integrated in the analysis (cf.  
503 Lewis 2021). Fifthly, the displacement curves were here interpolated to all site locations without accounting  
504 for increased uncertainty as one moves further away from the isobases of the displacement curves. This is  
505 also related to the fact that the RSL data can be handled in different ways than with the isobase method  
506 that has been used for the compilation of the employed displacement curves. Sixthly, neither the question of  
507 how site limits are defined nor the elevation range over which these extend was given much consideration (cf.  
508 Mjærum 2022). Finally, the radiocarbon dates and division of settlement phases at each site was here simply  
509 done by treating radiocarbon dates not overlapping at 99.7% as representing unrelated occupation events.  
510 This could also be handled differently (e.g. Bronk Ramsey 2009, 2015). While each of these factors will have  
511 variable impact on the final results, they clearly represent dimensions which would all benefit from further  
512 consideration and which means that some of the precision following from the outlined approach is likely to be  
513 spurious.

514 Given that shoreline dating is contingent on regularities in human behaviour it should naturally be applied  
515 with care. Furthermore, formulating and visualising the method along the lines of how radiocarbon dates  
516 are treated, as was done here, does stand the chance of giving a veneer of radiometric accuracy that is  
517 not warranted. That being said, the best chance we have of not throwing away precious temporal data, or  
518 exaggerating our handle on it, is arguably to rigorously evaluate the method using independent data such as  
519 radiocarbon dates, by offering a precise formulation of how it could be applied, by specifying what sources of

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520 uncertainty are accounted for and by making this process transparent through the open dissemination of  
521 underlying data and programming code.

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

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## 527 9 References

- 528 Åkerlund, Agneta  
529 1996 *Human responses to shore displacement: Living by the sea in Eastern Middle Sweden during the Stone*  
530 *Age*. Riksantikvarieämbetet, Stockholm.
- 531 Åkerlund, Agneta, Jan Risberg, Urve Miller, and Per Gustafsson  
532 1995 On the applicability of the  $^{14}\text{C}$  method to interdisciplinary studies on shore displacement and settlement  
533 location. *PACT* 49:53–84.
- 534 Amundsen, Øystein, Stig Knutsen, Axel Mjærum, and Gaute Reitan  
535 2006 Nøkleby i Ski – en tidligeolittisk jordbruksboplass? *Primitive tider* 9:85–96.
- 536
- 537 Åstveit, Leif Inge  
538 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.
- 539
- 540 Bakka, Egil, and Peter Emil Kaland  
541 1971 Early farming in Hordaland, western Norway. Problems and approaches in archaeology and pollen  
542 analysis. *Norwegian Archaeological Review* 4:1–17. DOI:10.1080/00293652.1971.9965136.
- 543 Bang-Andersen, Sveinung  
544 2012 Colonizing Contrasting Landscapes. The Pioneer Coast Settlement and Inland Utilization in  
545 Southern Norway 10,000–9500 Years Before Present. *Oxford Journal of Archaeology* 31:103–120.  
DOI:10.1111/j.1468-0092.2012.00381.x.
- 546 Barnett, Robert L., Dan J. Charman, Charles Johns, Sophie L. Ward, Andrew Bevan, Sarah L. Bradley,  
547 Kevin Camidge, Ralph M. Fyfe, W. Roland Gehrels, Maria J. Gehrels, Jackie Hatton, Nicole S. Khan, Peter  
548 Marshall, S. Yoshi Maezumi, Steve Mills, Jacqui Mulville, Marta Perez, Helen M. Roberts, James D. Scourse,  
549 Francis Shepherd, and Todd Stevens  
550 2020 Nonlinear landscape and cultural response to sea-level rise. *Science Advances* 6:107422.  
DOI:10.1126/sciadv.abb6376.
- 551
- 552 Berg-Hansen, Inger Marie  
553 2009 *Steinalderregistrering. Metodologi og forskningshistorie i Norge 1900-2000 med en feltstudie fra Lista i*  
554 *Vest-Agder*. Museum of Cultural History, University of Oslo, Oslo.
- 555 2018 Continuity and Change in Late- and Post-glacial Social Networks: Knowledge Transmission and  
556 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.
- 557 Bergsvik, Knut Andreas  
558 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.
- 559
- 560 Bevan, Andrew, Enrico R. Crema, Xiuzhen Li, and Alessio Palmisano  
561 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.  
562 27–52. Left Coast Press, Walnut Creek.
- 563 Bivand, Roger  
564 2021 *rgrass7: Interface Between GRASS 7 Geographical Information System and R*. R package version  
0.2-6.
- 565
- 566 Bjerck, Hein Bjartmann  
567 1990 Mesolithic site types and settlement patterns at Vega, Northern Norway. *Acta Archaeologica* 60:1–32.
- 568
- 569 2005 Strandlinjedatering. In *Norsk arkeologisk leksikon*, edited by Einar Østmo and Lotte Hedeager, pp.  
363–364. Pax, Oslo.

- 570
- 571 2008a Norwegian Mesolithic Trends: A Review. In *Mesolithic Europe*, edited by Geoff Bailey and Penny Spikins, pp. 60–106. Cambridge University Press, Cambridge.
- 572
- 573 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.
- 574
- 575 2017 Settlements and Seafaring: Reflections on the Integration of Boats and Settlements Among Marine 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.
- 576
- 577 Blankholm, Hans Peter
- 578 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>.
- 579
- 580 Borreggine, Marisa, Evelyn Powell, Tamara Pico, Jerry X. Mitrovica, Richard Meadow, and Christian Tryon
- 581 2022 Not a bathtub: A consideration of sea-level physics for archaeological models of human migration. *Journal of Archaeological Science* 137:105507. DOI:10.1016/j.jas.2021.105507.
- 582
- 583 Breivik, Heidi Mjelva
- 584 2014 Palaeo-oceanographic development and human adaptive strategies in the Pleistocene–Holocene transition: A study from the Norwegian coast. *The Holocene* 24:1478–1490. DOI:10.1177/0959683614544061.
- 585
- 586 Breivik, Heidi Mjelva, Guro Fossum, and Steinar Solheim
- 587 2018 Exploring human responses to climatic fluctuations and environmental diversity: Two stories from Mesolithic Norway. *Quaternary International* 465. Impacts of gradual and abrupt environmental changes on Late glacial to Middle Holocene cultural changes in Europe:258–275. DOI:10.1016/j.quaint.2016.12.019.
- 588
- 589 Breivik, Heidi, and Hein Bjartmann Bjerck
- 590 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*, edited by Hans Peter Blankholm, pp. 169–206. Equinox, Sheffield.
- 591
- 592 Brøgger, Waldemar Christofer
- 593 1905 *Strandliniens Beliggenhed under Stenalderen i Det Sydøstlige Norge*. Norges geologiske undersøkelse, Kristiania.
- 594
- 595 Bronk Ramsey, Christopher
- 596 2009 Bayesian Analysis of Radiocarbon Dates. *Radiocarbon* 51(1):337–360. DOI:10.1017/S0033822200033865.
- 597
- 598 2015 Bayesian Approaches to the Building of Archaeological Chronologies. In *Mathematics and Archaeology*, edited by Juan A. Barcelo and Igor Bogdanovic, pp. 272–292. CRC Press, Boca Raton.
- 599
- 600 Cahill, Niamh, Andrew C. Kemp, Benjamin P. Horton, and Andrew C. Parnell
- 601 2016 A Bayesian hierarchical model for reconstructing relative sea level: from raw data to rates of change. *Climate of the Past* 12(2):525–542. DOI:10.5194/cp-12-525-2016.
- 602
- 603 Conolly, James
- 604 2020 Spatial interpolation. In *Archaeological Spatial Analysis: A Methodological Guide*, edited by Mark Gillings, Piraye Hacıgüzeller, and Gary Lock, pp. 118–134. Routledge, London & New York.
- 605
- 606 Conolly, James, and Mark Lake
- 607 2006 *Geographical Information Systems in Archaeology*. Cambridge University Press, Cambridge.
- 608
- 609 Creel, Roger C., Jacqueline Austermann, Nicole S. Khan, William J. D’Andrea, Nicholas Balascio, Blake Dyer, Erica Ashe, and William Menke
- 610
- 611 2022 Postglacial relative sea level change in Norway. *Quaternary Science Reviews* 282:107422. DOI:10.1016/j.quascirev.2022.107422.
- 612
- 613 Crema, Enrico R.

- 
- 614 2012 Modelling Temporal Uncertainty in Archaeological Analysis. *Journal of Archaeological Method and*  
615 *Theory* 19(3):440–461. DOI:10.1007/s10816-011-9122-3.
- 616 2015 Time and Probabilistic Reasoning in Settlement Analysis. In *Mathematics and Archaeology*, edited by  
617 Juan A. Barcelo and Igor Bogdanovic, pp. 314–334. CRC Press, Boca Raton.
- 618 Crema, Enrico R., Andrew Bevan, and Mark W. Lake
- 619 2010 A probabilistic framework for assessing spatio-temporal point patterns in the archaeological record.  
620 *Journal of Archaeological Science* 37(5):1118–1130. DOI:10.1016/j.jas.2009.12.012.
- 621 Damlien, Hege, and Steinar Solheim
- 622 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.  
623 Equinox, Sheffield.
- 624 De Geer, Gerard
- 625 1896 *Om Skandinaviens geografiska utveckling efter Istiden*. P. A. Norstedt & Söner, Stockholm.
- 626
- 627 Eskeland, Knut Fossdal
- 628 2017 *Rapport, arkeologisk registrering. E18 Langangen Rugtvedt, 16/06999, Porsgrunn og Bamble kommune.*  
629 Skien.
- 630 Fossum, Guro
- 631 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,  
632 London & New York.
- 633 Fuglestvedt, Ingrid
- 634 2012 The Pioneer Condition on the Scandinavian Peninsula: the Last Frontier of a ‘Palaeolithic Way’ in  
635 Europe. *Norwegian Archaeological Review* 45(1):1–29. DOI:10.1080/00293652.2012.669998.
- 636 Gjerde, Jan Magne
- 637 2021 The Earliest Boat Depiction in Northern Europe: Newly Discovered Early Mesolithic Rock Art at  
638 Valle, Northern Norway. *Oxford Journal of Archaeology* 40:136–152. DOI:10.1111/ojoa.12214.
- 639 Gjerpe, Lars Erik, and Grethe Bjørkan Bukkemoen
- 640 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  
641 Oslo, Museum of Cultural History, Oslo.
- 642 Glørstad, Håkon (editor)
- 643 2002 *Svinesundprosjektet. Bind 1. Utgravninger avsluttet i 2001*. University of Oslo, Museum of Cultural  
644 History, Oslo.
- 645 (editor)
- 646 2003 *Svinesundprosjektet . Bind 2. Utgravninger avsluttet i 2002*. University of Oslo, Museum of Cultural  
647 History, Oslo.
- 648 (editor)
- 649 2004 *Svinesundprosjektet. Bind 3. Utgravninger avsluttet i 2003*. University of Oslo, Museum of Cultural  
650 History, Oslo.
- 651 2010 *The Structure and History of the Late Mesolithic Societies in the Oslo Fjord Area 6300-3800 BC*.  
652 Bricoleur Press, Lindome.
- 653 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  
654 and Håkon Glørstad, pp. 82–99. Oxbow Books, Oxford & Oakville.
- 655 2016 Deglaciation, sea-level change and the Holocene colonization of Norway. *Geological Society, London, Special Publications* 411:9–25. DOI:10.1144/SP411.7.
- 656 Glørstad, Håkon, Jostein Gundersen, Frode Kvalø, Pål Nymoen, David Simpson, and Birgitte Skar

- 658 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.
- 659
- 660 GRASS Development Team
- 661 2017 *Geographic Resources Analysis Support System (GRASS) Software, Version 7.2*. Open Source Geospatial Foundation.
- 662
- 663 Gundersen, Jostein
- 664 2013 Verken fjord eller fjell – steinalderen i det kystnære innlandet. Gamle og nye funn fra Notodden i Telemark. *Viking* 76:35–62.
- 665
- 666 Hafsten, Ulf
- 667 1957 De senkvartære strandlinje-forskyvningene i Oslotrakten belyst ved pollenanalytiske undersøkelser. *Norwegian Journal of Geography* 16(1-8):74–99. DOI:10.1080/00291955708622137.
- 668
- 669 1983 Shore-level changes in South Norway during the last 13,000 years, traced by biostratigraphical methods and radiometric datings. *Norwegian Journal of Geography* 37(2):63–79. DOI:10.1080/00291958308552089.
- 670
- 671 Hagen, Anders
- 672 1963 Problemkompleks Fosna. Opphav – kontakt med kontinentale grupper – forholdet til Komsa. In *Boplatsproblem vid Kattegat och Skagerack*, pp. 53–59. Göteborg och Bohusläns forminnesförening & Institutionen för nordisk fornkunskap, Gothenburg University, Gothenburg.
- 673
- 674 Helskog, Knut
- 675 1978 Late Holocene sea-level changes seen from prehistoric settlements. *Norwegian Journal of Geography* 32:111–119. DOI:10.1080/00291957808552032.
- 676
- 677 Herzog, Irmela
- 678 2013 The Potential and Limits of Optimal Path Analysis. In *Computational Approaches to Archaeological Spaces*, edited by Andrew Bevan and Mark Lake, pp. 179–211. Left Coast Press, Walnut Creek.
- 679
- 680 Hinsch, Erik
- 681 1955 Traktbegerkultur – Megalitkultur. En studie av Øst-Norges eldste neolitiske gruppe. *Universitetets Oldsaksamling Årbok* 1951/1953:10–177.
- 682
- 683 Hinz, Martin, Clemens Schmid, Daniel Knitter, and Carolin Tietze
- 684 2021 *oxcAAR: Interface to 'OxCal' radiocarbon calibration. R package version 1.1.0*.
- 685
- 686 Hollender, Artur
- 687 1901 Om sveriges nivåförändringar efter människans invandring. *Geologiska Föreningen i Stockholm Förhandlingar* 23(4):1118–1130. DOI:10.1080/00293652.1975.9965220.
- 688
- 689 Hughes, Anna L. C., Richard Gyllencreutz, Øystein S. Lohne, Jan Mangerud, and John Inge Svendsen
- 690 2016 The last Eurasian ice sheets – a chronological database and time-slice reconstruction, DATED-1. *Boreas* 45(1):1–45. DOI:<https://doi.org/10.1111/bor.12142>.
- 691
- 692 Hyndman, Rob J
- 693 1996 Computing and Graphing Highest Density Regions. *The American Statistician* 50(2):120–126.
- 694
- 695 Ilves, Kristin, and Kim Darmark
- 696 2011 Some Critical and Methodological Aspects of Shoreline Determination: Examples from the Baltic Sea Region. *Journal of Archaeological Method and Theory* 18:147–165. DOI:10.1007/s10816-010-9084-x.
- 697
- 698 Jakslund, Lasse (editor)
- 699 2001 *Vinterbrolokalitetene – En kronologisk sekvens fra mellom- og senmesolitikum i Ås, Akershus*. University of Oslo, Museum of Cultural History, Oslo.
- 700
- 701 (editor)
- 702 2012a *E18 Brunlanesprosjektet. Bind II. Undersøkte lokaliteter fra tidligmesolitikum*. University of Oslo, Museum of Cultural History, Oslo.
- 703
- 704 (editor)

- 705 2012b *E18 Brunlanesprosjektet. Bind III. Undersøkte lokaliteter fra tidligmesolitikum og senere*. University  
706 of Oslo, Museum of Cultural History, Oslo.
- 707 2014 Kulturhistorisk sammenstilling. In *E18 brunlanesprosjektet. Bind i. Forutsetninger og kulturhistorisk*  
708 *sammenstilling*, edited by Lasse Jakobsen and Per Persson, pp. 11–46. University of Oslo, Museum of  
Cultural History, Oslo.
- 709 Jakobsen, Lasse, and Per Persson (editors)
- 710 2014 *E18 Brunlanesprosjektet. Bind I. Forutsetninger og kulturhistorisk sammenstilling*. University of Oslo,  
711 Museum of Cultural History, Oslo.
- 712 Johansen, Erling
- 713 1963 Kyst(fangst)boplassenes strandbundenhet og strandlinjekronologien. In *Boplatsproblem vid Kattegat*  
714 *och Skagerack*, pp. 90–92. Göteborg och Bohusläns fornminnesförening & Institutionen för nordisk  
fornkunskap, Gothenburg University, Gothenburg.
- 715 1997 Eksperimentelle studier av flint og flint-vandringer i strandsonen. Et forsøk på å vinne ny kunnskap  
716 om våre boplasser i steinalderen. *Universitetets Oldsaksamling Årbok* 1995/1996:31–39.
- 717 Jørgensen, Erlend Kirkeng, Petro Pesonen, and Miikka Tallavaara
- 718 2020 Climatic changes cause synchronous population dynamics and adaptive strategies among coastal  
719 hunter-gatherers in Holocene northern Europe. *Quaternary Research*:1–16. DOI:10.1017/qua.2019.86.
- 720 Kjemperud, Alfred
- 721 1986 Late Weichselian and Holocene shoreline displacement in the Trondheimsfjord area, central Norway.  
722 *Boreas* 15(1):61–82. DOI:10.1111/j.1502-3885.1986.tb00744.x.
- 723 Kleppe, Else Johansen
- 724 1985 *Archaeological Data on Shore Displacements in Norway*. Norges geografiske oppmåling, Hønefoss.
- 725
- 726 Kleppe, Jan Ingolf
- 727 2018 The Pioneer Colonization of Northern Norway. In *Early Economy and Settlement in Northern Europe.*  
728 *Pioneering, Resource Use, Coping with Change*, edited by Hans Peter Blankholm, pp. 13–57. Equinox,  
Sheffield.
- 729 Lakens, Daniël, Anne M. Scheel, and Peder M. Isager
- 730 2018 Equivalence Testing for Psychological Research: A Tutorial. *Advances in Methods and Practices in*  
731 *Psychological Science* 1(2):259–269. DOI:10.1177/2515245918770963.
- 732 Lewis, Joseph
- 733 2021 Probabilistic Modelling for Incorporating Uncertainty in Least Cost Path Results: a Postdictive Roman  
734 Road Case Study. *Journal of Archaeological Method and Theory* 28(3):911–924. DOI:10.1007/s10816-  
021-09522-w.
- 735 Løken, Trond
- 736 1977 Mølen – et arkeologisk dateringsproblem og en historisk identifikasjonsmulighet. *Universitetets*  
737 *Oldsaksamling Årbok* 1975/1976:67–85.
- 738 Marwick, Ben, Carl Boettiger, and Lincoln Mullen
- 739 2018 Packaging Data Analytical Work Reproducibly Using R (and Friends). *The American Statistician*  
740 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*  
743 *Porsgrunn. Bind 1. Tidlig- Og mellommesolittiske lokaliteter i Vestfold og Telemark*. Portal forlag,  
Kristiansand.
- 744 Mikkelsen, Egil
- 745 1975 Mesolithic in South-Eastern Norway. *Norwegian Archaeological Review* 8(1):1118–1130.  
746 DOI:10.1080/11035890109445866.
- 747 Milne, Glenn A
- 748 2015 Glacial isostatic adjustment. In *Handbook of sea-level research*, edited by Ian Shennan, Antony J Long,  
749 and Benjamin P Horton, pp. 421–437. Wiley, Chichester.

- 750 Milne, Glenn A., W. Roland Gehrels, Chris W. Hughes, and Mark E. Tamisiea  
751 2009 Identifying the causes of sea-level change. *Nature Geoscience* 2(7):471–478. DOI:10.1038/ngeo544.
- 752
- 753 Mjærum, Axel  
754 2018 Hinterland discoveries: Middle Mesolithic woodland utilization and the case of the site Eidsberg, eastern Norway. *Current Swedish Archaeology* 26(1):159–188. DOI:10.37718/CSA.2018.11.
- 755
- 756 2022 A Matter of Scale: Responses to Landscape Changes in the Oslo Fjord, Norway, in the Mesolithic. *Open Archaeology* 8(1):62–84. DOI:10.1515/opar-2022-0225.
- 757
- 758 Møller, Jakob J  
759 1987 Shoreline relation and prehistoric settlement in northern norway. *Norwegian Journal of Geography* 41:45–60. DOI:<http://dx.doi.org/10.1080/00291958708552171>.
- 760
- 761 Mörner, Nils-Axel  
762 1976 Eustasy and Geoid Changes. *The Journal of Geology* 84(2):123–151. DOI:10.1086/628184.
- 763
- 764 1979 The Fennoscandian Uplift and Late Cenozoic Geodynamics: Geological Evidence. *GeoJournal* 3(3):287–318. DOI:10.1007/BF00177634.
- 765
- 766 Nielsen, Svein Vatnåg  
767 2021 Early farming in Southeastern Norway: New evidence and interpretations. *Journal of Neolithic Archaeology* 23:83–113. DOI:10.12766/jna.2021.4.
- 768
- 769 Nielsen, Svein Vatnåg, Per Persson, and Steinar Solheim  
770 2019 De-Neolithisation in southern Norway inferred from statistical modelling of radiocarbon dates. *Journal of Anthropological Archaeology* 53:82–91. DOI:10.1016/j.jaa.2018.11.004.
- 771
- 772 Nordqvist, Bengt  
773 1995 The Mesolithic settlement of the west coast of Sweden - with special emphasis on chronology and 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.
- 774
- 775 1999 The Chronology of the Western Swedish Mesolithic and Late Paleolithic: Old Answers in Spite of New Methods. In *The Mesolithic of Central Scandinavia*, edited by Joel Boaz, pp. 235–253. University of Oslo, Oslo.
- 776
- 777 Norwegian Mapping Authority  
778 2018 *Produktspesifikasjon. Nasjonal modell for høydedata fra laserskanning (FKB-laser)*. FKB-laser\_v30.
- 779
- 780 2021 Tidevannstabeller for den norske kyst med Svalbard samt Dover, England.
- 781
- 782 Nummedal, Anders  
783 1923 Om flintpladsene. *Norwegian Journal of Geography* 7(2):89–141.
- 784
- 785 Østmo, Einar  
786 1988 *Etableringen av jordbrukskultur i Østfold i steinalderen*. The University Collection of National Antiquities, University of Oslo, Oslo.
- 787
- 788 2008 *Auve. En fangstboplass fra yngre steinalder på Vesterøya i Sandefjord. I. Den arkeologiske del*. Museum of Cultural History, University of Oslo, Oslo.
- 789
- 790 Parnell, A. C., J. Haslett, J. R. M. Allen, C. E. Buck, and B. Huntley  
791 2008 A flexible approach to assessing synchronicity of past events using Bayesian reconstructions of sedimentation history. *Quaternary Science Reviews* 27(19–20):1872–1885. DOI:10.1016/j.quascirev.2008.07.009.
- 792
- 793 Persson, Per  
794 2008 Nauen 5.2 – Stenåldersboplatter och fossil åkermark. In *E18-prosjektet Vestfold. Bind 2. Steinalderboplatter, boplasspor, graver og dyrkningspor*, edited by Lars Erik Gjerpe, pp. 163–198. University of Oslo, Museum of Cultural History, Oslo.
- 795
- 796 Prescott, Christopher

- 797 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.
- 798
- 799 R Core Team
- 800 2021 *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria.
- 801
- 802 Ramstad, Morten
- 803 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.
- 804
- 805 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
- 806
- 807
- 808
- 809
- 810
- 811
- 812
- 813 2020 The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP). *Radiocarbon* 62(4):725–757. DOI:10.1017/RDC.2020.41.
- 814
- 815 Reitan, Gaute, and Inger Marie Berg-Hansen
- 816 2009 *Lundevågenprosjektet, delrapport 1. Sammenfattende rapport. Lunde, 6/1, 6/35 og Skjolnes 7/23, 7/27, Farsund kommune, Vest-Agder*. Oslo.
- 817
- 818 Reitan, Gaute, and Per Persson (editors)
- 819 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.
- 820
- 821 Reitan, Gaute, and Lars Sundström (editors)
- 822 2018 *The Stone Age Coastal Settlement in Aust-Agder, Southeast Norway*. Cappelen Damm Akademisk, Oslo.
- 823
- 824 Roalkvam, Isak
- 825 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>.
- 826
- 827 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.
- 828
- 829 Rønberg, Frank Halvar N.
- 830 2012 *Bosettings- og aktivitetsspor. Larønningen, 221/2138. Skien, Telemark*. University of Oslo, Museum of Cultural History, Oslo.
- 831
- 832 Romundset, Anders
- 833 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.
- 834
- 835 2021 *Resultater fra NGUs undersøkelse av etteristidas strandforskyvning nord i vestfold*. Geological Survey of Norway, Trondheim.
- 836
- 837 Romundset, Anders, Stein Bondevik, and Ole Bennike
- 838 2011 Postglacial uplift and relative sea level changes in Finnmark, northern Norway. *Quaternary Science Reviews* 30(19-20):2398–2421. DOI:10.1016/j.quascirev.2011.06.007.
- 839
- 840 Romundset, Anders, Ola Fredin, and Fredrik Høgaas

- 841 2015 A Holocene sea-level curve and revised isobase map based on isolation basins from near the southern  
842 tip of Norway. *Boreas* 44:383–400. DOI:10.1111/bor.12105.
- 843 Romundset, Anders, Thomas R. Lakeman, and Fredrik Høgaas
- 844 2018 Quantifying variable rates of postglacial relative sea level fall from a cluster of 24 isolation basins in  
845 southern Norway. *Quaternary Science Reviews* 197:175–192. DOI:10.1016/j.quascirev.2018.07.041.
- 846 2019 Coastal lake records add constraints to the age and magnitude of the Younger Dryas ice-front oscillation  
847 along the Skagerrak coastline in southern Norway. *Journal of Quaternary Science* 34(2):112–124.  
DOI:<https://doi.org/10.1002/jqs.3085>.
- 848 Schmitt, Lou, Stephan Larsson, Jan Burdukiewicz, John Ziker, Krister Svedhage, Jeanette Zamon, and  
849 Steffen Holger
- 850 2009 Chronological Insights, Cultural Change, and Resource Exploitation on the West Coast of Sweden  
During the Late Palaeolithic/Early Mesolithic Transition. *Oxford Journal of Archaeology* 28:1–27.  
DOI:10.1111/j.1468-0092.2008.00317.x.
- 851 Schülke, Almut
- 852 2020 First visit or revisit? Motivations of mobility and the use and reuse of sites in the changing coastal  
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,  
854 London & New York.
- 855 Shennan, Ian
- 856 2015 Handbook of sea-level research: Framing research questions. In *Handbook of Sea-Level Research*, edited  
by Ian Shennan, Antony J Long, and Benjamin P Horton, pp. 3–25. Wiley, Chichester.
- 857 Shetelig, Haakon
- 858 1922 *Primitive Tider i Norge – En oversikt over stenalderen*. John Griegs Forlag, Bergen.
- 859 Sognnes, Kalle
- 860 2003 On shoreline dating of rock art. *Acta Archaeologica* 74:189–209.
- 861 Solheim, Steinar
- 862 2012 Lokal praksis og fremmed opphav. Arbeidsdeling, sosiale relasjoner og differensiering i østnorsk  
863 tidligeolitikum. Unpublished PhD thesis, Oslo.
- 864 (editor)
- 865 2017 *E18 Rugtvedt-Dørdal. Arkeologiske undersøkelser av lokaliteter fra steinalder og jernalder i Bamble  
866 kommune, Telemark fylke*. Portal forlag, Kristiansand.
- 867 2020 Mesolithic coastal landscapes. Demography, settlement patterns and subsistence economy in south-  
868 eastern Norway. In *Coastal Landscapes of the Mesolithic: Human Engagement with the Coast from the  
869 Atlantic to the Baltic Sea*, edited by Almut Schülke. Routledge, London & New York.
- 870 2021 Timing the Emergence and Development of Arable Farming in Southeastern Norway by Using Summed  
871 Probability Distribution of Radiocarbon Dates and a Bayesian Age Model. *Radiocarbon* 63(5):1–22.  
DOI:10.1017/RDC.2021.80.
- 872 Solheim, Steinar, and Per Persson
- 873 2018 Early and mid-Holocene coastal settlement and demography in southeastern Norway: Comparing dis-  
tribution of radiocarbon dates and shoreline-dated sites, 8500–2000 cal. BCE. *Journal of Archaeological  
874 Science: Reports* 19:334–343. DOI:10.1016/j.jasrep.2018.03.007.
- 875 Sørensen, Rolf
- 876 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>.
- 877 1999 En <sup>14</sup>C datert og dendrokronologisk kalibrert strandforksyvningskurve for sørøst-Norge.  
878 In *Museumslandskap. Artikkelsamling til Kerstin Griffin på 60-årsdagen. Bind A*, edited by Lotte  
879 Selsing and Grete Lillehammer, pp. 227–242. AmS-rapport 12A. Museum of Archaeology, Stavanger.
- 880 Sørensen, Rolf, Kari E. Henningsmoen, Helge I. Høeg, and Veronika Gälman

- 883 2014 Holocene landhevningsstudier i søndre Vestfold og sørøstre Telemark – Revidert kurve. In *Vestfold-*  
884 *baneprosjektet. Arkeologiske undersøkelser i forbindelse med ny jernbane mellom Larvik og Porsgrunn.*  
885 Bind 1, edited by Stine Melvold and Per Persson, pp. 36–47. Portal, Kristiansand.
- 886 Sørensen, Rolf, Kari E Henningsmoen, Helge I Høeg, and Veronika Gälman  
887 in prep Holocen vegetasjons historie og landhevning i søndre Vestfold og sørøstre Telemark. In *The Stone*  
888 *Age in Telemark. Archaeological results and scientific analysis from Vestfoldbaneprosjektet and E18*  
889 *Rugtvedt-Dørdal*, edited by Per Persson and Steinar Solheim.
- 890 Sørensen, Rolf, Helge I. Høeg, Kari E. Henningsmoen, Göran Skog, Solveig F. Labowsky, and Bjørg Stabell  
891 2014 Utviklingen av det senglasiale og tidlig preboreale landskapet og vegetasjonen omkring steinalder-  
892 boplassene ved Pauler. In *E18 Brunlanesprosjektet. Bind 1. Forutsetninger og kulturhistorisk sam-*  
893 *mennstilling*, edited by Lasse Jakslund and Per Persson, pp. 171–213. University of Oslo, Museum of  
Cultural History, Oslo.
- 894 Stokke, Jo-Simon Frøshaug, and Gaute Reitan  
895 2018 Kvastad A2. Lokalitet med funn fra tidlig- og mellommesolitikum og dyrkningsspor fra mellom- og  
896 senneolitikum. In *The Stone Age Coastal Settlement in Aust-Agder, Southeast Norway*, edited by  
897 Gaute Reitan and Lars Sundström, pp. 375–407. Cappelen Damm Akademisk, Oslo.
- 898 Stroeven, Arjen P., Clas Hättestrand, Johan Kleman, Jakob Heyman, Derek Fabel, Ola Fredin, Bradley W.  
899 Goodfellow, Jonathan M. Harbor, John D. Jansen, Lars Olsen, Marc W. Caffee, David Fink, Jan Lundqvist,  
900 Gunhild C. Rosqvist, Bo Strömberg, and Krister N. Jansson  
901 2016 Deglaciation of Fennoscandia. *Quaternary Science Reviews* 147:91–121.  
DOI:10.1016/j.quascirev.2015.09.016.
- 902 Stuvier, Minze, and Paula Reimer  
903 1989 Histograms obtained from computerized radiocarbon age calibration. *Radiocarbon* 31(3):817–823.  
DOI:10.1017/S0033822200012431.
- 904 Svendsen, John Inge, and Jan Mangerud  
905 1987 Late Weichselian and Holocene sea-level history for a cross-section of western Norway. *Journal of*  
*906 Quaternary Science* 2(2):113–132. DOI:10.1002/jqs.3390020205.
- 907 Tallavaara, Miikka, and Petro Pesonen  
908 2020 Human ecodynamics in the north-west coast of Finland 10,000–2000 years ago. *Quaternary Interna-*  
909 *tional* 549:26–35. DOI:10.1016/j.quaint.2018.06.032.
- 910 van der Plicht, Johannes  
911 1993 The Groningen Radiocarbon Calibration Program. *Radiocarbon* 35(1):231–237.  
DOI:10.1017/S0033822200013916.
- 912 Wang, Ian  
913 2019 *topoDistance: Calculating topographic paths and distances. R package version 1.0.1. Https://CRAN.r-*  
*project.org/package=topoDistance.*
- 914 Wenn, Camilla Cecilie  
915 2012 *Bosettingsspor, produksjonsområde og dyrkningsspor fra Neolitikum til Folkevandringstid. Bratsberg,*  
63/69, 244. Skien kommune, Telemark. University of Oslo, Museum of Cultural History, Oslo.
- 916 Wikell, Roger, Fredrik Molin, and Mattias Pettersson  
917 2009 The Archipelago of Eastern Sweden - Mesolithic Settlement in Comparison with  $^{14}\text{C}$  and  
918 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.
- 919 Yubero-Gómez, María, Xavier Rubio-Campillo, and Javier López-Cachero  
920 2016 The study of spatiotemporal patterns integrating temporal uncertainty in late prehistoric settlements  
921 in northeastern Spain. *Archaeological and Anthropological Sciences* 8(3):477–490. DOI:10.1007/s12520-  
015-0231-x.