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Research Article

Axel Mjærum*

A Matter of Scale: Responses to Landscape Changes in the Oslo Fjord, Norway, in the Mesolithic

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Abstract: Present-day global warming has great consequences, both for individuals and on a larger scale for society as a whole. However, environmental changes also affected everyday life in the past. The purpose of this article is to apply perspectives developed in studies of how contemporary societies adapt to shore-level changes and to use this insight in a study of the way Mesolithic populations handled a situation of large land uplift. More specifically, the author discusses four common adaptation strategies devised to cope with changing sea level, both on a site level and on a regional scale – to accommodate, relocate, protect, or not respond to the changing environment. In the Oslo Fjord in Norway, the shorelines moved from approximately 200–40 m above the present-day sea level in the period 9300–3900 cal BC, caused by the strong post-glacial rebound. Along the shores lived populations that based much of their life on the local marine resources. Building on information from the large habitation area Havsjødalen and a statistical analysis of 529 critically selected sites in the region, the author concludes that single sites were systematically accommodated or relocated when the distance to the shores receded. However, sea level changes caused more dramatic regional landscape transformation and a less bountiful environment *c.* 5000 cal BC, with a period of maladaptation and a subsequent population collapse as a result. Like modern societies facing human-caused climate changes, the Mesolithic population had difficulties in handling the need for large-scale shifts in their society.

Keywords: environmental changes, adaptation, relocation strategies, population dynamics, site counts, Scandinavia

1 Introduction

Melting glaciers in the Early Holocene led to a rise in the global sea level and a regional rebound of landmasses in areas that were relieved of the weight of the ice (Påsse & Daniels, 2015; Smith, Harrison, Firth, & Jordan, 2011). Among the consequences were significant shore level displacements across Europe (e.g. Astrup, 2018; Bailey, Harff, & Sakellariou, 2017; Bjerck, 2008), which made adaptation a necessary course of action for the Mesolithic hunter-fisher-gatherers who lived along these coasts.

Problems related to changing sea levels are also very much a part of the present-day world, and multiple studies discuss the best way to respond to these developments in the environment (e.g.

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* **Corresponding author: Axel Mjærum,** Department of Archaeology, Museum of Cultural History, University of Oslo, Oslo, Norway, e-mail: a.j.mjarum@khm.uio.no

Figure 1: The studied area in the innermost part of the Oslo Fjord in eastern Norway. Map: Axel Mjærum, Museum of Cultural History.

Oppenheimer et al., 2019). Used in the context of shore level adjustments, the concept of *adaptation* can refer "to a process, action or outcome in a system (household, community, group, sector, region, country) in order for the system to better cope with, manage or adjust to some changing condition, stress, hazard, risk or opportunity" (Smit & Wandel, 2006, p. 282). In this article, I argue that our insight into how people today adapt to present-day environmental changes also offers interesting perspectives on how humans handled landscape developments in the Mesolithic.

In the Oslo Fjord area in Norway (Figure 1), the isostatic rebound has been stronger than the global sea level rise during the entire Holocene (Sørensen, 2002; Figures 4 and 5), and the shorelines moved from approximately 200 to 40 m above the present-day sea level during the Mesolithic period, lasting from 9300 to 3900 cal BC. Consequently, islands, inlets, and straits appeared and disappeared, fjords were transformed into lakes, shorelines moved, and coastal ecosystems were affected and altered. During this timeframe, hunter-fisher-gatherers heavily dependent on fish and sea mammals populated the Oslo Fjord area (e.g. Glørstad, 2010; Mansrud & Persson, 2018; Schülke, 2020a). Sites related to these populations and their activities are numerous[1] and located up to 195 m above the present-day sea level in the region, with the oldest traces of shore-bound activity highest up in the terrain (Figure 3, cf. Roalkvam, Mjærum, & Persson, 2020).

How close to the shorelines the region's former coastal hunter-gatherers settled and also established the sites where they chose to perform their different tasks is a much-debated question (e.g. Berg-Hansen, 2009; Bergsvik, 1991; Bjerck, 1990; Mjærum, 2019; Schülke, 2020b), and the distance must have been affected by factors such as the shape of the coast, the direction of the wind and waves, possibilities to go ashore, the opportunities for fishing, and the type of activities to be performed. Anyhow, based on our knowledge of the region's Holocene isostatic rebound and the position of the different sites above the present-day sea level, we can, in fact, see a close general correspondence between typological dates,

1 In total 529 Mesolithic and Neolithic hunter-fisher-gatherer sites are included in this study.

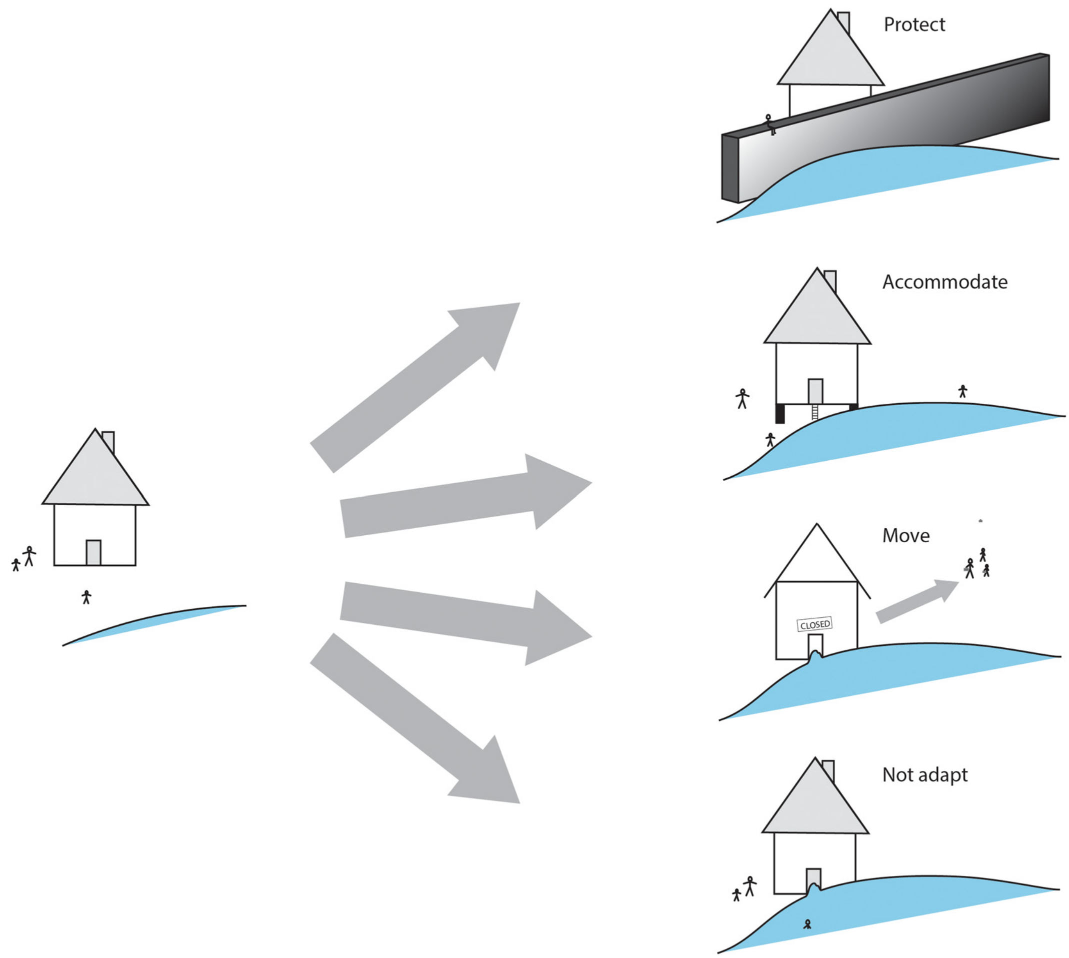

Figure 2: In general, people choose one or more of four strategies when they adapt to changing sea levels – they protect, accommodate, they leave the area, or continue their activities without any form of adaptation. Illustration: Axel Mjærum, Museum of Cultural History.

radiocarbon dates from hunter-gatherer sites, and shoreline dates in the Oslo Fjord region (Brøgger, 1905; Fossum, 2020; Solheim & Persson, 2018; Figure 5).

This correlation between sites and Mesolithic shorelines raises questions about how Mesolithic people adapted to shore-level changes in an area like the Oslo Fjord, where people experienced significant landscape developments. Moreover, as argued, knowledge of modern adaptation strategies can bring new insights to the study of this problem. By combining this approach with the region's large and relatively well-dated Mesolithic record, I will discuss here how the Mesolithic archipelago population adapted to changes in the sea levels on a small scale using excavation results from single sites. This approach will be combined with counts of the number of sites at different altitudes as a proxy for how the region's populations were affected by, and adapted to, larger and more abrupt landscape developments caused by the sea level changes.

2 Present-day Adaptation to Changing Sea Levels

2.1 Adaptation to Flooding and Rising Sea Levels

The low-lying megacity of Jakarta in Indonesia is an example of an area that has a long history of coastal and riverine flooding. The flood hazard is driven by subsidence, poor city planning, and river

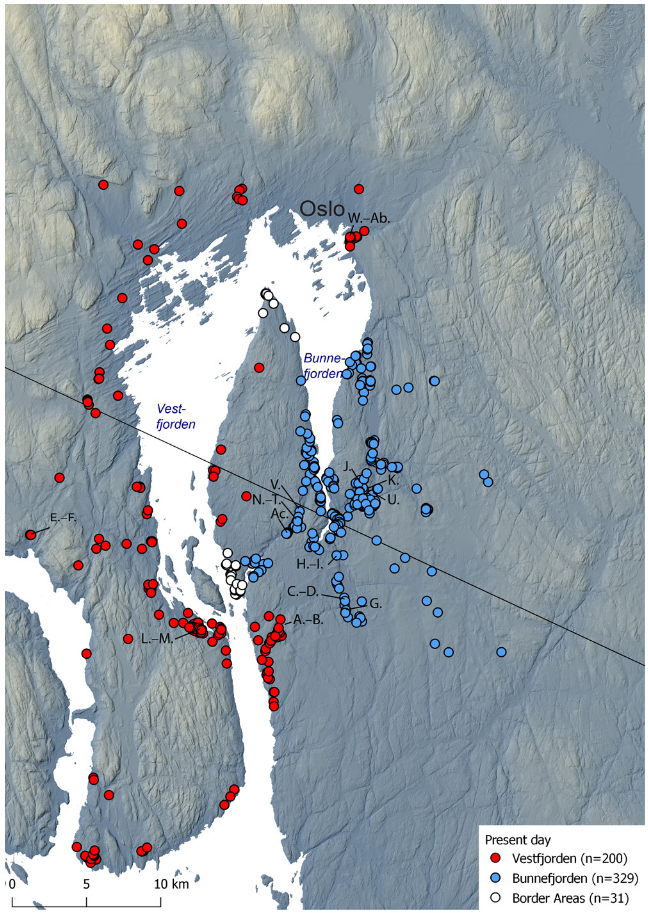

Figure 3: The present-day landscape in the Oslo Fjord area with the 329 critically selected sites located in the Bunnefjorden area and the 200 sites in the Vestfjorden area. The black line marks a base-isobar with an orientation of N30°E established by the direction of the isostatic rebound in the Oslo Fjord area. To obtain a more precise shore level date, the sites have been recalibrated in accordance with the distance to this base. Illustration: Isak Roalkvam, MCH.

sedimentation, which is reinforced by climate changes (Marfai, Sekaranom, & Ward, 2015; Ward, Pauw, van Buuren, & Marfai, 2013). The devastating effect is that significant parts of the city have been inundated multiple times in the last few decades, and it is expected that problems related to flooding will increase in the future.

The community of Jakarta has responded and adapted in different ways to the hazard of high water levels (Marfai et al., 2015). Physical adaptation includes elevating house levels, building multistorey houses, and the construction and cleaning of small dykes. Large projects have also been conducted in the city, such as rehabilitation of flood ways and improvement of the coordination of flood mitigation work (The World Bank, 2019). In April 2019, however, Indonesia's president Joko Widodo announced that the government is planning to move the capital city, partly due to the expected increase in problems with seasonal floods (BBC News, 2019). The floods in Jakarta demonstrate four essential adaptation strategies to changing sea levels (Figure 2). One strategy is to protect, for example by constructing seawalls and dykes. A second option is to accommodate by flood-proofing and by raising structures, and a third is to move people and assets to safer areas (Diaz, 2016, p. 144). A fourth option is not to adapt, and thereby not respond to the changes in the environment, a strategy that can easily lead to costly effects of maladaptation to the environment.

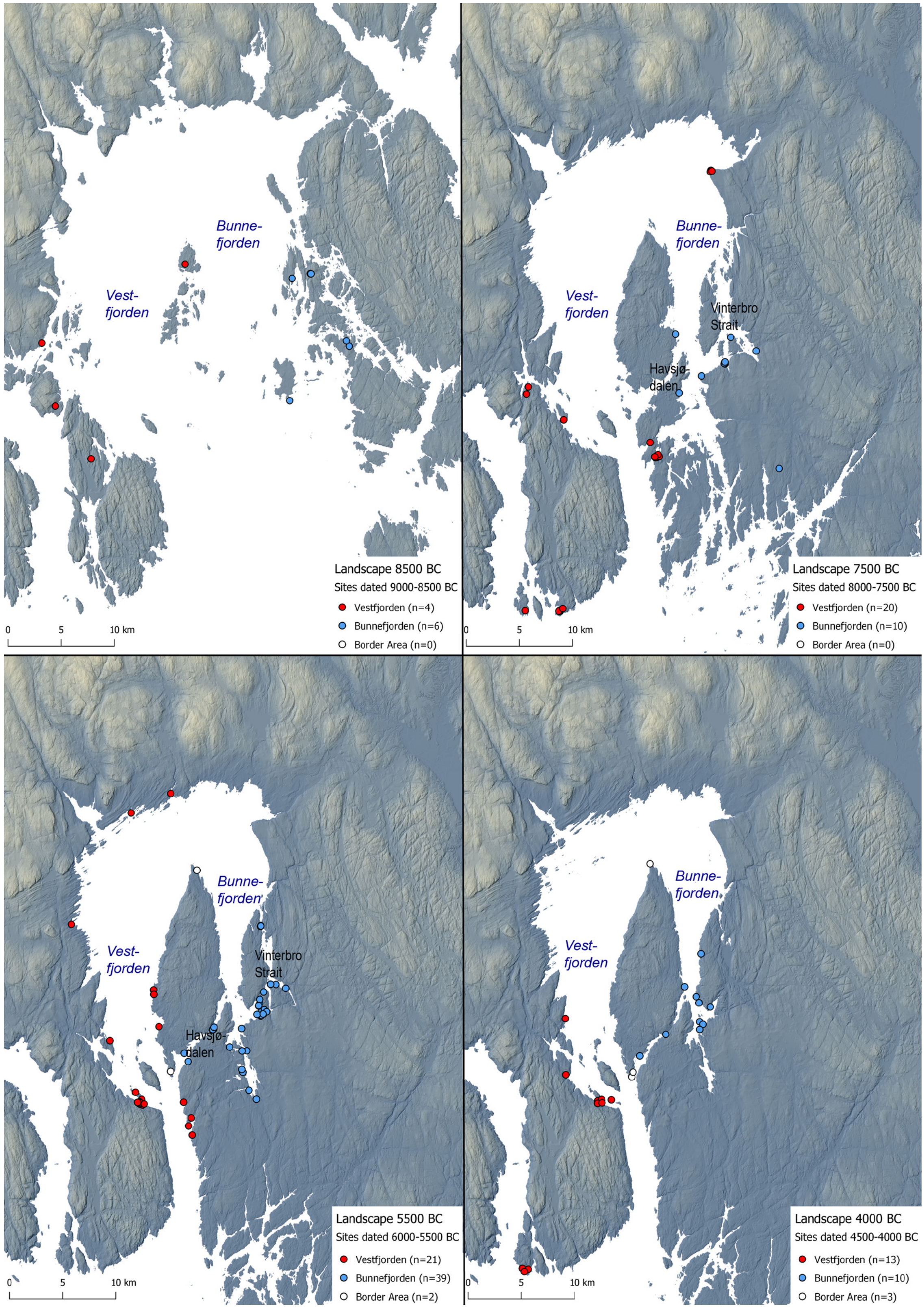

Figure 4: In the Boreal period (*c.* 8250–7000 cal BC), the area under study went from being an archipelago landscape to a more closed, sheltered fjord system. By *c.* 8000 cal BC, the sea had withdrawn to approximately 115 m above the present level, and two straits slowly appeared. Around 7500 cal BC the shore level was 90 m above the present, and the strait of Havsjødalen linked Bunnefjorden and Vestfjorden. The two straits existed for 2500 years but decreased in width and depth as the land rebounded. Around 5400 cal BC, a process started whereby the Vinterbro sound, with the nearby locus Nøstvet, became dry land, and by *c.* 5000 cal BC the Havsjødalen sound closed. These events removed the two straits, and from *c.* 5000 cal BC Bunnefjorden became a more remote area in the innermost part of the Oslo Fjord. Illustration: Isak Roalkvam, MCH.

2.2 Adaptation to Land Uplift

The coastline along the Bothnian Bay in Sweden and Finland is another area significantly affected by present-day shoreline changes, but in another sense than in Jakarta. Due to the same isostatic uplift process that affects the Oslo Fjord area, the land rebound is still up to 1 cm higher than the sea level rise each year in this part of Sweden and Finland (cf. Nordman et al., 2020). The town of Luleå, located at a site on the Swedish part of the coastline, was at first a commercial settlement and then developed into a political and religious centre during the Middle Ages (Luleå kommun, 2021; UNESCO, 2021). The building of a cathedral started in the 15th century and in 1621 the King formally founded Luleå as a town. A pier was established and then extended to enable ships to reach the town, but after only 28 years it was concluded that the harbour had become unusable due to the land uplift. The commercial centre was thus forced to move to the town's present-day location, 10 km further out the fjord. However, the Old Town with its large church continued to fulfil religious and social needs for the region's population, despite the loss of its mercantile importance and unfavourable harbour conditions.

Luleå New Town has also been affected by land uplift since it was founded. The land area of the central part of Luleå is 40% larger than 150 years ago (Carlsson & Johansson, 2016, pp. 40–41), which has had the consequence that older parts have gradually lost their original contact with the waterfront. One solution to adopt in this situation was to expand the town into the new land areas, and another was to fill out the harbour areas in order to better integrate the sea and the newly built areas in the years to come (Carlsson & Johansson, 2016, p. 87). The example of Luleå shows the vital need to adapt, also in situations with a decreasing sea level, and that people both adapt and relocate in order to handle the changing environment, and even then, situations of maladaptation can occur. However, protection is likely a less necessary strategy when the land is rising.

The use of Luleå Old Town as a place for worship and as a location for social meetings in recent centuries exemplifies that the question of adaptation strategies is about more than environmental changes and economic optimization. It is also dependent on the vulnerability to sea level alterations, the ability of the society under discussion to predict hazards and risks, and the adaptive capacity of the settlement (cf. Astrup, 2018, pp. 31–33; Smit & Wandel, 2006). Additionally, the degree of dependency of the society in question on the sea is a key factor in the understanding of adaptation strategies. The Norwegian Mesolithic societies discussed in this article were largely based on marine resources and boat transport (Gjerde, 2021; Glørstad, 2010; Mansrud & Persson, 2018), and thereby much more affected by shore level changes than the later farming societies in the same region. A study of adaptation strategies must also consider cultural aspects and preferences, as well as an individual's room for making choices within a framework of ecological and social constraints (cf. Giddens, 1984).

2.3 Adaptation – Also a Matter of Scale

Adaptation is also a matter of scale. To illustrate the scale perspective, sunbathers on a sandy beach have been used as an example (Toi, Klein, & Nicholls, 2008, p. 433). The people close to the shore would drown if they did not adapt to the tide. However, they see, hear, and potentially feel the coming high tide, and in just seconds, they can get on their feet and move to higher ground. The point of this example is to illustrate the little concern about adaptation in systems that can change rapidly, monitor their surroundings, and have incentives and abilities to avoid potentially negative consequences of change. Adaptation is a longer lasting and more problematic process in larger, complex systems for people who need to change a significant part of their subsistence, and at places where material things, memories, histories, and traditions play a significant role (cf. entrapment, Hodder, 2012, pp. 88–112). The social, emotional, and cultural costs of leaving settlements, villages, or cities behind should therefore also be taken into consideration when adaptation to a changing environment is discussed, and this is closely linked to the fact that human adaptation to a changing sea level is more than a consequence of the changing environment.

3 Methodological Approaches

3.1 The Shore Level History of the Oslo Fjord Area

The isostatic rebound effect is fairly well studied in the Oslo Fjord region, with a detailed shore level curve produced for the Ski–Ås terminal moraine at the east side of the Oslo Fjord (Sørensen, 2002, 2006, cf. Figure 5). The curve has validity for the "base-isobar" with an orientation of N30°E (Figure 3), established by the direction of the isostatic rebound in the Oslo Fjord area (Sørensen, Bakkelid, & Torp, 1987, cf. 2003, p. 48). Some of the sites, however, are located as much as 25 km away from this baseline, in areas with a significantly different shore level displacement history. To make the whole area comparable, adjustments are needed (cf. Fossum, 2020; Solheim & Persson, 2018, p. 337). In this study, a recalibration of altitudes is therefore carried out in accordance with a method based on a semiempirical mathematical model presented by Tore Påsse (Påsse, 2003, pp. 48–49, Table 42; cf. Påsse & Daniels, 2015; Figure A1).

To test the validity of this method, the shore level displacement curve for Lake Vaglarna in Bohuslän, Sweden, has been recalibrated to the Oslo Fjord area in line with Påsse's mathematical principles (Figures 3 and 5, Figure A1). The validity of the method has also been tested by plotting radiocarbon- and typology-dated sites, dates that are adjusted in line with the method described (Tables A1 and A2). There is a fairly good correspondence between the mathematical model, an independently produced regional displacement curve for the Oslo Fjord area (Sørensen, 2006), and radiocarbon-dated Stone Age sites from between *c.* 7000 and 4000 cal BC, the period of main interest in this article (Figure 5, Tables A1 and A2). Therefore, the recalibrated Vaglarna curve most likely offers relatively precise dates of the shore-bound sites, especially for the numerous sites located relatively close to the base-isobar in the Bunnefjorden area (Figure 3). The plots, however, show a discrepancy between the curve from 2006 (Sørensen, 2006), and geological and archaeological data obtained from the first part of the Mesolithic (before 7000 cal BC) and the Neolithic (*c.* 3900–1700 cal BC, Figure 5). To make it possible to integrate sites dated to before 7000 cal BC in the analysis, an adjusted version of the curve for the Oslo Fjord region is used (Figure 5, red dashed line, based on Sørensen, 2015, and Table A2), whereas the Neolithic part of the curve is constructed from the existing curve from the region (Sørensen, 2006). However, all sites from all periods that were located at a distance from the baseline have been recalibrated in accordance with Påsse's principles.

This approach only offers rough dates of the sites. To reduce the uncertainties of the analysis and statistics, the sites are therefore organized in groups of 500 years, as well as being presented as 1,000 year averages. The exact fixation points of the 500 year intervals are chosen because the categories correspond well with the main landscape changes in the region (cf. Figure 4).

3.2 The Archaeological Record

Extensive archaeological surveys have been conducted in the inner Oslo Fjord region, especially during the last 30 years (Damlien et al., 2021). A total of 625 Stone Age sites have been located, mainly by test pitting (Figure 3, Askeladden, 2019). Approximately 100 of the sites are, however, excluded in the further discussion, including 31 from the border region between two analysed areas, Bunnefjorden and Vestfjorden (Figure 3), sites located along present freshwater lakes (n = 14), sites which can potentially be linked to Neolithic farming (Nielsen, 2021), stray finds, duplicates in the data set, and sites lacking precise spatial information. The further analysis is thus based on a total of 529 sites, of which approximately 50 have been excavated in more detail (e.g. Ballin, 1998; Berg, 1997; Damlien et al., 2021; Glørstad, 2006, p. 73; Jaksland, 2001).

Altogether 329 of these areas with Stone Age activity are located in an area of approximately 435 sq. km related to Bunnefjorden, whereas 200 sites were in the three times larger (1,325 sq. km) Vestfjorden area (Figure 3). The shores of Vestfjorden were approximately 2.7 times longer than in Bunnefjorden when the sea level was 50 m above the present (*c.* 5000 cal BC). These numbers indicate a generally denser population in the Bunnefjorden area than in the western part of the Fjord system. The further analysis of Mesolithic adaptation strategies will be based on this compiled data set from the Oslo Fjord region, as well as a case study from the central part of this area – Havsjødalen (Figure 4).

3.3 The Havsjødalen Excavation

In 2015, a rescue excavation took place ahead of construction work on a road in the central part of Havsjødalen, the strait that linked the Bunnefjorden and the Vestfjorden area from approximately 7500 to 5000 cal BC (Mjærum, 2021). This made it possible to conduct the first extensive study of a centrally positioned dwelling site in the inner part of the Oslo Fjord area, and thereby gain new knowledge of adaptation strategies at a site scale. At the time of the rescue campaign, the Havsjødalen sites were partly located in a forest area little affected by modern activities (sites 3–5), and partly in cropland (sites 1, 2, and 6).[2] There have also been archaeological surveys in other parts of Havsjødalen. The result is multiple sites located approximately 90–40 m a.s.l., which indicates extensive activity in the area *c.* 7000–4500 BC (Figures 4 and 6–9).

4 Adaptation Strategies on Site Level

The former tidal range is a key issue that needs to be addressed in order to understand the relationship between settlements and former shores in Havsjødalen and elsewhere along the coast, although it has been little discussed in studies of settlement locations during the east Norwegian Mesolithic. The present tidal range in the inner part of the Oslo Fjord is moderate, less than 0.5 m at spring tide and up to 1.67 m above the mean on rare occasions (high water with 100 year return period, Kartverket, 2019). Before 8000 cal BC, the tidal variation was significantly larger than today, whereas the situation since 6000 cal BC has been much like today (Uehara, Scourse, Horsburgh, Lambeck, & Purcell, 2006), even though the land upheaval process caused significant local tidal range changes. Relatively small tidal variations, combined with the sheltered location of many sites, made it theoretically possible to settle close to the sea at many sites. Based on the covariation between C14 dates, typological dates, and past sea level (cf. Figures 5 and 6, Tables A1 and A2), it is likely that this was also often the case. Such a conclusion is strengthened by the fact that many the sites offered excellent harbours when they were shore bound (Damlien et al., 2021; Glørstad, 2010).

To gain more precise knowledge of the relationship between settlements (i.e. lithic scatters) and former seashores, there have been studies of the amount of salt water patina on lithic artefacts at some sites (e.g. Jaksland, 2004, p. 274; Jaksland & Tørhaug, 2004, p. 74). At other sites, the fluctuations in the amount of phosphate have been used as a method to identify the relationship between settlement areas and the former shores (e.g. Broadbent, 1979; Ilves & Darmark, 2011; Melvold & Persson, 2014; Viken, 2018). Neither of these methods has so far led to conclusive evidence regarding the general distance between the former activity areas and the shores in the Oslo Fjord region.

In the absence of sites with detailed information on the exact relationship between former activity and shorelines, more general thoughts about the background to the identified lithic scatters can possibly help us to understand the degree of shore-boundedness. A large share of the sites in the area can be interpreted as being the result of one or multiple short-term visits to a place where different types of procurements were

2 At the infield sites in Havsjødalen, the plough soil was systematically test-pitted before it was stripped off using an excavator. Finally, the cultural layers and parts of the subsoil were dug by hand and water-sieved. In the forest areas, test pits were excavated by hand and approximately 100 sq. m was investigated through manual digging and sieving of soil. In Havsjødalen, a total of 143 sq. m was excavated by hand and sieved in areas that were divided into squares and layers. The artefacts that were found could therefore be related to coordinate systems. Different types of archaeometrical analysis were used with the aim of obtaining more information about the substance, the ages of the sites, and changes in the landscape.

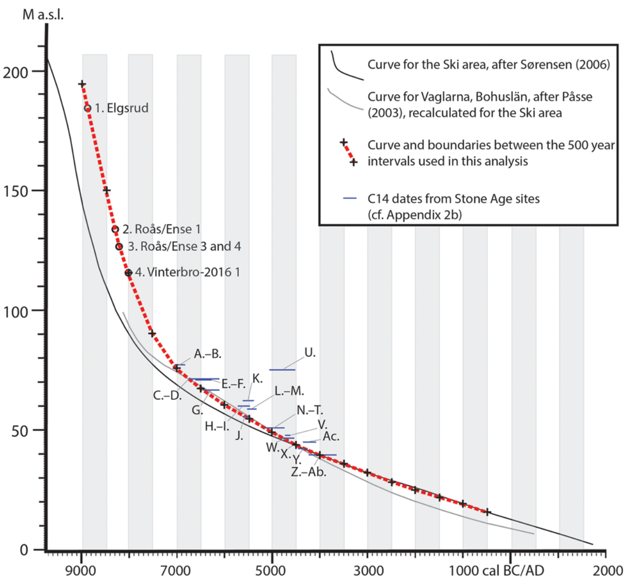

Figure 5: The analysis in this article is based on a compilation of geological data (Påsse, 2003; Sørensen, 2006) and the archaeological record from the region. Illustration: Per Persson and Axel Mjærum, MCH.

planned and executed, and where resources were stored (e.g. Glørstad, 2010, cf. Binford, 1980, pp. 10–12). Naturally, well-drained places with good harbours were relatively easy to find in the fjord landscape, and the most fitting locations could be chosen for each visit. The temporary character of many of these stays also made the regression of the shorelines irrelevant, and some of the activities were most likely performed close to the former shores, and even in the tidal zone. In this way, many of these stays can be compared to the abovementioned example of the sunbather (Toi et al., 2008, p. 433), able to adapt effortlessly to the landscape changes. However, constructions of a more permanent character, such as dwellings, and hearths made for reuse required a somewhat more secluded position, as is well illustrated by the results from the excavation campaign in Havsjødalen.

4.1 Havsjødalen and Two Main Strategies of Adaptation

Site 3 in Havsjødalen was located approximately 1 m above the sill in the former strait that linked Vestfjorden and Bunnefjorden (Figures 4 and 6). An oval pit-hut with a floor size of 6.5 m × 3.7 m was found (Figures 6–8). The floor was dug 0.4 m into the ground. The dwelling had a central hearth and probably also a system of ventilation in the form of trenches. The hut was likely rebuilt during its usage time; the nearby ground was accommodated in the form of a 4.8 m long and 0.4 m deep drainage ditch that protected the hut from rainwater. The hut structure in itself points towards extensive activity; and/or overwintering/seasonal visits for a certain period or in the long term. The interpretation was confirmed by the find of 61,500 lithic artefacts (Figure 8), more than at any other single phased Mesolithic site in eastern Norway (cf. Eigeland & Fossum, 2014; Glørstad, 2010), and far more than at any other excavated dwelling structure in the country (Fretheim, 2017, Appendices 1 and 2, no other dwelling unit has yielded more than 17,500 lithic artefacts). The sound closed *c.* 5000 cal BC but the activity continued for some time when site 3 was located along a shallow bay (Figure 6). The inhabitants at site 3 chose not to respond to this change in conditions immediately. However, around 4800 cal BC the activity was relocated, probably to site 1 (cf. Figure 9). This form of repositioning, where sites were moved to a place nearby, happened multiple times in Havsjødalen, with the result being sites at different altitudes and with different dates along the sound (Figure 6). The same density of sites has been identified along the nearby Vinterbro Strait (cf. Figure 4; Jaksland, 2001), and related to resource-rich areas in other parts of coastal Norway (e.g. Bergsvik, 2002; Bruen Olsen, 1992;

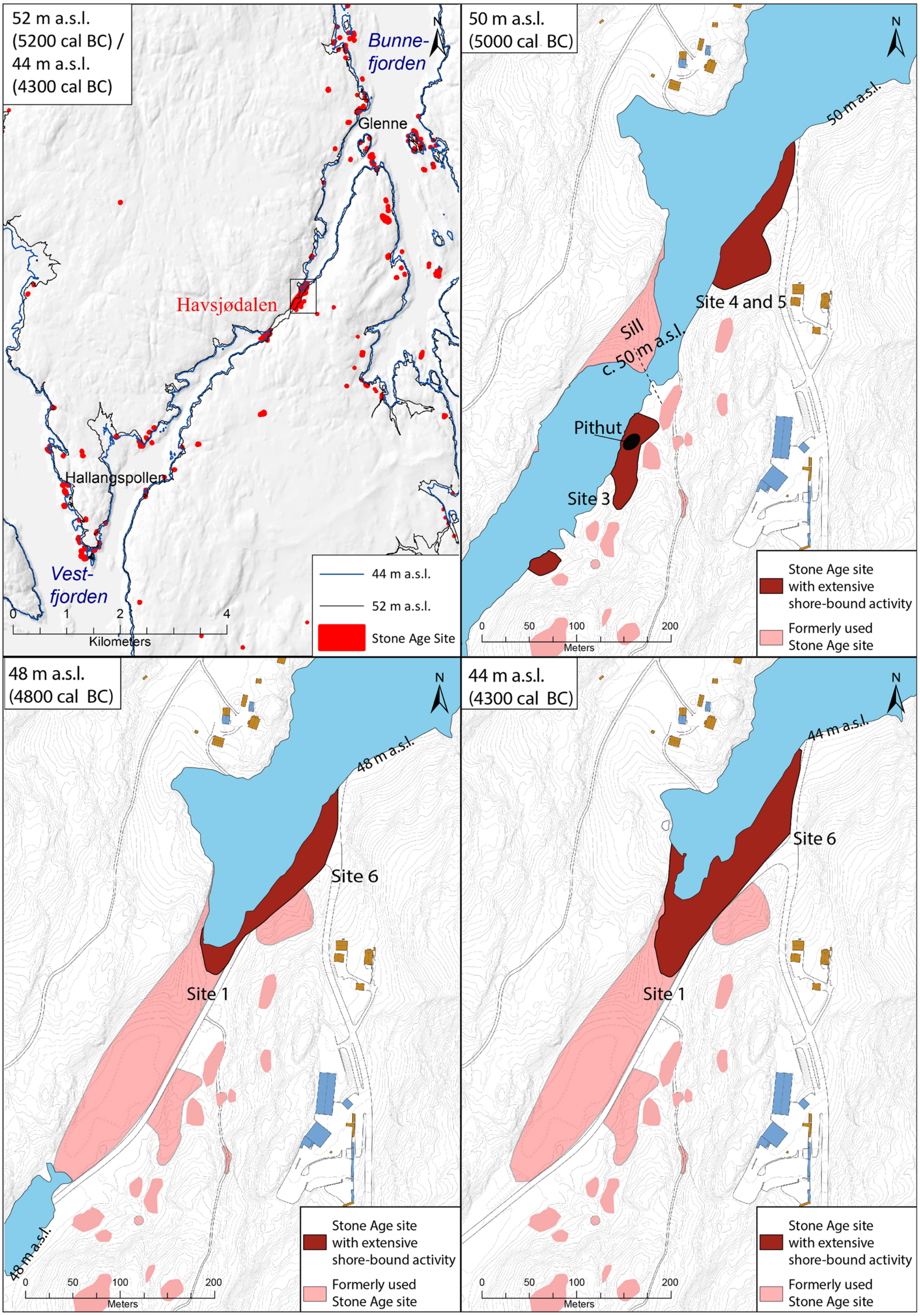

Figure 6: The changes in sea level and settlement activity in Havsjødalen from *c.* 5200–4300 cal BC. Map: Axel Mjærum, MCH.

Figure 7: The hut in Havsjødalen. The hut floor is seen as an oval, dark layer of cultural deposits measuring approximately 3 m × 6 m. Photo: Carine Eymundsson, MCH.

Glørstad, 2010). Without doubt, movements of sites were a common way to adapt to shoreline changes in the past, as sometimes happens in the modern world (cf. the examples of Jakarta and Luleå).

Site 1 was a former habitation area that covered over 4,000 sq. m in sloping terrain 49.2–45 m a.s.l. Based on the finds from the modern plough soil at the site, as many as 140,000 lithic artefacts could have been deposited at this location, a number that indicates activity on a very large scale. One radiocarbon date from a pit points towards activity along the shores *c.* 4700 cal BC in the upper part of the slope, at a time when the lowermost areas of the settlement were below the water surface. Since lithics were found *in situ* at different heights down to 45 m a.s.l., it is likely that at least some of the activity was moved downward in the terrain, in line with the regressing water. Most likely this part of Havsjødalen was left as a central place for activity around 4400 cal BC, when there was only poorly drained clay soil along the shores.

Indications of such a gradual movement of activity have been observed at multiple sites located in sloping terrain in eastern Norway, and hillsides in the region can potentially cover hundreds, and even thousands, of years of shore-bound activity at different altitudes (Glørstad, 2010, p. 109; Mjærum, 2009; Reitan, Danielsen, Gummesson, & Schülke, 2019, p. 36). In the cases where traces of activity have been found at different altitudes at single sites, chronological studies, as well as radiocarbon dates from manifest structures such as hearths, pits, and cultural deposits, commonly prove a pattern where site activities were gradually moved. This must be seen as an accommodation to the regression process, as higher parts of the sites become less intensively used with an increasing distance to the shore. This strategy is comparable to what is taking place in the gradually expanding Luleå New Town. However, most activities in a modern town are independent of access to the waterfront (Kostof, 1992, pp. 44–46), and as a consequence these areas remain as central areas, despite a gradually increased distance to the shore.

Since the year 2000, approximately 230 Stone Age sites have been excavated in the former archipelago landscape of eastern Norway, most of them in regions with significant shore level displacement (Damlien et al., 2021). In this large set of data, there are some examples of Mesolithic inland revisits at sites that originally were shore bound (Schülke, 2020b). It is hard to find examples of sites from any parts of the Mesolithic which were neither relocated nor accommodated by a slow movement of the activity in line with the regressing shorelines. However, one site stands out in a regional context, Sandholmen, a site with evidence of 25 pit houses, which was originally located near the sea shore at the outlet of the large Glomma River (Eigeland, Mansrud, & Persson, 2016).

When Sandholmen was first visited, salmon were able to reach the waterfalls close to the settlement. A dramatic change occurred at the place *c.* 7200 BC when new obstacles to migrating fish emerged in the river,

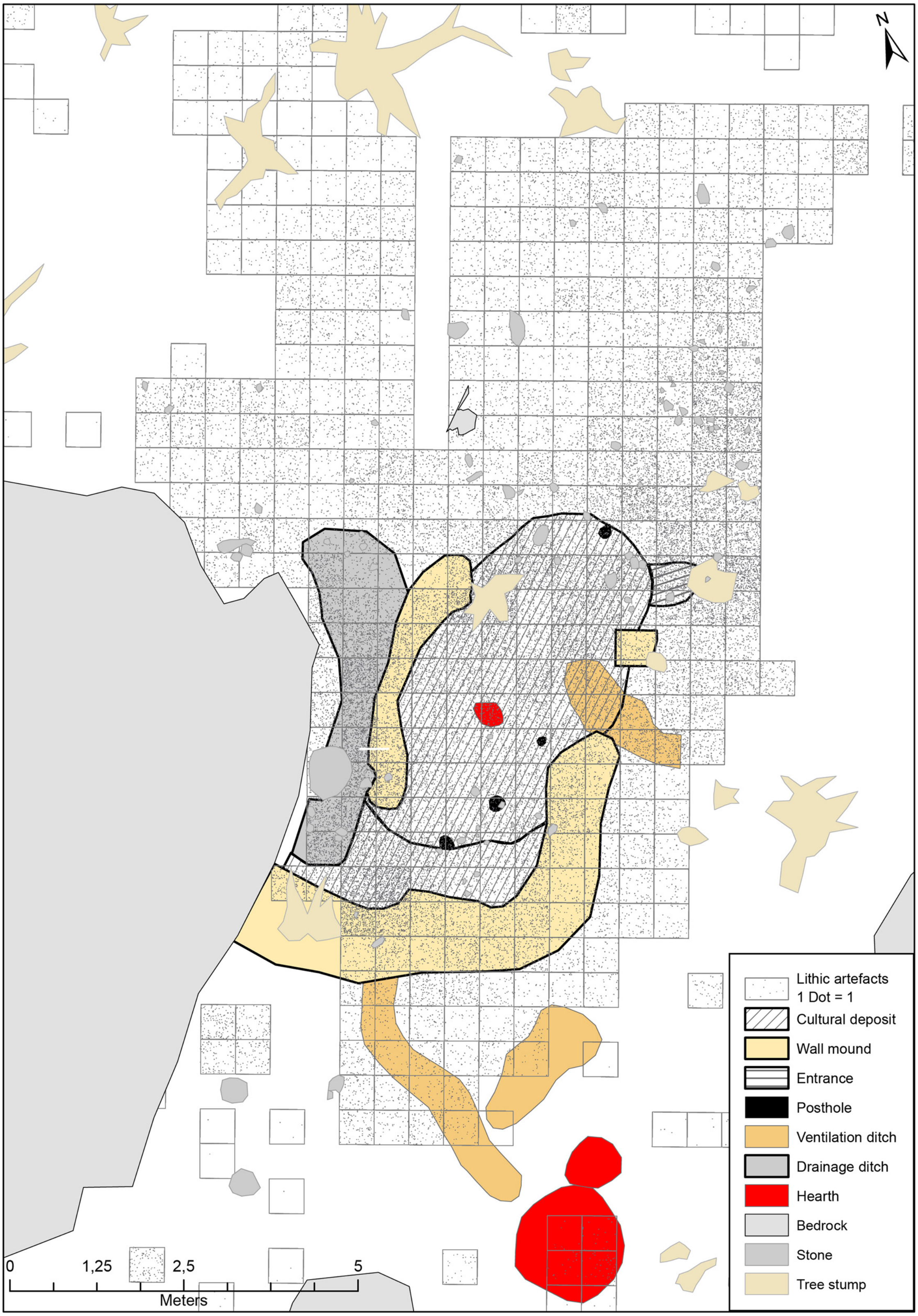

Figure 8: Interpretation of key features and artefact distribution uncovered during the excavation of Site 3 in Havsjødalen. Map: Axel Mjærum, MCH.

caused by the isostatic uplift in the area. It is likely that this stopped the migration of salmon up to Sandholmen, and today this anadromous fish can only reach the lower parts of Glomma. The youngest C14 sample from Sandholmen is, however, dated to *c.* 6100 BC, a time when the site was situated about 100 m away from the riverbank and 40 m above the past sea level. The location was then used as an inland site for approximately 1,000 years and long after salmon potentially disappeared from the area, and despite significant landscape changes (Mjærum & Mansrud, 2020).

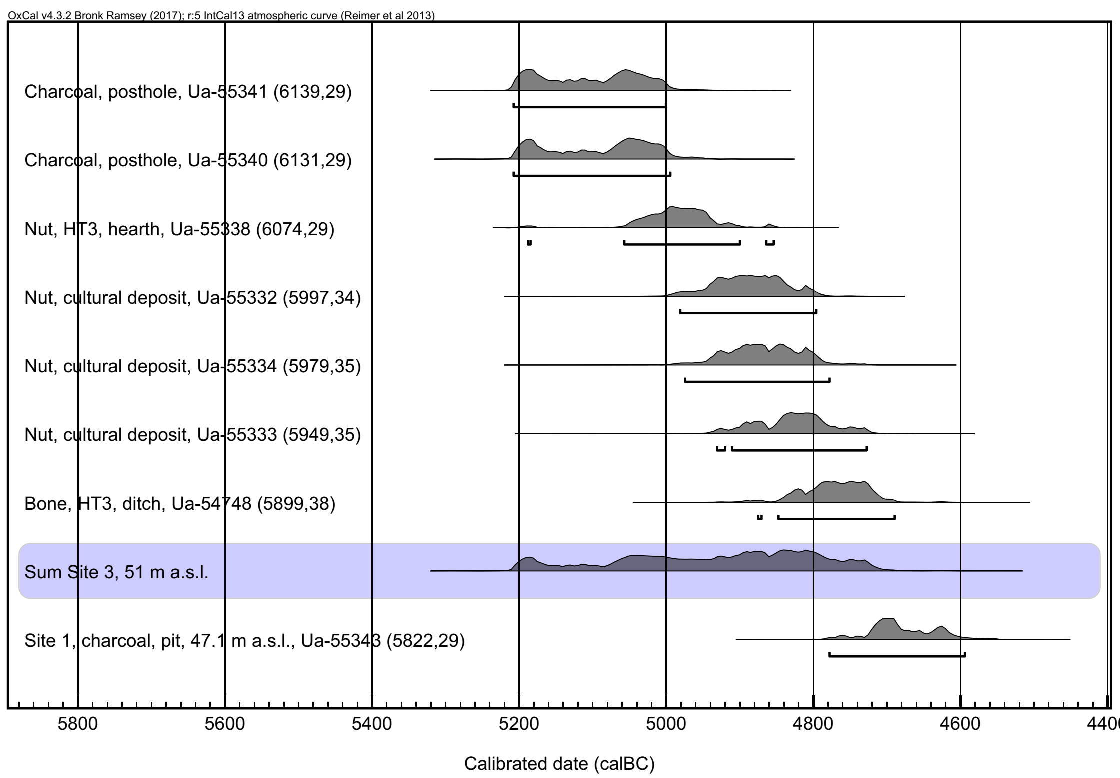

Figure 9: Radiocarbon dates from the sites in Havsjødalen.

This long-lasting continuity makes Sandholmen an extraordinary place in a regional setting, and it can be argued that it was not used mainly as a habitation area. Even if it lacks direct evidence of salmon fishing,[3] the central position of the site in its initial phase and the very large number of pit houses in the area make it plausible that fishing was an important cause for the establishment of the site, and potentially can it have been a meeting place with important social functions (Mjærum & Mansrud, 2020, pp. 285–288). At first, it was visited during the salmon fishing season, but later it retained its social importance long after the last salmon was caught at the site. In this way, the economic aspects of the site may have been subordinate to its social and cultural significance, in the same manner as the Church Town of Old Luleå, which can explain the continuity of use long after it lost its position along the seashore.

5 Adaptation Strategies on a Regional Level

The archaeological record thus points towards the conclusion that much of the same adaptation strategies to the regressing shores existed during the whole Mesolithic in the Oslo Fjord region (for a similar

3 Only a small part of the site has been excavated (Eigeland et al., 2016) and bones of salmon are seldom preserved in archaeological records from the region (Mjærum & Mansrud, 2020).

conclusion, see Roalkvam et al., 2020). This shared response of relocation and accommodation opens for a use of site counts at different altitudes as a proxy for the total activity/population in areas with changes in shore levels through time (cf. Breivik, Fossum, & Solheim, 2018; Jørgensen, Pesonen, & Tallavaara, 2020; Manninen, Tallavaara, & Seppä, 2018; Solheim & Persson, 2018). The large number of sites within a long time span also makes site counts a useful method to study population dynamics and the larger-scale effects of the shore level in the Oslo Fjord region.

Based on radiocarbon probability distributions and site count data, it has previously been concluded that in general there is no, or only a small accumulated, long-term population growth among hunters and gatherers (e.g. Boone, 2002; Shennan et al., 2013). However, environmental and economic changes commonly trigger boom and bust cycles (Bevan et al., 2017; Jørgensen et al., 2020). Is there any evidence for such cycles in the Oslo Fjord region, and what can the population dynamics tell us about adaptation strategies in the region?

In the western part of the Oslo Fjord, the land rise process has mainly transformed the micro topography in the coastal landscape from 7500 cal BC until recently, while the larger landscape forms were only slightly changed (Figure 4). Site counts per metre of height in Vestfjorden ($n = 200$) indicate approximately the same population size in 7000 and 4000 cal BC and a somewhat higher activity in the period in between.

A system of sounds was formed in the Bunnefjorden area *c.* 7500 cal BC, and this lasted until *c.* 5000 cal BC (Figure 4). Around 7500 cal BC there was also a large-scale, long-lasting boom in activity in Bunnefjorden, with a population that can have been as much as two to three times higher than in previous and later periods (Figures 10 and 11). The boom is statistically significant in the record from the Bunnefjorden area, and most likely affected the population in Vestfjorden as well. This result stands out compared with site counts performed in the other coastal areas of southern Norway, where the period from 7500 to 5500 cal BC has been identified as a period with stable or slightly fluctuating population size (Bergsvik, Darmark, Hjelle, Aksdal, & Åstveit, 2021; Solheim & Persson, 2018, p. 341). This makes it even more likely that the population boom which started *c.* 7500 cal BC was closely linked to the landscape changes in Bunnefjorden. In this way, the extensive data provide information about the close relation between the sites and the straits in Bunnefjorden that were already noticed more than 100 years ago (Brøgger, 1905; Hansen, 1904). The results thus confirm the large consequences that environmental changes could have on a regional level, and the close link between the development of settlements and the maritime environment.

The situation in the Neolithic (dated to *c.* 3900–1700 cal BC in the region) is volatile and needs to be commented on. Peaks 4000–3500 cal BC and 3000–2500 cal BC can partly be explained by a bias caused by the many sites that have been identified in some intensely surveyed areas in Bunnefjorden. The variations can also be understood as caused by the limited shore level displacement in this period, which indicates that a moving average calculation provides a better impression of the situation (Figures 10 and 11). However, there was in fact a complex interplay between coastal hunter-fisher-gatherers and inland farmers in the east Norwegian Neolithic (Nielsen, Persson, & Solheim, 2019), which can also very well have an added influence on the results. After the final breakthrough of a farming economy *c.* 2350 cal BC the majority of the settlements were moved inland, and in line with other studies the shore-bound settlements disappeared almost entirely from the archaeological record (Prescott, 2012; Prøsch-Danielsen, Prescott, & Holst, 2018; Solheim & Persson, 2018).

5.1 Maladaptation to a Changing Landscape

Approximately 5000 cal BC, Havsjødalen and the rest of the Bunnefjorden area was transformed from a centrally located, resource-rich sound area to a less bountiful environment between two fjords (Figure 4). Several sites are positioned in areas which became dry land just after the “sound phase” ended, such as site 1 in Havsjødalen. Based on the existence of such places, Glørstad (2010, p. 98) has previously argued that people chose to stay despite suboptimal conditions, held back by the long history these people had to the area. The compiled data set from the inner Oslo Fjord area offers an opportunity to study the adaptation strategies to this major event on a larger scale.

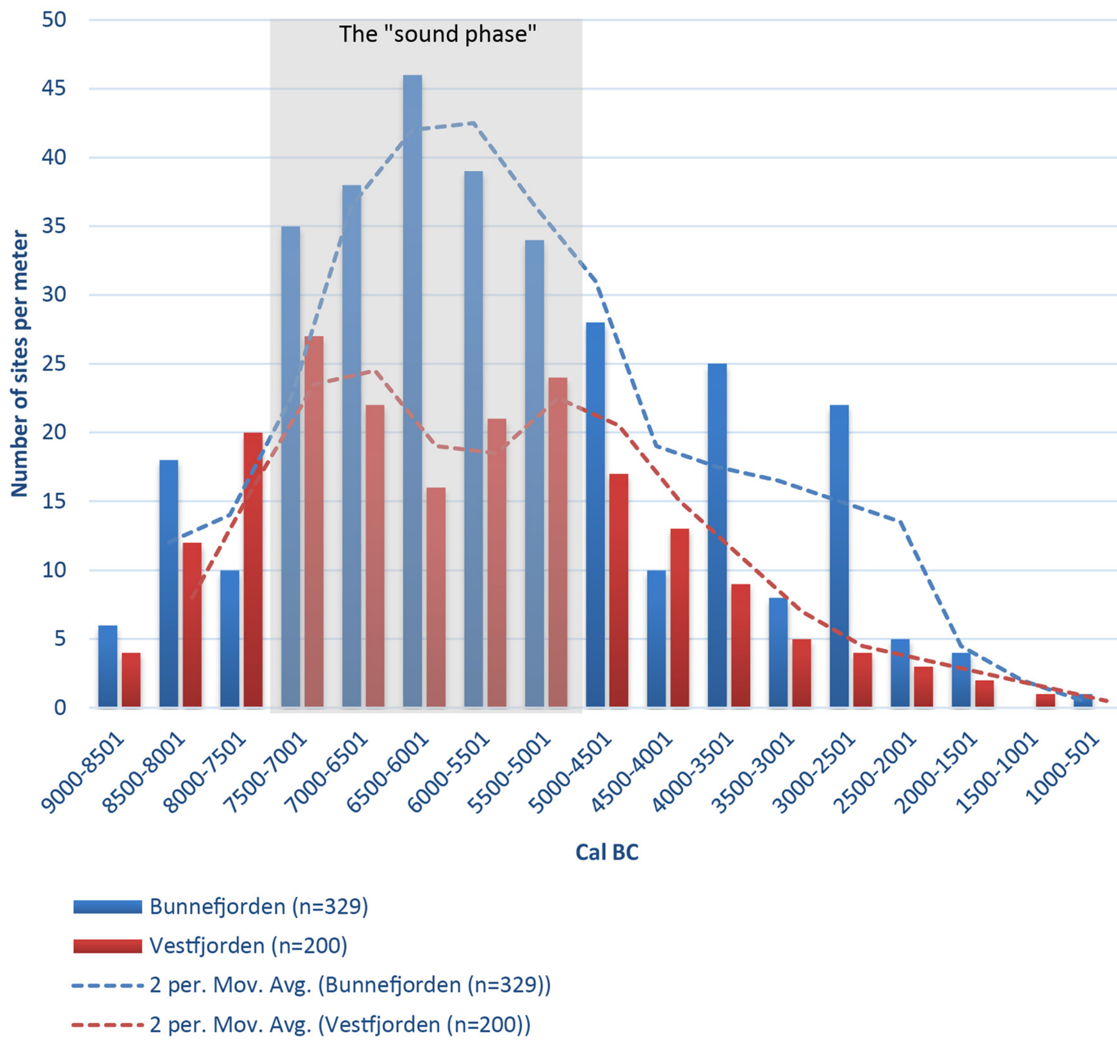

Figure 10: Number of sites in two parts of Inner Oslo Fjord distributed in 500 year intervals. The date of each site is based on the shore-level displacement curves.

In the Bunnefjorden area there are 34 sites dated to the period before this transition (5500–5000 cal BC), while the number of sites immediately after the end of the sound phase (5000–4500 cal BC) is only slightly smaller (n = 28). However, between 4500 and 4000 cal BC the number of sites is significantly reduced, as only 10 known sites fall into this timeframe. These changes are much less profound in the Vestfjorden area (Figures 10 and 11). It is hard to find reasons in the archaeological survey history of the region that can have caused a bias that can fully explain these numbers (cf. Amundsen, 2012; Damlien et al., 2021). Therefore, the explanation for these numbers is more likely closely linked the Mesolithic population's response to the landscape changes in the Bunnefjorden area.

At first, Bunnefjorden as a whole was little affected by this transformation, with large-scale activity continuing until *c.* 4500 cal BC. Even if the adaptation strategies worked on a site level (as discussed in the above paragraph), a bust *c.* 4500 cal BC points out that a mismatch occurred between the population size and available resources on a greater scale. The decline can then be understood as the effect of a period of severe maladaptation caused by sea level regression and landscape changes in the Bunnefjorden area between *c.* 5000 and 4500 cal BC.

As emphasized in the introduction section, it is difficult to adapt to environmental developments in situations where the economic, social, emotional, and cultural costs are high. While single Mesolithic sites were well adapted to the landscape, it was much more difficult for the settlement system to adjust. The

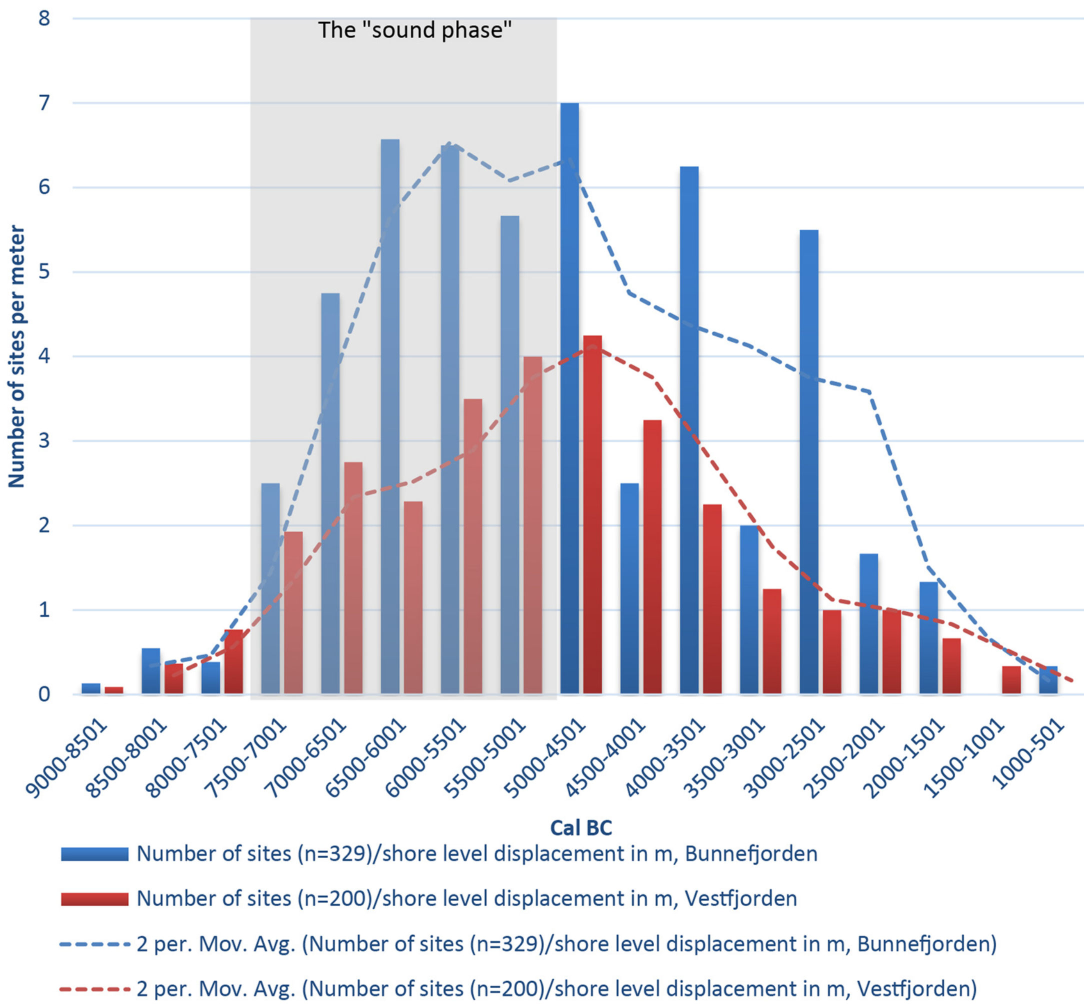

Figure 11: The number of sites in Vestfjorden and Bunnefjorden distributed in 500 year intervals and divided on the transgression rate in metres per interval.

2,500 year long population boom in the Bunnefjorden area took place in a period which, despite important changes and developments, was primarily characterized by a large degree of cultural continuity (Bjerck, 2008; Reitan, 2016). When the sounds disappeared from the region between 5400 and 5000 cal BC, it is therefore likely that there had been a relatively stable population in the area for multiple generations, who also had an affinity for the area (Glørstad, 2010, p. 98). The region was not only an area for hunting, fishing, and gathering but also a social arena, a place the inhabitants knew well with all its resources, histories, and myths, and the population was thus entrapped in the system (cf. Hodder, 2012, pp. 88–112). When viewed in this light, the decision to stay in the area is understandable, even if this was not an adequate response to the large-scale regional landscape upheavals. For large parts of the population in Bunnefjorden 5000 cal BC, it must have been difficult to totally abandon an area or find entirely new ways of living in order to respond to environmental changes. The phase of maladaptation did not end before the population in the region was reduced centuries later.

6 Concluding Remarks

The Mesolithic population in the inner part of what is now the Oslo Fjord in Norway was significantly affected by environmental changes, just as humans around the world are today, and as we will be to an even greater extent in the years to come. However, in the past, and in the future, adaptation is largely a matter of scale. Most of the Oslo Fjord's shore-bound Stone Age sites are the result of one or multiple short-term visits, and the activity could easily be relocated when the shores retreated. We also see that the activity in even the largest habitation areas was systematically accommodated or relocated when the distance to the shore became too long, commonly when the high-water mark had retreated to a few metres below the dwellings. Based on a modern rational perspective, we can thus conclude that the population routinely responded systematically and adequately to the region's shore level changes.

Nevertheless, we also see how a landscape upheaval *c.* 5000 cal BC affected the large-scale features of the topography in ways that required a bigger and more profound response. The excavation of the settlements in Havsjødalen gives an instructive illustration of how a society's lack of ability to respond on a larger scale led to a period of maladaptation in a landscape where some of the resource base had disappeared. In this case, the result was a regional population collapse.

In every way imaginable it is easier for a Stone Age population to adapt to environmental changes than it is for inhabitants in towns like Luleå and megacities like Jakarta. However, this study proves the difficulties even Mesolithic societies could have in accommodating changes that disrupted their deep-rooted social structures. In this way, it can be argued that the population in the former sound system of the eastern Oslo Fjord faced some of the same problems that we do today. For us to be able to handle ongoing global sea level changes it is not sufficient to find ways to mitigate the changing conditions. We also need to confront the causes of climate change. This requires us to make demanding decisions, to make global efforts and cut emissions. People in the past experienced difficulties in handling the need for large-scale shifts in their society, and in the same way we will also encounter similar problems when we face such challenges in the future.

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Appendix

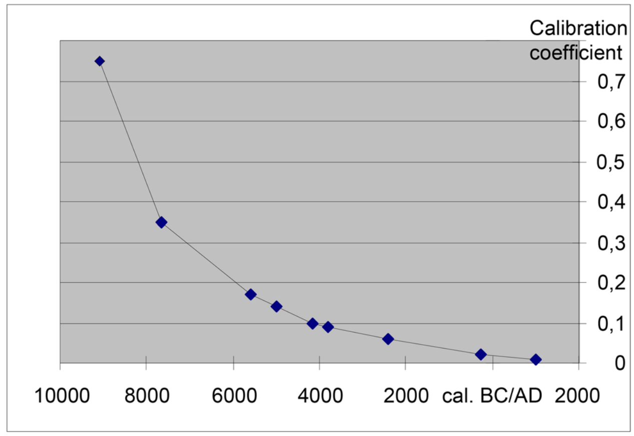

Figure A1: Sites in this article are dated by their position above present sea level and their distances to the “base-isobar” (Figure 3). The above calibration coefficient is applied to adjust for the spatial variance in shore level changes in the region through time. The plot is based on a study by Tore Påsse (2003, pp. 48–49, Table 42) and redrawn by Per Persson, MCH.

Table A1: Sites from before 7000 cal BC used to adjust the early part of the shore level displacement curve presented in Figure 5

Sites (cf. Figure 3)	Site names	Site ID	m a.s.l.	Methods for dating	Estimated age (cal BC)	References	Distance to base-isobar (km)	Relative height (cf. Figure A1)
1	Elgsrud 1	171112	194	Typological and based on a nearby radiocarbon dated natural shell bed (196–197 m a.s.l, Sørensen, 2015).	8900	Eymundsson (2015)	12	184
2	Roås/Ense 1	139240	137	Typological, shore level (based on information from Elgsrud 1), and two radiocarbon dates from a nearby surveyed site (134 m a.s.l, 8177–7738 cal BC, (8810 ± 40 BP, Beta-288432) and 8177–7738 cal BC (8810 ± 40 BP, Beta-288433).	8300	Eymundsson, McGraw, Nielsen, & Damlien (2018)	5	134
3	Roås/Ense 3 and 4	58970, 139239	130	Same as Roås/Ense 1	8200	Eymundsson et al. (2018)	5	127
4	Vinterbro-2016 1	160295	118	Typological and shore level (based on information from Elgsrud 1).	8000	Mjærum, Ødeby, & Havstein (2018)	3	116

Table A2: Radiocarbon dated sites from the study area. The heights of the sites are recalibrated in accordance with Figure A1. The dates have been applied to validate the shore level displacement curves used in the study (Figure 5)

Sites (cf. Figures 3 and 5)	Site names	Site ID	m a.s.l.	Dating materials	Lab no.	BP	SD	Cal BC (2 sigma)	Distance to base-isobar (km)	Relative height (cf. Figure A1)	Dates (cal BC) based on recalibration (cf. Figure 5)
A	Trolldalen	127451	75	*Betula*	Ua-49212	7977	44	7050–6701	−8	77	7000–6500
B	Trolldalen	127451	75	Nut (*Corylus*)	Ua-49209	7876	53	7028–6602	−8	77	7000–6500
C	Trosterud	27045	70	Charcoal	Tua-1549	7745	75	6753–6440	−4	71	7000–6500
D	Trosterud	27045	70	Charcoal	Tua-1548	7435	75	6444–6101	−4	71	7000–6500
E	Hyggen vest	89364	68	Charcoal	Tua-5896	7540	45	6467–6257	−10	71	7000–6500
F	Hyggen vest	89364	68	Charcoal	Tua-5897	7670	45	6597–6433	−10	71	7000–6500
G	Kvestad 3	16982	66	Nut (*Corylus*)	Tua-1547	7435	70	6442–6106	−4	67	6500–6000
H	Vassum	173454	60	Bone, cremated	LuS-15456	6725	40	5720–5560	−1	60	6000–5500
I	Vassum	173454	60	Bone, cremated	LuS-15457	6645	40	5635–5490	−1	60	6000–5500
J	Nøstvet	41534	57	Bone, cremated (*Mammalia*)	TUa-4602	6565	45	5616–5473	4	56	6000–5500
K	Vinterbro-krysset	22698	62	Deer antler	TRa-3965	6545	50	5617–5383	3	61	6000–5500
L	Storsand R54	62765	56	Charcoal	β-110232	6460	50	5508–5323	−10	58	6000–5500
M	Storsand R54	62765	56	Charcoal	β-110233	6450	50	5486–5321	−10	58	6000–5500
N	Havsjødalen 3	117996	51	*Quercus*	Ua-55341	6139	29	5210–5000	−1	51	5500–5000
O	Havsjødalen 3	117996	51	*Salix*	Ua-55340	6131	29	5210–4990	−1	51	5500–5000
P	Havsjødalen 3	117996	51	Nut (*Corylus*)	Ua-55338	6074	29	5025–4940	−1	51	5500–5000
Q	Havsjødalen 3	117996	51	Nut (*Corylus*)	Ua-55332	5997	34	4935–4840	−1	51	5500–5000
R	Havsjødalen 3	117996	51	Nut (*Corylus*)	Ua-55334	5979	35	4940–4800	−1	51	5500–5000
S	Havsjødalen 3	117996	51	Nut (*Corylus*)	Ua-55333	5949	35	4900–4780	−1	51	5500–5000
T	Havsjødalen 3	117996	51	Bone, cremated (*Mammalia*)	Ua-54748	5899	38	4876–4690	−1	51	5500–5000
U	Vinterbro 3	21302	67	Charcoal	T-13136	5905	105	5049–4520	3	66	6500–6000
V	Havsjødalen 1	62021	48	Charcoal	Ua-55343	5822	29	4730–4610	−1	48	5000–4500
W	Ekeberg	97724	49	*Betula*	Tua-5534	5820	55	4800–4538	18	47	5000–4500
X	Ekeberg	97724	46.5	*Salix/Populus*	T-17917	5645	80	4683–4631	18	44	4500–4000
Y	Ekeberg	97724	44	*Prunus/Sorbus*	Tua-5533	5505	45	4454–4263	18	42	4500–4000
Z	Ekeberg	97724	40	*Betula*	Beta-219418	5240	40	4229–3968	18	38	4000–3500
Aa	Ekeberg	97724	40	*Betula*	Beta-219416	5040	40	3953–3714	18	38	4000–3500
Ab	Ekeberg	97724	40	*Betula*	Beta-219417	4990	40	3815–3661	18	38	4000–3500
Ac	Havsjødalen-2013	117440	45	*Betula*	Ua-48227	4539	38	4330–4050	−2	45	5000–4500