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Submerged Mesolithic plant remains reveal lush thermophilous woodland on remote isle off the SW-Norwegian coast

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ABSTRACT

A palaeoecological multidisciplinary study from a well-preserved bark dominated structure and other organic sediments are presented. The study provides new data about Mesolithic coastal environments and includes a reconstruction of concurrent vegetation units, concluding that thermophilous woodland was established at the outer SW-Norwegian coast as early as 9000-8500 cal. BP. A pine bark dominated, possibly human made, structure was recovered from the former seabed at the Kvitsøy archipelago. The study involves various palaeoecological proxies, and synthesises results from soils, pollen, macro botanical remains, insect and mite analyses. The organic deposits are beach-derived, possibly trampled in sediments and includes abundant well-preserved waterlogged plant remains and arthropods. Species from the tidal zone are well represented, and upland taxa from fen and swamp communities, coastal heath and open woodland including *Pinus sylvestris* L., *Betula pubescens* L., and more warm demanding species such as *Malus sylvestris* (L.) Mill, *Crataegus* L., *Prunus padus* L., *Quercus* L., *Betula pendula* Roth, *Corylus avellana* L., *Alnus glutinosa* (L.) Gaertn and possibly *Ulmus glabra* Huds. and *Tilia cordata* Mill. Wild apples and hazelnuts were infested by the moth *Cydia pomonella* (L.) and the weevil *Curculio nucum* (L.) respectively. The beetle and mite fauna provides evidence of taxa associated with open coastal woodland and the tidal zone and driftwood. A large variety of edible plants are documented, of which seeds, fruits, roots, a.o., indicate the possibility of their seasonal collection from spring until late autumn. The plant and insect data provide additional evidence which could be associated with human impact. These results highlight the importance of integrated palaeoecological studies for establishing facts about past local environments and detecting slight human impact from this and similar contexts.

1. Introduction

Palaeoenvironmental studies at or near archaeological sites provide key information about flora and fauna related to human activity, climate change and past distributions of species (*e.g.* Panagiotakopulu, 2014, Gron and Rowley-Conwy, 2018, Birks, 2019; Panagiotakopulu and Sadler, 2021). Through several recent empirical studies, there has been a growing understanding of the importance of plants and vegetation in northern European Mesolithic hunter-gatherer-fisher cultures, not only through raw material exploitation and indirect influence, but possibly also through deliberate transformation of the botanical landscape in which they travel. Large-scale archaeobotanical and palaeoecological investigations of Mesolithic settlements in forested landscapes present convincing evidence that hunter-gatherers did take an active role in manipulating woodland by controlled fires, chopping, and possibly pruning (e.g., Bishop et al., 2015; Selsing, 2016, Blaesild et al., 2024). Such practices are, however, difficult to document in small settlements along the outer coast and on small islands where the vegetation cover is scarce, and inference of human impact depends more on the total quality of the material recovered from the individual site. Finds of tools or other artifacts of wood or other biological material may provide important information but are rarely found during regular archaeological

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excavations due to poor preservation conditions. The limited access to sites with good preservation conditions for organic materials is thus an important challenge. However, if microscopic biological material that can identify local ecosystems and plant communities is available, this will provide a plausible picture of the ecological conditions for human interactions with the environment. The geographical distribution of species is affected by a range of environmental factors with changing impact through time, of which human activity is one. The natural distribution range of a plant species is basically regulated by its physiological migration ability, the rate and type of environmental change and the adaption capacity of the species. Finds of plant and animal diasporas in palaeoecological records from sites at or near archaeological sites and ecological boundaries are thus important evidence of former distributional ranges.

Macro-botanical information, extracted from dry on-site archaeological investigations, depends largely upon the amount of preserved charred material and favours species with hardy seeds, typical of many agricultural species (Fuller and Lucas, 2014). The pre-agricultural archaeobotanical assemblages may for this reason be rather scarce. Supplementary pollen analysis will provide a wider range of floristic diversity of local and regional flora (e.g., Halvorsen and Hjelle, 2017; Jensen, 2020, Lechterbeck and Jensen, 2020). Yet, if well preserved waterlogged material is available from a site, identification utilising a larger set of characteristic criteria of the species is possible (Steiner et al., 2022; Bishop et al., 2022) and a more comprehensive picture of the local ecological communities of the past is achievable. Waterlogged biological remains with good stratigraphical and chronological control, like the ones presented in the present publication, are hence excellent information sources for isolated coastal sites and sites with low empirical human impact.

On sandy raised beaches, Mesolithic peat deposits may be exposed by repeated storm activity, and several such sites connected to human settlements have been investigated in Northwest Europe, like Westward Ho! in Southwest England (Balaam et al., 1987). Other sites are now below present water level, like Tybrind Vig in Denmark (Kubiak-Martens, 1999). Shoreline sites with natural waterlogged context are rare in Norway, due to disturbance or redeposition caused by sea-level changes or later human activity, and a generally steep and rocky coastline topography. Very few intact archaeological sites from the Middle Mesolithic have been excavated in South-Western Norway (Bang-Andersen, 1995; Skjelstad and Midtbø, 2011; Dugstad, 2022), and almost none with waterlogged material or other preserved organic material except for hazelnuts and charcoal. There is, however, an untapped potential for finding submerged stone age remains and waterlogged debris along this coastline (Nymoen and Skar, 2011). The colonization of the southwest coast of Norway is believed to have occurred shortly after the deglaciation. The mountain lake areas at 760 masl were used for seasonal hunting already at c. 8700 BCE (Bang-Andersen, 2006).

This study aims to provide new knowledge about the terrestrial environment on coastal islands used by Mesolithic hunter-gatherer-fishers, and to gain more information about species distribution in the early phase of forest establishment after the deglaciation. The southwest coast of Norway is at the border of the thermophilous forest distribution in Europe and a bioclimatic key area (Moen, 1999). The empirical basis is botanical, zoological and soil micromorphological data from a well-preserved Mesolithic bark dominated organic structure. It was recovered from the former seabed at Kvitsøy, SW-Norway and discovered by chance during an archaeological excavation in 2015. It provided new and partly unexpected knowledge of the natural environment and long-term, possible permanent use of the area in the Middle and Late Mesolithic times, i.e., 8100-6400 BCE and 6400-4000 BCE according to conventional dating of archaeological periods in Norway.

1.1. *Study area*

The Kvitsøy archipelago is in the outer part of the Bokna fjord, SW Norway (Fig. 1). The distance to the mainland south-east of Kvitsøy is approx. 10 km, and the same distance applies to the neighbouring large islands in the north (Karmøy) and northeast (Rennesøy). The archipelago is exposed to the open North Sea to the west and consists of around 170 islands and islets, the largest island covering an area of 2,3 km^3 with a maximum altitude of 24 masl.

1.2. *Geology and environment*

The bedrock of the archipelago consists mainly of slaty greenstone, with phyllite outcrops near the site, which is at the highest point (3.5 masl) of a 40–50 m broad N-S running sediment-filled former strait (Figs. 1 and 2). The minimum time since the deglaciation of the outer part of the Boknafjord region is estimated to be around 18 k cal. BP, based on radiocarbon dating of lake sediments on the southern part of Karmøy (Vasskog et al., 2019). Kvitsøy is located approximately at the same isobase for the Younger Dryas (YD) chronozone as the Relative sea-level (RSL) curve for southern Karmøy (Fig. 3, op. cit.). This curve includes two minima, 2–4 m below present sea level at around 13.8 and 10 k cal. BP, and two maxima culminating 5–7 m above the present sea level at around 12 ka and 8–7 ka, the last one known as the Tapes Transgression (Fjeldskaar and Bondevik, 2020).

The bark structure, which makes up the main part of the present investigation, was recovered at c. 1.5 m below the present topsoil, i. e. c. 2 m above present-day sea. The radiocarbon dated time span of c. 8200–6500 BCE (2 σ) (Table 1, Fig. 4) fits well with formation during the regression minimum phase, before full inundation of the site. In 2022, supplementary fieldwork was conducted 55 m to the south at 1 m depth. A well humified, semi-continuous peat layer of 5-10 cm thickness, and with wood and twigs from *Alnus (alder)*, was then recovered, and both bulk peat and wood were radiocarbon dated. The resulting age span was between 10300 and 8600 cal. BP (8400–6600 BCE), hence overlapping with the dates from the bark structure (Kilhavn et al. forthcoming).

The present day bioclimate is classified as boreonemoral, strongly oceanic with mild winters based on botanical criteria (Moen, 1999). Grassland pasture, heathland, and mires dominate the landscape, which is strongly influenced by long-term traditional sheep farming. The natural seashore consists mainly of bird manured rocks and gravelly and stony shores influenced by seaweed and other organic material washed onto the shore. A systematic survey of habitats and biological diversity in the Jærstrendene landscape conservation area was carried out in 2008 and 2010 (Jordal and Johnsen, 2009; Lundberg, 2010). The survey area covers the coastline south of the Boknafjord, including Kvitsøy and the smaller islets between Kvitsøy and the mainland. Much of the original vegetation has unfortunately disappeared because of farming activity.

1.3. *Archaeology*

The Kvitsøy archipelago is in a strategic position relative to present and ancient coastal traffic routes and easy access to rich marine resources, such as fish and marine mammals and nesting seabirds. Archaeological registrations document occupation over a long-time span in form of a rock shelter, possible house foundations, a megalith, burial mound, and a medieval church ruin. However, systematic scientific investigations on the natural history and archaeology were not performed until 2015, when the archaeological excavation providing basic data for this study was carried out (Dugstad et al., 2018). This was a cultural heritage investigation in connection with the planning of a new highway. Three Late Mesolithic settlements were excavated. They were located along the eastern brink of the former strait at an altitude of 6–11 masl. One of them with a paved floor and two with an earth floor correlated with a fireplace and cultural layers. Other finds reflecting sporadic occupation of the area dates to the Early Neolithic and Early

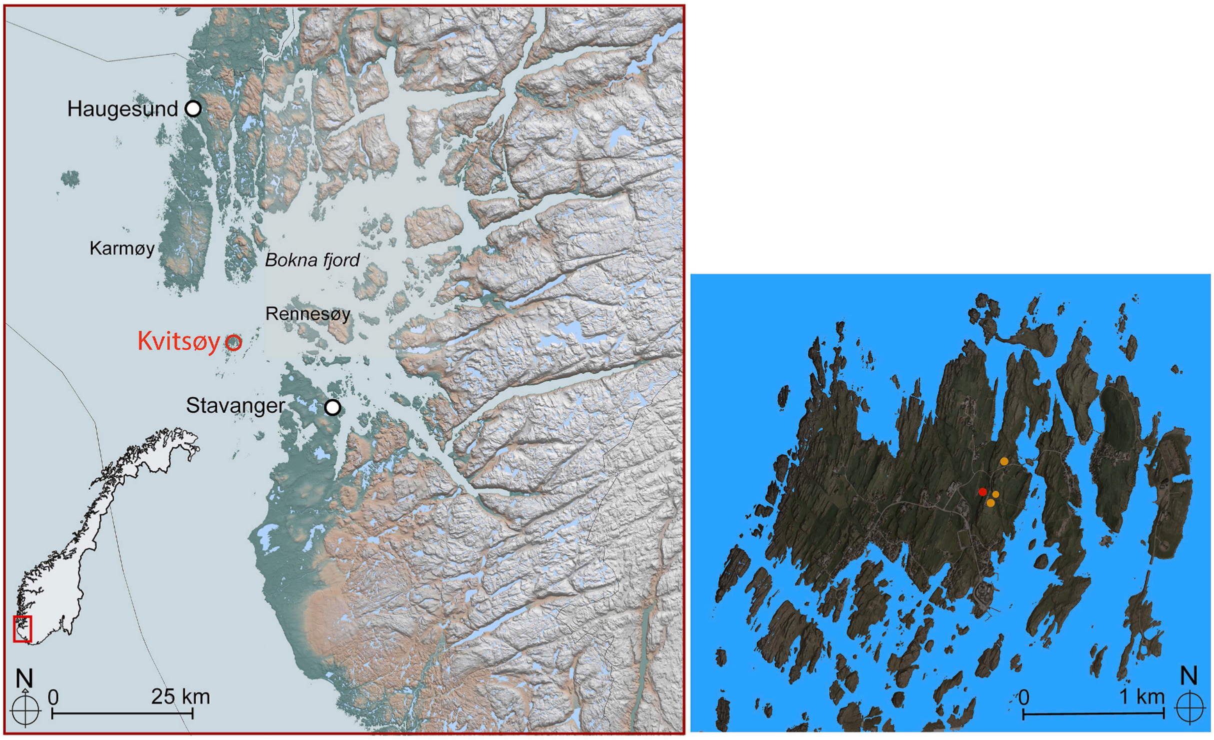


Fig. 1. Left: Map of Southwestern Norway and the Kvitsøy site (UTM: Sone 32V E 294556 N 6552859 or N59.0655° - E 5.4162). Right: Map of the Kvitsøy archipelago. Red dot: The Middle Mesolithic site of this study. Yellow dots: Late Mesolithic and younger sites. Maps: T. G. Bell, Am-UiS.

Fig. 2. Drone photo of the archaeological excavation site at Kvitsøy, Norway. Arrow marks where the Middle Mesolithic bark structure was recovered from the former seabed. View towards south. Photo: Am-UiS.

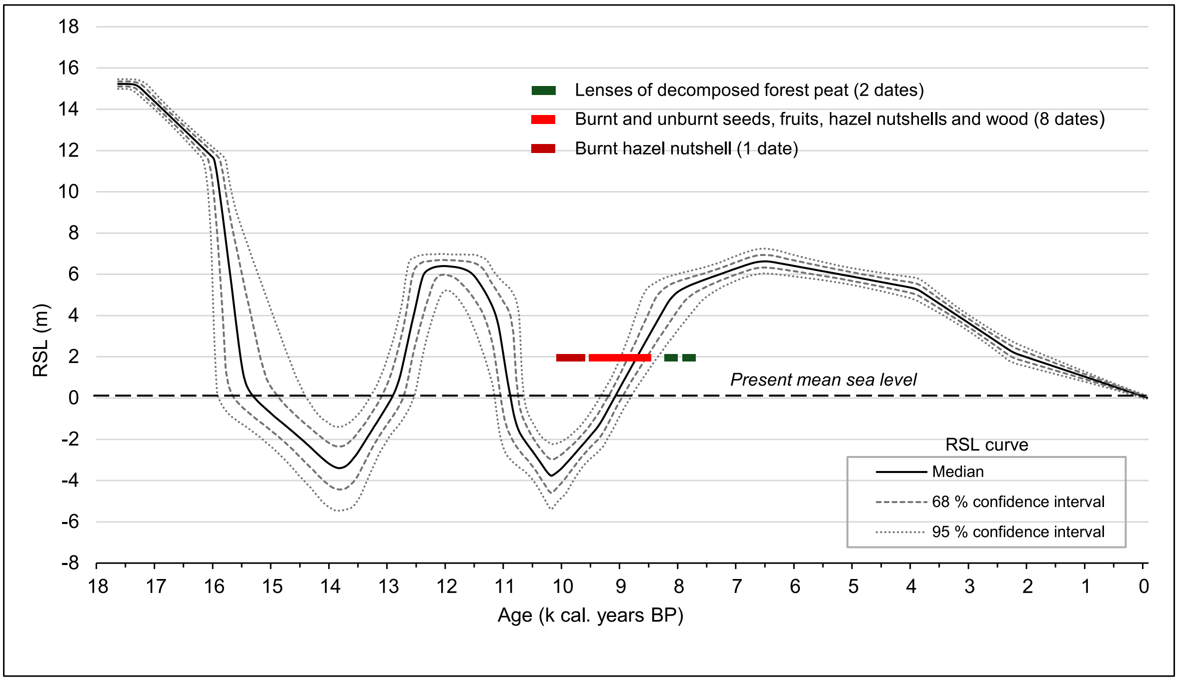


Fig. 3. Relative sea-level (RSL) curve for southern Karmøy (Vasskog et al., 2019), redrawn with permission from Vasskog. Radiocarbon dates from the present study at Kvitsøy are plotted on the curve.

Table 1
Radiocarbon dates of the bark structure and adjacent organic lenses at Kvitsøy, Norway. Calibration according to Intcal 20 Athmospheric curve (Reimer et al., 2020) using Oxcal v. 4.4.4 (Bronk Ramsey, 2021).

Lab. no	Material	Context Square/Layer/Sample	^{14}C yr BP ± 2 σ	Cal yr BP 2 σ	BCE 2 σ
Tra 11613	Highly decomposed organic sediment	Lense in marine sediment profile	7080 ± 25	7967–7845	6018–5896
Tra 11614	Highly decomposed organic sediment	Lense in marine sediment profile	7470 ± 20	8362–8195	6413–6246
Beta 610229	*Crataegus* unburnt fruit	Org. structure, 7929/L1/601	7850 ± 40	8970–8540	7021–6591
UB 32179	*Corylus* burnt nutshell	Org. structure, 7937/L1/158	7984 ± 40	8998–8650	7049–6701
UB 32180	*Corylus* burnt nutshell	Org. structure, 7937/L2/193	8310 ± 55	9465–9130	7516–7181
UB 32183	*Corylus* burnt nutshell	Org. structure, 7982/L2/183	8830 ± 46	10154–9692	8205–7743
Beta 425417	*Corylus* whole unburnt nut	Org. structure, 7937/L3/196	7810 ± 40	8716–8454	6767–6505
UB 32181	*Corylus* burnt nutshell	Org. structure, 7937/L3	8320 ± 44	9463–9140	7514–7191
UBA 40317	*Atriplex* unburnt seeds	Org. structure, 7978/L4/201	7913 ± 33	8980–8599	7031–6650
UB 32182	*Pinus* wood, unburnt phloem	Org. structure, 7962/L4	7993 ± 44	9003–8650	7054–6701
Tra 11615	*Pinus* wood, burnt phloem	Org. structure, L5	7925 ± 25	8979–8606	7030–6657

Bronze Age as well as Iron Age and medieval times.

The site of the present investigation in the former strait was selected as a place to trace midden deposits originating from the upland Late Mesolithic settlements and if possible, remains of transgressed Mesolithic settlements through a minor investigation. The investigation was however, significantly expanded by the finds of submarine lenses of strongly decayed organic sediments and a large, isolated bark dominated structure of approximately 12 m^2 buried 10–20 cm below that, confirming the potential of a transgressed terrestrial land surface and onsite human activity. The excavation included a N-S longitudinal trench (1,5 m deep), across the highest point and with two E-W transverse trenches on either side (1–2,6 m and 2,3 m deep) extending towards the centre of the former strait (Figs. 5 and 6). Additionally, an area surrounding the bark structure was uncovered and investigated through test pits. Altogether, an area of 210 m^2 was investigated.

The bark structure has several characteristics that indicate a human construct, like the form and shape of a sitting- or sleeping-mat and presence of burnt flint, burnt and unburnt hazelnuts, charcoal fragments and partly burnt wood (Dugstad, 2022). It was excavated as one unit, and dated to the Middle Mesolithic period, but it has been modified by subsequent wave activity and erosion due to sea level changes. This makes interpretation challenging and it is difficult to ascertain whether it in fact was a man-made structure and whether it was *in situ*. However, burnt, and processed flint finds of the Middle Mesolithic are in themselves evidence that the site was used by hunter/gatherers. The preliminary botanical studies showed that good terrestrial resources were also available throughout the period (Dugstad et al., 2018). More analyses have subsequently been carried out in the present interdisciplinary research project, providing a more solid empirical base for the interpretation of locally available natural resources and any human influence on the environment.

2. Material and methods

Altogether 69 soil samples from the bark structure were analysed with respect to plant macrofossils and 8 for invertebrates, 11 for pollen, and two for soil chemistry and micromorphology (Table 2). In addition, 6 pollen samples from two of the peat lenses found stratigraphically above the bark structure have been analysed (Figs. 5 and 7).

2.1. Sampling in field

The entire bark structure was divided into 1 m^2 squares, which were then subdivided into four 0.25 m^2 sub-squares (Fig. 8). Soil samples for

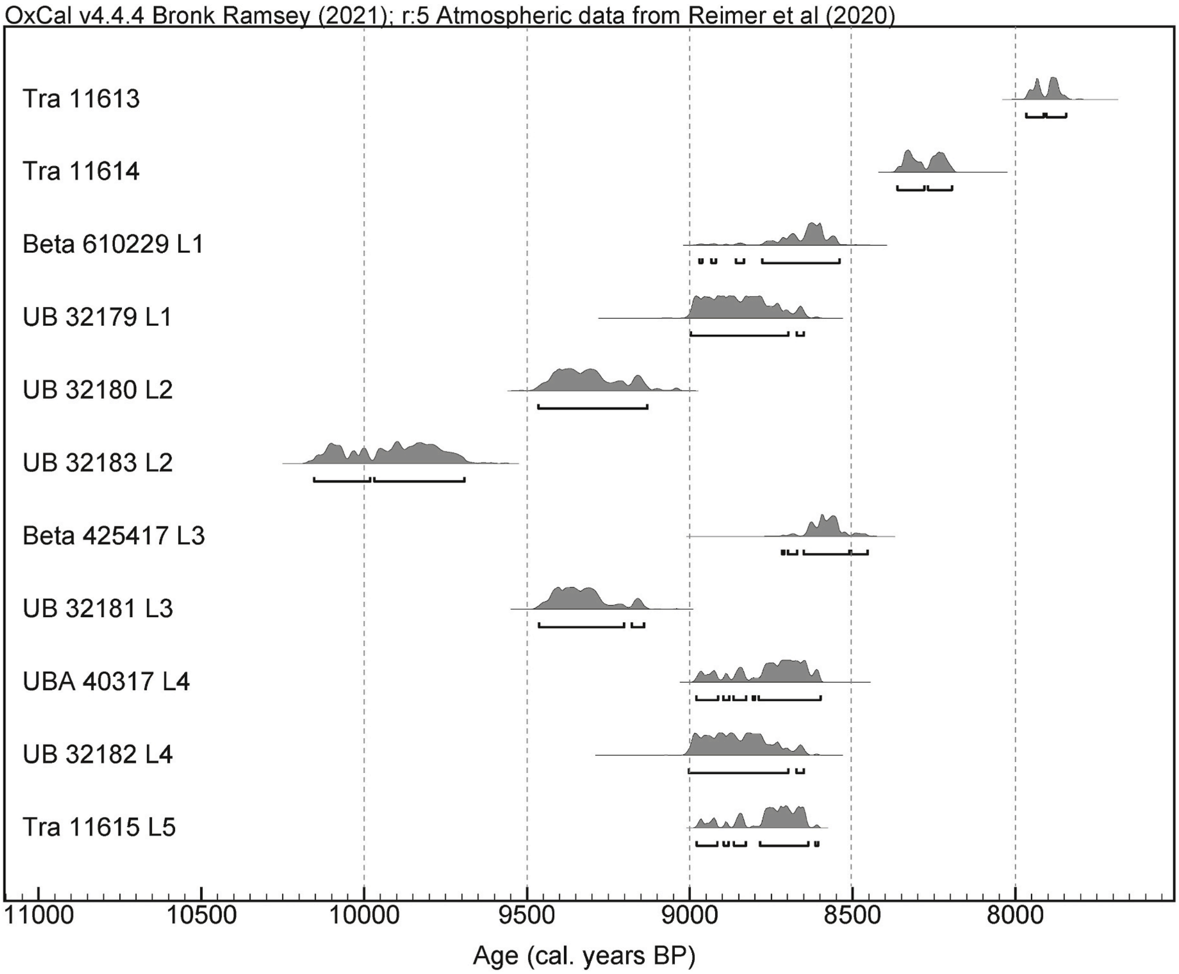


Fig. 4. Calibrated radiocarbon dates from organic lenses (Tra 11613 and 11614) and the bark structure with information about layer (L 1–5) added) at Kvitsøy, Norway.

laboratory analyzes (sample volume 0.5 L) were collected systematically from every represented layer in the southwestern corner of each subsquare. Due to the differing extent of the layers, not all were evident in all the squares (Fig. 8). From the remaining parts of the squares a soil sample was sieved in the field through a 2 mm mesh (sample volume range 3–22 L). Soil micromorphology, chemistry and magnetic susceptibility were carried out on a monolith sample derived from the SW part of the bark structure (Fig. 7), covering bark layers L1, L2 and L3. Pollen samples were taken with small glass test tubes directly from cleaned cut surfaces of soil profiles, the monolith sample and from lumps in soil samples before wet sieving.

2.2. *Laboratory treatment*

2.2.1. *Radiocarbon dating*

All ^{14}C dates has been carried out using AMS technique on identified charred plant material or organic matter sediment (bulk), interpreted as of terrestrial origin, and performed by the laboratories Beta Analytic Radiocarbon dating, CHRONO Centre Queens University Belfast and National Laboratory for Age Determination, Trondheim (Table 1). Nine out of 11 dates are on selected plant macrofossils from the bark structure, with the purpose of covering the complexity of the structure in terms of stratigraphical layers, horizontal spread and mixture of burnt and unburnt hazel nuts, pine wood and the characteristic fruits of *Crataegus* (hawthorn) and *Atriplex* (saltbush). The latter plant genus inhabits the marine tidal zone and thus indirectly dates the period when sea level reached the site.

Calibration is based on the Intcal20 atmospheric curve (Reimer et al., 2020) by means of Oxcal v 4.4.4. (Bronk Ramsey, 2021).

2.2.2. *Bulk soil chemical and physical properties*

A five-parameter analysis routine was applied throughout the study (6 bulk samples analysed). It has been developed and adapted for soil prospection and bulk analysis of occupation soils and features. Analysed parameters comprise organic matter (loss on ignition [LOI], Carter, 1993), two fractions of phosphate (inorganic [Cit-P] and sum of organic and inorganic [Cit-POI], Engelmark and Linderholm, 1996; Linderholm, 2007) and magnetic susceptibility (MS-χlf) and MS550 (Clark, 2000; Linderholm, 2007; Engelmark and Linderholm, 2008). These analyses provide information on various aspects concerning phosphate, iron and other magnetic components and total organic matter in soils and sediments, and its relationship to phosphate (Viklund et al., 2013).

2.2.3. *Soil micromorphology*

The undisturbed monolith samples were impregnated with a clear polyester resin-acetone mixture, ahead of curing and slabbing for 75x50 mm-size thin section manufacture by Spectrum Petrographics, Vancouver, Washington, USA (Murphy, 1986; Goldberg and Macphail, 2006). The thin section was further polished with 1000 grit papers and analysed using a petrological microscope under plane polarised light (PPL), crossed polarised light (XPL), oblique incident light (OIL) and using fluorescence microscopy (blue light – BL), at magnifications ranging from ×1 to x200/400. Thin sections were described, ascribed soil microfabric types (MFTs) and microfacies types (MFTs) and counted

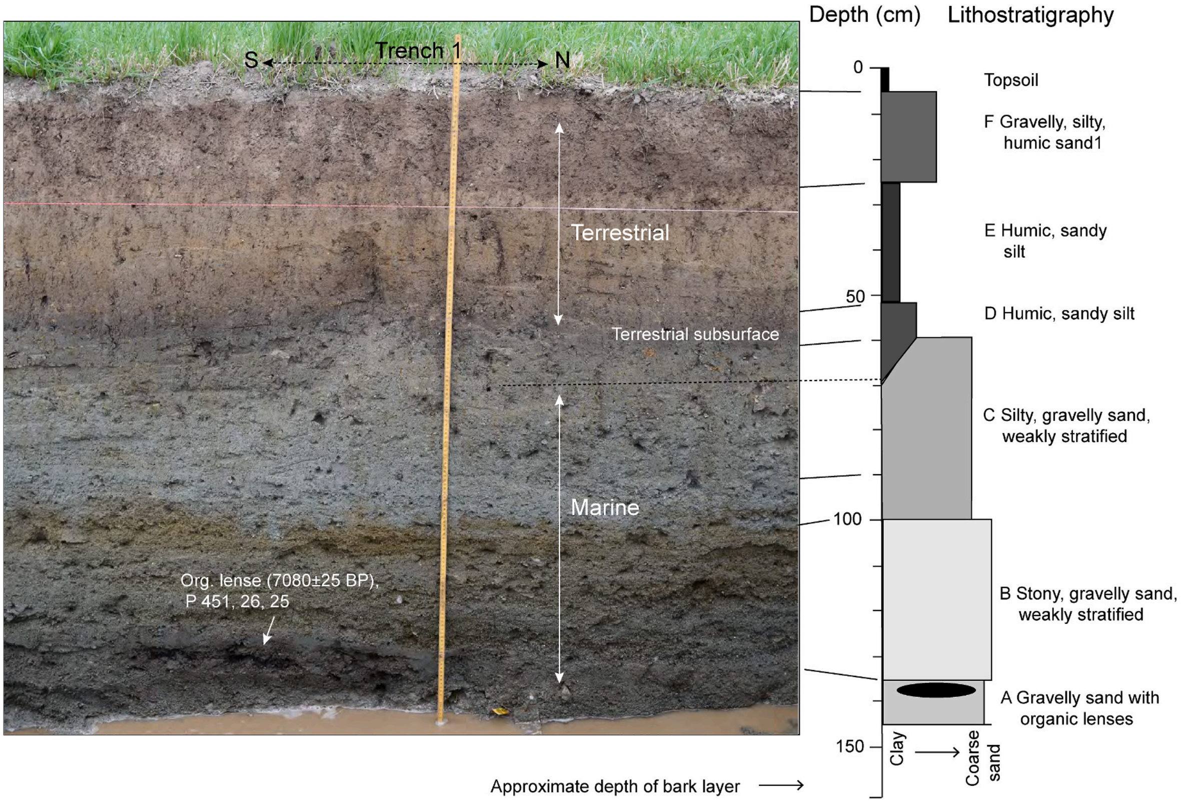


Fig. 5. Lithostratigraphy of the sediment profile of trench 1.

Fig. 6. The sampling site in the former seabed at Kvitsøy, Norway, with the exposed Middle Mesolithic bark structure before sampling. Position of Late Mesolithic organic lenses to the left. Photos: Am-UiS.

according to established methods (Bullock et al., 1985; Courty et al., 1989; Courty, 2001; Macphail and Cruise, 2001; Stoops, 2003; Stoops et al., 2018).

2.2.4. *Pollen analysis*

Soil samples with a volume of 1 cm^3 were treated with 37.5% HF (hydrofluoric acid) to remove mineral particles, then prepared according to the standard acetolysis method as described in Fægri and Iversen (1989). Material <0.25 mm is taken care of by this method. As only a proportion of the sample is analysed, 2 tablets *of Lycopodium clavatum* (L.) spores (batch 483216 Lund University, Sweden) were added before the acetolysis to calculate the concentration of pollen and other microfossils in the entire sample (Stockmarr, 1971). Pollen identifications are based on Fægri and Iversen (1989); Moore et al. (1991) and Beug (2004) as well as the modern reference collection at Archaeological Museum, University of Stavanger (AM-UiS). Nomenclature mainly follows Fægri and Iversen (1989). Numerical calculations and production of pollen diagrams have been carried out using the computer program Tilia version 3.0.1 (www.TiliaIT.com).

2.2.5. *Macrofossil analysis*

Wet-sieving was carried out using four mesh sizes (>2 mm, 1–2 mm,

Table 2
Overview of analysed squares from the Middle Mesolithic bark structure at Kvitsøy, with numbers of analysed samples per square, as well as numbers of observed taxa of plant macrofossils, pollen types, insects (mainly Coleoptera) and arachnids (soil mites). Please note that all samples are analysed for plant macrofossils, while only preselected samples are analysed for pollen, insects, and mites. Empty cells mean no analysis.

Square	Layers	Volume litre	Sieved fraction	Samples, numbers	Plant macro (charred)	Pollen	Insect	Mite
7909	L2	5	>2 mm	1	1			
7921	L3	5	>2 mm	1	6			
7925	L2, L3, L4	21	>0.25 mm	4	17 (1)	21	4	
7929	L1, L4	17	>0,5 mm	4	10 (2)			
7933	L1, L2, L4	20	>2 mm	3	4 (1)			
7937	L1, L2, L3, L4	26.5	>0.25 mm	8	19 (3)		1	
7941	L1, L4	22	>2 mm	2	5 (1)			
7945	L1	8.5	>0,5 mm	2	15 (2)	28		1
7949	L1	5.0	>2 mm	1	3 (1)			
7954	L1, L2	18.5	>0.25 mm	4	18 (1)	21		
7974	L2	0.5	>0,5 mm	1	1			
7978	L2, L4	20.5	>2 mm	3	13 (1)			
7982	L2	14.5	>0.25 mm	2	10 (2)			
7986	L4	20	>2 mm	2	4 (1)	25		
7990	L2, L4	32.5	>0,5 mm	4	12	22	1	4
8002	L2, L4	4.5	>0,5 mm	2	23 (1)	20	5	5
8006	L2, L4	17.5	>0,5 mm	3	20 (1)	22		1
8010	L2, L4	32	>2 mm	2	7 (1)			
8014	L2	5.5	>0.25 mm	2	14	23	5	0
8026	L4	0 5	>0,5 mm	1	17 (1)		4	1
8042	L4	5.0	>2 mm	1	3			
8058	L4	0.5	>0.25 mm	1	5 (1)			
8074	L1	9.0	>2 mm	1	2 (1)			
8078	L1, L2s	11.5	>0,5 mm	2	8 (1)			
8082	L1	8.5	>0.25 mm	2	15 (1)			
8086	L4	6.0	>2 mm	1	4			
8106	L1	5.0	>2 mm	1	2 (1)			
8118	L2	5.0	>2 mm	1	2 (1)			

Fig. 7. Sampling of a sediment monolith from the bark structure for soil micromorphology and pollen analyses.

0.5–1 mm, 0.25–0.5 mm) and samples stored in distilled water in cold storage at the AM-UiS. The identification of plants was made with the help of literature (Beijerinck, 1947; Cappers et al., 2006), the reference collections of modern fruits and seeds at AM-UiS, and the Herbarium of the University of Turku. In addition to the plant macrofossil analysis, several other materials such as charcoal, burnt bones, sclerotia, insects, soil mites, annelids, earthworm cocoons and artifacts, were noted. The insect and mite material were recovered from the small samples of only 0.5 L. As the optimal sample size for fossil insect remains is 5 L, the assemblages recovered were small, the specimens fragmented, and the results therefore limited. The insect remains were identified using entomological keys and modern comparative material, including the Osborne insect collections in the School of GeoSciences, University of Edinburgh. The taxonomy of Coleoptera follows Böhme (2005). Selected charcoal material was analysed for wood type taxa by using published literature (Schweingruber, 1990) and the wood reference collection at AM-UiS for identification.

2.3. Data handling

There is a difference in sieving technique between macrofossil samples collected for laboratory analysis and the ones sieved in field, which has impact on the outcomes of the analyses. This, and the general complexity of sampling levels and subsequent subjective selection of

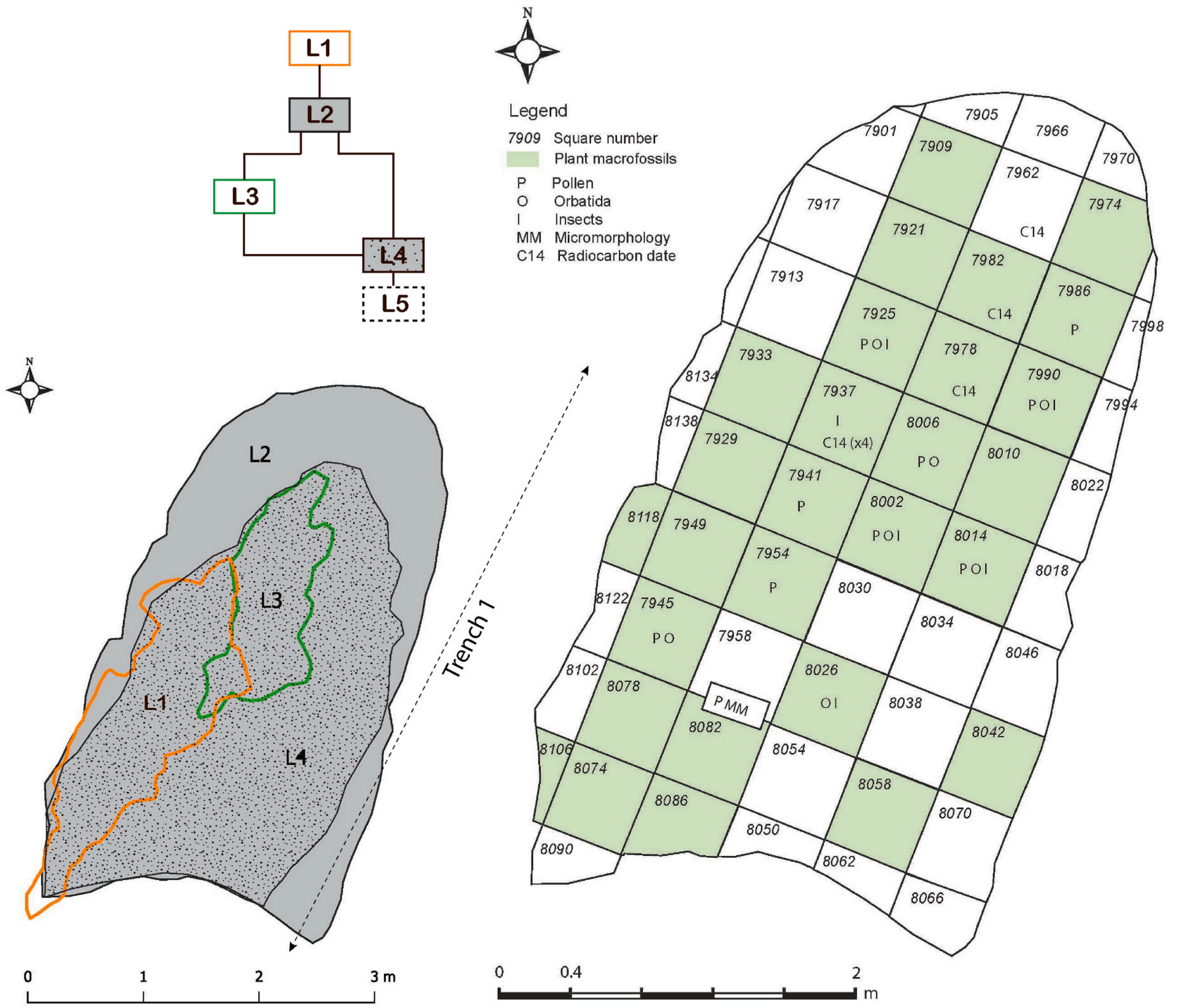


Fig. 8. Left: Plan of the isolated bark structure at Kvitsøy, Norway, with the four bark dominated layers superimposed. Above is a vertical matrix showing the relative position of the layers. Right: Overview of analysed squares (green colour) with annotations on type of analysis. See Table 2 for more information about sample context.

samples for analysis, is taken in account in data processing. The low number of samples analysed for invertebrates (insects and mites) did not allow these specimens to be included in statistical analyses. All plant macrofossil data are standardised so that they show observed numbers per 10 L soil volume. Only taxa that are identified to species, genus or family level are included. To look for any ecological or environmental trends in the plant macrofossil data of the bark structure, ordination technique was carried out separately on the material sieved in field (>2 mm) and in the laboratory (0.25- > 2 mm) using Canoco ver 5 (Ter Braak and Smilauer, 2012). An initial Detrended Correspondence Analysis (DCA) using detrending by segments, showed a gradient length well below 4 SD units along the first axis, indicating a linear response. Consequently, Principal Component Analysis (PCA) was preferred. Carbonised plant macrofossils were treated as independent supplementary variables.

3. Results

3.1. Sediment stratigraphy and radiocarbon dating

The sediment stratigraphy down to ground water level at c. 150 cm was uncovered in trench 1 which runs parallel to the direction of the former strait in a N-S direction (Fig. 5). A terrestrial subsurface at ca. 50–60 cm below the topsoil was documented by pollen analysis and correlated with similar subsoil layers in other soil profiles of the investigation area interpreted as possible Bronze age (Dugstad et al., 2018). Directly beneath this subsurface, thick marine deposits prevailed (Fig. 5). The boundary between layer B and C is more clearly defined with gravel and cobbles further south in the trench, and assumed to represent the maximum of the Tapes transgression, c. 7500 cal. BP. Within the bottom layer A, a lense of humified organic sediment was recovered and radiocarbon dated as Late Mesolithic, 7080 ± 25 BP (Table 1, Figs. 4 and 5). Pollen analysis shows that this is terrestrial soil, likely representing rip-off clasts from a forest floor. Uncovering the area west of trench 1, several similar organic lenses were observed at approximately the same stratigraphic level. The organic sediment of one of these lenses is radiocarbon dates as 7470 ± 20 BP (Figs. 4 and 6, Table 1). A cobble and boulder layer was recovered directly above the level of this organic lense (Fig. 6), and seems to be part of a fanlike layer extending c. 120 m southwards. Radiocarbon dating of charcoal beneath and above the cobble and boulder layer at the southern border of it, rendered ^{14}C-dates in reversed order, indicating erosion. Charcoal samples beneath the layer was dated as 5200 ± 30 BP and 4120 ± 30 BP, while the one sample from above the stone layer was dated to 5240 ± 30 BP. The event presumably resulting in a rock fall, by e.g. frost weathering, may be fixed to the time span covered by the three ^{14}C-dates, sometime between Late Mesolithic and Middle Neolithic. Whether this event had a causal relationship with the formation of the organic clasts requires further investigation.

The bark structure, which is the main object of investigation in this study, was recovered 10–20 cm below the level of the organic lenses (Fig. 5). The southern tip of the structure tangents trench 1 (Fig. 8). The structure consisted of four bark-dominated layers (L1-4), with fine grained sand in between the layers and underneath the structure. The layers had different extent, thickness and degree of preservation which could be clearly distinguished in the field (Figs. 7 and 8). In addition, pieces of bark, charcoal, small logs, and sticks were found in a less clearly defined bottom layer (L5). Some of these were examined for chop marks, but without positive results. The dating of the bark structure span from c. 10150 cal. BP to c. 8450 cal. BP, with most dates between c. 9000 and 8450 cal. BP, placing it convincingly within the Middle Mesolithic period. A collection of unburnt fruits from the shore bound plant species *Atriplex* was ^{14}C-dated as c. 8980 to 8600 cal. BP.

3.2. Soil micromorphology, chemistry, and magnetic susceptibility

3.2.1. Soil micromorphology

Seventeen major characteristics were identified and counted from three major layers represented in two thin sections from 2 bulk samples:

M411B: The lower sample is dominated by poorly sorted fine and medium sands, containing coarse sands and gravel, and containing a fine organic component with frequent fragments or burrow fills of microlaminated humic silts and fine sands, and very few fine clasts of black peat (Fig. 9A). Common fine angular gravel (max 10 mm), with sand-size clasts of humic silts, abundant black woody bark fragments (max 5 mm) and rare traces of fine charcoal (max c. 1 mm), occur. Many probable broad narrow burrows, and occasional probable thin organic excrements were observed.

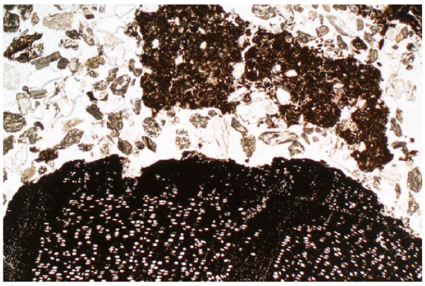
This is a moderately poorly sorted sandy and gravelly substrate of possible beach origin, with large amounts of fragmented bark inclusions. Burrow-fragments and burrow fills of microlaminated humic silts testify to flooding/inundation in a wetland environment. The sands and gravels have been disturbed by invertebrate burrows, but it is also conceivable that fragmentation of bark partially occurred through trampling (Rentzel et al., 2017).

M411A: Upwards, there continues to be dominant poorly sorted fine and medium sands, containing coarse sands and gravel, and a fine organic component, with few burrow fragments or burrow fills (e.g. at 0–5 mm) of microlaminated humic silts and fine sands, and few fine fragments of black peat, especially at 40–75 mm depth (Fig. 9B). There are many fine woody bark fragments (max c. 1 mm) and rare both fine and coarse wood charcoal (max 6 mm), with possible examples of charred peat. Many probable thin and broad burrows, and occasional very thin organic and broad organic excrements, sometimes containing silt and fine sand, occur. Upwards, there is a slight increase in charcoal content, with diminishing amounts of bark fragments. The inclusion of peat clasts also suggests such wetland deposits were nearby. Again, trampling may have led to sands containing tracked-in finely fragmented bark and peat.

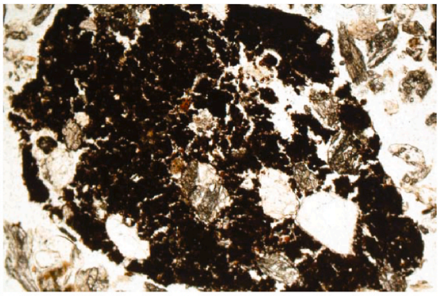
3.2.2. Five parameter bulk analyses

The 411A-411B sample revealed no magnetic susceptibility enhancement evidence of burning (MS = 15–16 χ lf 10-8m3 kg-1) and proxy indicators of low amounts of iron present (MS550 = 14–28 χ lf 10-8m3 kg-1). These sands, however, contain moderately small amounts of organic matter (2.0–3.4% LOI) and phosphate (400–450 ppm CitPOI), the latter in a mainly inorganic form (PQuota = 1.0–1.2). These data reflect the generally iron-depleted nature of the sands, with small peaks

a: Scan of M411A; silts, sands and fine gravel, with examples of charcoal (Ch; Fig b), peat (P; Fig c) and broad burrows (B). Frame width is ~50mm.

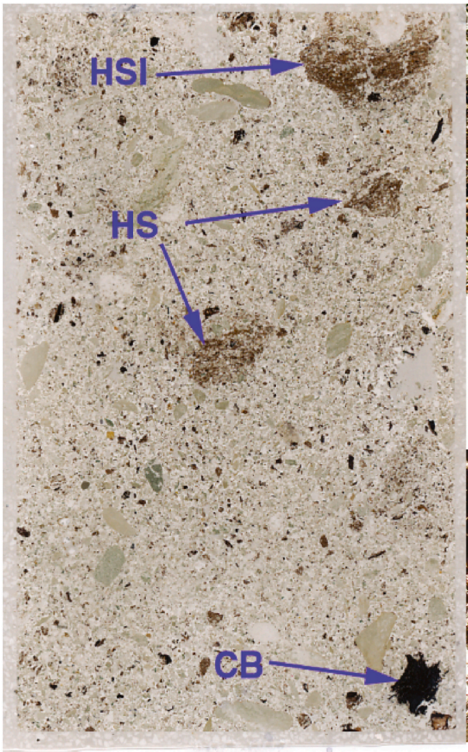


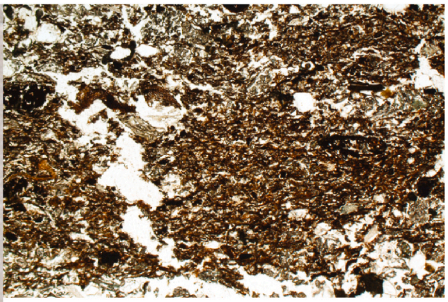
b: Photomicrograph of M411A; coarse wood charcoal, sands and fragment of bioworked organic sediment. PPL. Frame width is ~4.62mm



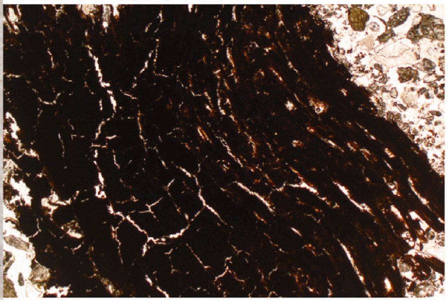
c: Photomicrograph of M411A; fragment of peat soil with embedded silt and fine sand. PPL. Frame width is ~2.38mm.

Fig. 9. AB: Micromorphology results from sample M411A (above) and M411B (below) of the Middle Mesolithic bark structure at Kvitsøy, Norway. Depth overview of the scanned sample (a) and exaggerated details (b and c).





b: Photomicrograph of M411B; microlaminated humic silts infill (HS in fig. a), with horizontally oriented (detrital) plant fragments, PPL. Frame width is ~4.62mm.



a: Scan of sample M411B; silts, sands, and gravels with fine bark fragments as well as an example of coarse bark (CB), burrow infills of humic silts (HS) and humic silt inwash (HSI). Frame width is ~50mm.

c: Photomicrograph of M411B; bark – possibly partially decayed – 'blackened' (CB in fig. a). Plane polarised light (PPL). Frame width is ~4.62mm.

Fig. 9. (*continued*).

in organic matter and phosphate content, possibly recording trampling-in of organic occupation material.

3.3. *Botanical data*

3.3.1. *Pollen and plant macrofossils*

From the bark structure, waterlogged plant macrofossils are most abundant. A total of 48 taxa were identified to species or genus level. Apart for *Corylus* (hazel) nuts of which nearly half of the nutshell fragments are carbonised, only single carbonised seeds of *Veronica serpyllifolia* L. (thymeleaf speedwell), *Arctostaphylos uva-ursi* (L.) Spreng. (common bearberry) and *Rosa* cf. *canina* L. (dog rose) are recorded, in separate layers of the central part of the bark structure (Fig. 10). No charred bark fragments were recorded. Out of several wooden logs and sticks of different size, one pine stick located near a possible hearth was partly burnt. Charcoal (charred wood fragments) is documented in 48 out of 67 soil samples, of which a few are identified as *Pinus* (pine), *Alnus*, *Quercus* (oak), *Corylus*, and *Betula* (birch). The pollen analysis resulted in a high diversity of taxa with the highest pollen concentration of forest trees and as for the Middle Mesolithic bark structure, sea-shore herbs, while dwarf shrubs are slightly more abundant in the Late Mesolithic lenses (Fig. 11). *Pinus*, *Corylus* and *Alnus* are the most abundant tree taxa. Fifteen pollen and spore taxa of the bark structure have their counterparts in macrofossils while 29 taxa are only recorded as pollen or spores. Forty plant macrofossil taxa may be recognized in the pollen record as well, while nine are only found as macrofossils. Spore-producing taxa and many tree species are only present as microfossils. In four of the samples from the bark structure, possible coprophilous flask fungi spores of the *Sordaria* and *Podospora* type were observed.

3.3.2. *PCA-ordinations*

The results of the PCA ordinations (Fig. 12) reveal no significant correlation between taxa and layers of the bark structure, nor between taxa and square, which implies that the variation in deposited plant remains is random. It must though be emphasised that this is not a full-scale analysis of the total macrofossil content of the structure, although the selection of samples under study is sufficiently representative to catch any obvious trend in the distribution of taxa within and between layers. Few charred taxa are recorded in the material, but there is a clear positive correlation between charred and uncharred *Corylus* as well as *Crataegus* in the material sieved in field (Fig. 12).

3.4. *Invertebrates*

The insects from Kvitsøy, Coleoptera and Diptera, were recovered from 7 different samples related respectively to 7 squares (Table 2, Fig. 8). Twenty taxa were recovered, Coleoptera and Diptera, primarily fragments of elytra of Coleoptera and fragments of dipterous puparia (Table 3). As a result of fragmentation, only 9 taxa were possible to be identified to the lowest taxonomic level. Most of the beetle taxa were recovered from squares 8002 and 8014, while calliphorids were present from 7925.

The finds of Oribatid mites consisted mainly of shells (exoskeletons without legs) of which altogether ten taxa were identified (Table 3). A few taxa allowed identification to species level while others only to genera or family level.

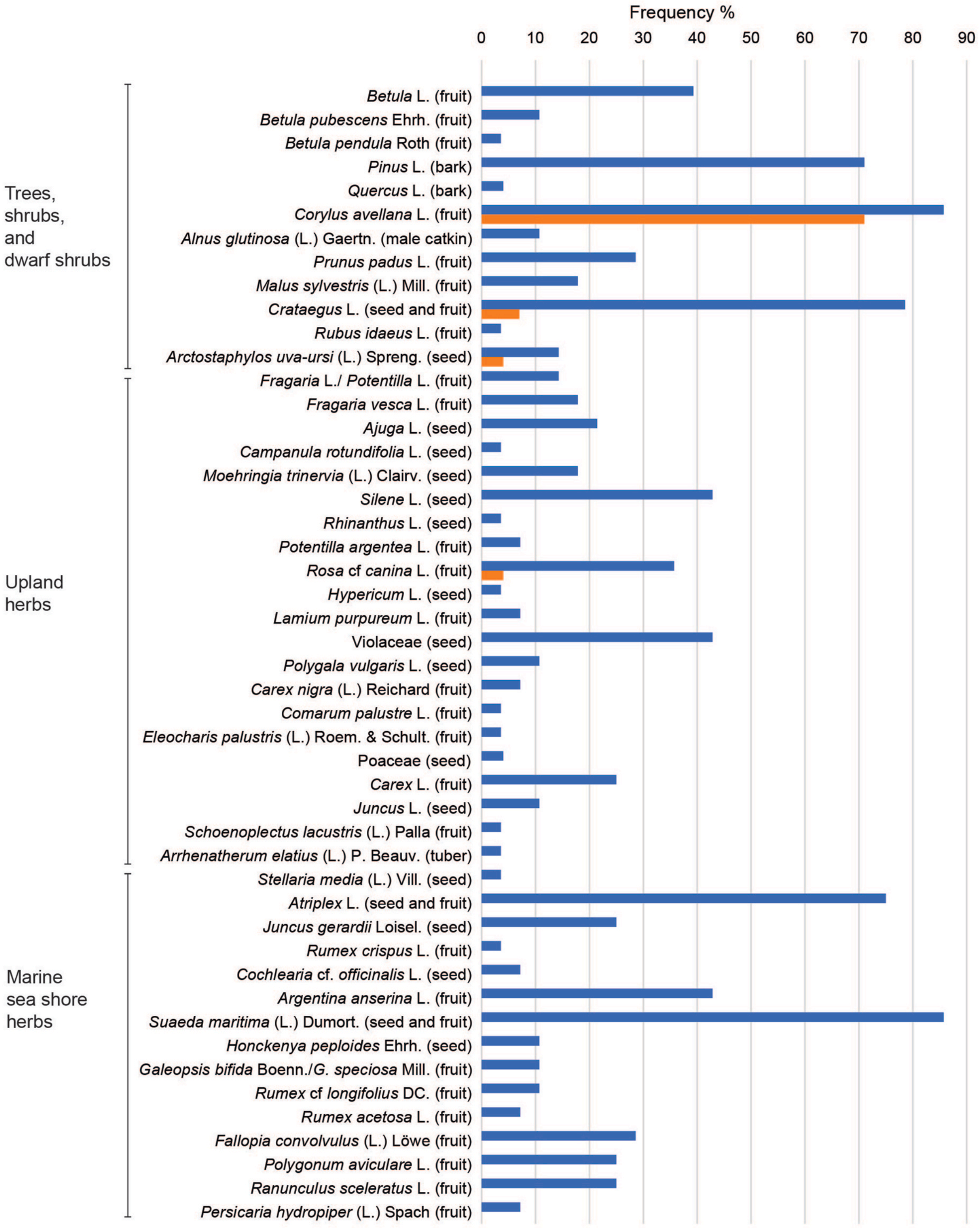


Fig. 10. Plant taxa observed in the Middle Mesolithic bark structure at Kvitsøy, expressed as frequency of identified plant macrofossils as percentages of all analysed squares. *Pinus* and *Quercus* represent tentative frequency of identified bark fragments. *Arrhenatherum elatius* is identified as possibly *Arrhenatherum elatius* ssp. *bulbosum* or *Phleum pratense*. Blue bars: Waterlogged. Red bars: Carbonised.

4. Discussion

4.1. Sediments and chronology

The bark structure appeared in the field as an isolated structure, stratigraphically located at approximately the same level as the recent discovery of a semi-continuous peaty organic layer with abundant remains of tree trunks and possibly redeposited peat clasts (Kilhavn et al. forthcoming). Radiocarbon dates of these two features overlap, placing the event during the Early Holocene regression minimum but with rising sea level (Fig. 3), the Middle Mesolithic in archaeological terms.

The radiocarbon dates have been carried out on wood as well as fruits. While the wood theoretically may be older than the time of deposition, being e.g., driftwood, the coherence in age with local growing seeds counters this assumption. There is no clear chronostratigraphic order of the dates within the bark structure, as samples

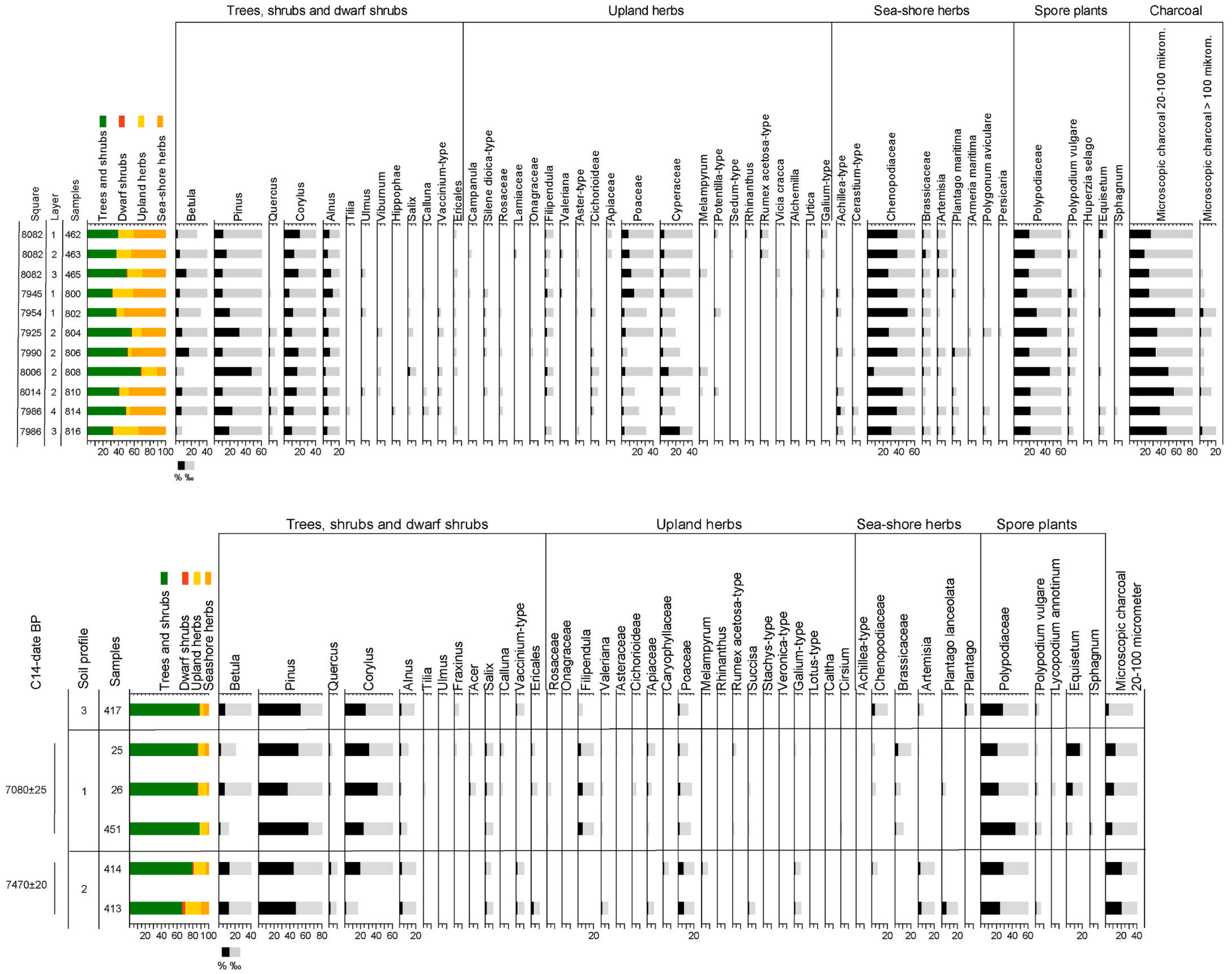


Fig. 11. Results from pollen analysis of selected soil samples from the Middle Mesolithic bark structure (above) and from the Late Mesolithic organic lenses (below) at Kvitsøy, presented as percentages. Please note different scales on the x-axes.

from the different stratigraphical layers give reversed dates (Table 1, Fig. 4). The differentiation into organic layers separated by sand may therefore be a secondary feature resulting from wave action and the successive inundation of the site. This hypothesis is confirmed by the nature of the biological content as well as the soil micromorphology.

The results from the soil micromorphology analyses indicate that the Middle Mesolithic sandy sediments, which contain fine gravel and are burrowed, are probably beach derived. They include fragmented bark, but no *in situ* bark floors were encountered. In lower sample 411B the beach deposits were also affected by inundation and fine wetland sedimentation (burrow infills of microlaminated organic silts) (Macphail et al., 2010). The presence of rare wood charcoal and fragments of peat (mainly in 411A) could suggest trampling (Rentzel et al., 2017) of occupation material including bark with introduction of local wetland soils and sediments; a sandy substrate, such as a beach sediment quite rapidly accumulates, and materials are easily incorporated by trampling (cf. Mesolithic Hengistbury Head and Star Carr; (Barton, 1992; Macphail and Goldberg, 2018). The deposits are hence unlayered and unlaminated, poorly sorted with silts, sands and gravels, and as such unlikely to be a natural sediment in a beach setting (Reineck and Singh, 1980). In addition, the association with elevated levels of phosphate is inconsistent with natural beach sedimentation and may serve as an anthropogenic marker.

A characteristic feature of the botanical content of the bark structure is the frequent presence of *Atriplex* fruits (Fig. 10). The large occurrence of Chenopodiaceae pollen (Fig. 11) is likely derived from *Atriplex*. The finding of both fruits and pollen is a strong indication of local growth. This genus includes species living in the marine tidal zone and may serve as a proxy indicator of the local sea level ca 9000-8600 cal. BP (Table 1, Figs. 3 and 4). Radiocarbon dated plant macrofossils overlapping this time span, include burnt and unburnt hazel nuts, burnt and unburnt pine wood and an unburnt fruit of *Crataegus* (Table 1). Finds of hazel nuts with beetle and possible rodent marks (Fig. 13) are not directly dated and may be older as the radiocarbon dated macrofossil assemblage also contains up to 1000 years older hazel nutshells (Table 1). Boreholes in some trunks by *Teredo* sp. (shipworm) and possibly *Limnoria lignorum* (gribble) (Fig. 13) indicate seawater below the high tide level at the site but neither of the trunks is radiocarbon dated. The bark structure thus contains material bearing evidence of terrestrial exposure as well as in seawater, covering a total time span of about 1500 years. The main part of the sequence seems to have been deposited on the former beach during c. 9000-8600 cal. BP, but with intrusion of material from the older terrestrial surface.

The well humified organic sediment and the pollen deposition record

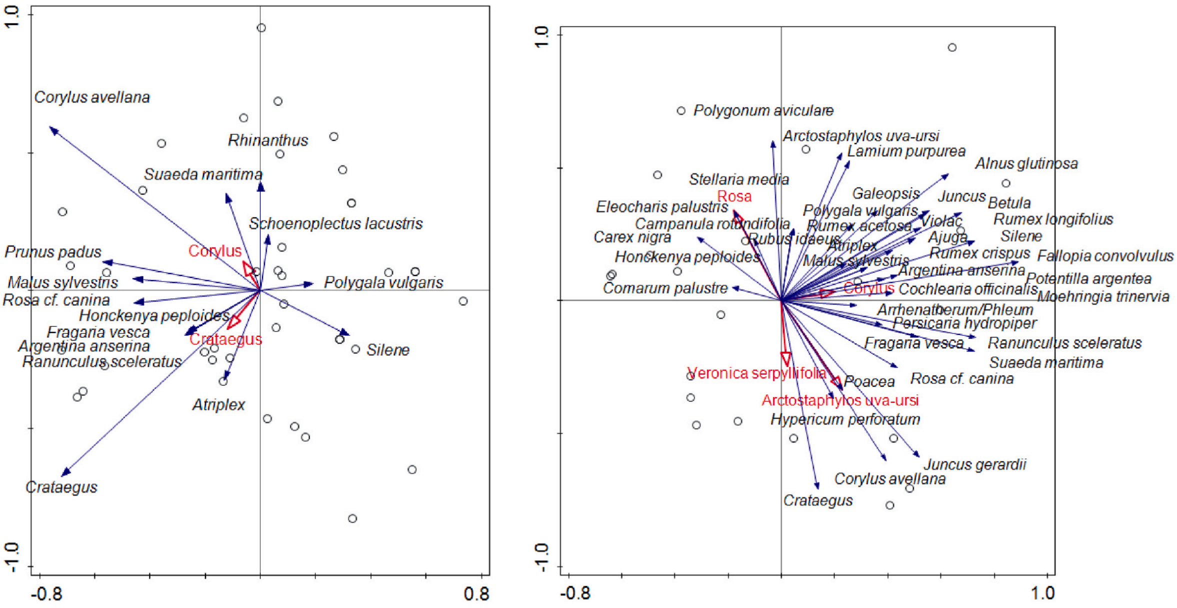


Fig. 12. Ordinations of plant macrofossils from the Middle Mesolithic bark structure, Kvitsøy. Left: A Principal Component Analysis (PCA) of data from soil samples sieved in field using 2 mm mesh size. Response variables are uncarbonized plant macrofossils, while carbonised plant macrofossils are treated as supplementary variables. Explained cumulative variation of the two principal axes is 56, while pseudo-canonical correlation (supplementary) is 0,19, total variation accounted for by the supplementary variables being 2,4 %. Right: A Principal Component Analysis (PCA) of data from soil samples sieved in the laboratory using multiple sieves with a range in mesh sizes from 0,25 to 2 mm. Response variables are uncarbonized plant macrofossils, while carbonised plant macrofossils are treated as supplementary variables. Explained cumulative variation of the two principal axes is 40, while pseudo-canonical correlation (supplementary) is 0,53, total variation accounted for by the supplementary variables being 19,8 %.

of the Late Mesolithic organic clasts (Fig. 11) reflect more of an upland vegetation than that of the Middle Mesolithic bark structure The representation of marine littoral plants is markedly less, especially when it comes to Chenopodiaceae pollen, presumably reflecting *Atriplex* species. The sea level was higher during the Late Mesolithic and the upland character of the clasts indicates a rip off from the vegetated upland brinks, possibly because of storm activity or other catastrophic events.

4.2. *Environment*

4.2.1. *Flora and vegetation*

The relatively high levels of pollen from *Betula* (birch), *Pinus*, *Corylus* and *Alnus* combined with the abundant finds of macro remains, whether deposited naturally or by human agency, indicate that these species grew near the site. Pollen from *Alnus* and *Betula* represent black alder and the downy and silver birches according to the identification of catkins and seeds (Fig. 10). Downy birch is the pioneer forest tree in Norway, colonizing rapidly from nearby refugia after the Younger Dryas cold period in SW-Norway (Paus et al., 2023) where a wide strand flat area persisted in front of the glacier. Hazel established thickets very early in SW-Norway and may have delayed the dispersal of pine in this region some. The oldest radiocarbon dated hazel nut at Kvitsøy is a burnt nutshell dated to 8830 ± 46 BP (Table 1, Fig. 4). No Early Mesolithic settlement is so far documented on Kvitsøy, but hunter gatherers may still have brought hazel nuts to the isle sporadically. However, based on pollen analytical evidence from sites on the mainland and larger islands, the rise in *Corylus* pollen values happened earlier, exemplified with the dates of 9595 ± 360 BP and 9110 ± 240 BP on Rennesøy (Prøsch-Danielsen, 1993), increasing summer temperatures lead to a rapid colonization. Natural dispersal of nuts with viable kernels to Kvitsøy by long distance flying birds like the nutcracker and the jay, is likely, or by currents over the sea given enough floating power. The latter option requires some empty space within the nutshell, as caused by drying and still be able to germinate as proved by Ridley (1930), cited in Tallantire (2002).

Quercus is represented by small pollen values, but one waterlogged acorn kernel and a bark fragment identified as oak, were found in material not included in the systematic analysis. Singular oak trees may thus have grown on the isle. The earliest Holocene radiocarbon dates of *Quercus* in Rogaland are four AMS-dates of charcoal spanning between 9400 ± 70 BP and 9540 ± 80 BP (Bang-Andersen, 2006). The charcoal is from hearths in the mountain area and represent reuse of wood from the coastal lowland. Whether the small pollen observations of *Tilia* (lime) and *Ulmus (elm)* are local, or represent long distance dispersal, is more uncertain. *Tilia cordata* is, however, insect pollinated and produces little pollen. The N-fixation of *Alnus glutinosa* improves the soil quality and is beneficial to *Ulmus glabra*. Several other species belonging to the mixed oak forest (Quercetum mixtum) are recorded as macrofossils, like e.g. *Malus sylvestris* (wild apple), *Prunus padus* (bird cherry) and *Crataegus*, where *Crataegus monogyna* (Jacq.) and *C. rhipidophylla* (Gand.) are relevant native species. *Viburnum opulus* (guelder-rose) and *Hippophaë rhamnoides* (sea buckthorn) are only recorded as pollen and identified at genus level but represented with one native species in Northern Europe. Both pollen types have a distinct character and a short dispersal radius. A total of six waterlogged fruits of *Malus sylvestris* are recorded and the trees probably grew near the study site. The species thrives in open, warm deciduous forest, mainly on alkaline soil, and sea shoreline outcrops and may have been part of the woodland border shrub vegetation together with *e.g.*, *Crataegus* sp., *Hippophaë rhamnoides*, *Rosa* sp. (rose) and *Prunus padus*. Most Rosaceae species are pollinated by insects and produce little pollen, and the Rosaceae family is represented by low pollen values (Fig. 11). Pollen from *Malus*, as for many other species from the Rosaceae family, is difficult to identify to genus or species in fossil sediments. However, several pollen identified as *Malus sylvestris* were found in a basal marine sandy gyttja dated as 7130 ± 100 BP at Stavanger Airport, Sola (Prøsch-Danielsen, 2006). The gyttja layer contained artifacts of Late Mesolithic typology, and bones from mammals, birds, and fish, of which a tooth from wild boar Sus scrofa was dated to 6110 ± 40 BP. The pollen assemblage was dominated by forest tree taxa as *Betula*, *Alnus*, *Pinus*, *Corylus* and to a lesser extent *Quercus* and *Ulmus*.

From the collection of identified plant taxa in the bark structure and

Table 3
Minimum numbers of individuals (MNI) of identified specimens of insects and arachnids (soil mites) from the Middle Mesolithic bark structure at Kvitsøy, Norway.

Taxa	Squares							
Class, order/suborder, family, species	7925	7937	7945	7990	8002	8006	8014	8026
Insecta								
Coleoptera								
Carabidae								
Carabidae indet.								1
Pterostichus melanarius (Ill.)				1				
Calathus melanocephalus (L.)							1	
Hydrophilidae								
Hydrobius fuscipes agg.					1			
Staphylinidae								
Anotylus sp.		1						
Othius punctulatus (Goeze)	1							
Elateridae								
Hypnoidus riparius (F.)					1			
Dryops cf. *similaris* Bollow	1							
Rhizophagidae								
Rhizophagus cf. *ferrugineus* (Payk.)							1	
Cucujidae								
Monotoma sp.							1	
Cryptophagidae								
Atomaria sp.					1			
Phalacridae								
Phalacrus substriatus Gyll.							1	
Curculionidae								
Rhopalomesites tardyi (Curtis)							1	
Diptera								
Calliphoridae								
Calliphoridae indet.	2							
Protophormia sp.	1							
Muscidae								
Muscidae indet.					1			
Heleomyzidae								
Heleomyzidae indet.								1
Sphaeroceridae								
Sphaeroceridae indet.								1
Ephydridae								
Ephydridae indet.					1			
Trichoptera								
Trichoptera indet.								1
Arachnida								
Oribatida								
Oribatida indet., juvenile				1				
Carabodidae								
Carabodes subarcticus (Trägårdh)				1				
Punctoribatidae								
Punctoribates cf. *punctum* (C.L. Koch)			1	1				
Galumnidae								
Galumnidae indet.				1	2			
Ameronothridae								
Ameronothrus cf. *marinus* (Banks)						1		
Ceratozetidae								
Ceratozetes cf. *gracilis (Michael)*								1
Trichobates incisellus (Kramer)					1			
Oribatulidae								
Oribatula interrupta (Willmann)					2			
Scheloribatidae								
Scheloribatidae indet.					1			

the classification of Norwegian vegetation units (Fremstad, 1997), a tentative reconstruction of local vegetation units during the Middle Mesolithic period, may be outlined (Table 4). The classification is based on the concept of ecological gradients, such as changes in soil type, moisture, nutrient availability, regional or local climate etc. (op. cit.). Despite the small size of the isles of the archipelago, a varied topography with multiple ecological niches persisted. The fertilization by drifted seaweed and bird manure gave for instance rise to a varied flora along the seashores, and natural occurrences of spring water to swamps and lush woodland.

A pollen-based vegetation modelling (Hjelle et al., 2018) found that the highest estimated cover of trees and shrubs along the south-western coast of Norway was between 8200 and 6200 cal. BP with broadleaved thermophilous forest trees (*Fraxinus* (ash), *Quercus*, *Tilia* and *Ulmus)* as an important constituent. The openness of the forest varied among sites along with the variation in local topography and soil types, heaths and mires being an important regulating factor. In Rogaland, pollen analyses show that thermophilous forest existed within this period on the mainland but also on the larger islands in Boknafjorden, such as Rennesøy (Prøsch-Danielsen, 1993), Bokn (Jensen, C. unpubl.) and Karmøy (Skjelstad and Midtbø, 2011). The present study at Kvitsøy provides for the first-time convincing evidence that thermophilous plant communities occupied parts of the smaller and more remote isles as early as from c. 9000 cal. BP and possibly earlier based on the radiocarbon dates of *Corylus* nuts.

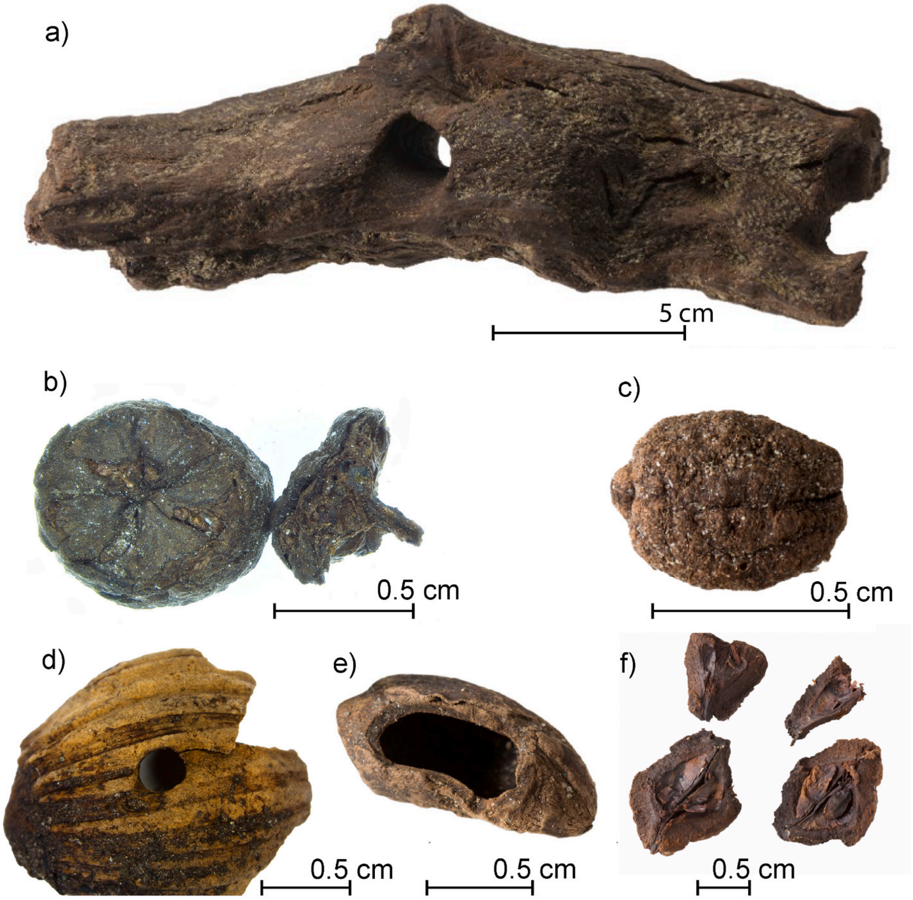


Fig. 13. Examples of plant remains from the Middle-Mesolithic bark structure, Kvitsøy. a) Water saturated wood with the exit bore holes from ship worm clam (*Teredo* sp.) and small burrow marks possibly made by the gribble *Limnoria lignorum*, b) *Alnus glutonosa* catkins, c) Fruit from *Crataegus* sp., d) *Corylus avellana* nut with bore hole possibly made by the beetle *Curculio nucum*, e) *Corylus avellana* nut with possible rodent gnaws opening, f) *Malus sylvestris* fruit fragments. Photos: Annette G. Øvrelid (a, c, e, f), Elin Hamre (b) and Christin E. Jensen (d), Am-UiS.

4.2.2. *Fauna*

Two species of carabs were identified to the lowest taxonomic level from the material studied. The eurytopic *Pterostichus melanarius* (Ill.) frequents riparian zones and is often found in decaying plant and flood debris as well as under bark (Lindroth, 1986; Koch, 1989), and *Calathus melanocephalus* (L.) is often found under grass, straw and plant litter in meadows but is also recorded from dunes (Koch, 1989). The aquatic fauna is represented by *Hydrobius fuscipes* agg., a fairly eurytopic species, found in stagnant water, including pools with detritus, and in streams in areas where flow is slow, among vegetation (Hansen, 1987; Friday, 1988; Duff, 1993). The staphylinid *Othius punctulatus* (Goeze) is associated with deciduous and coniferous leaf litter (Koch, 1989). The mould feeders *Atomaria* sp. and *Monotoma* sp. also frequent decaying vegetation (Koch, 1989a), whilst the small flightless elaterid *Hypnoidus riparius* (F.) is a dweller in moist environments, near water (Lindroth et al., 1973), frequenting forest soil in birch scrub (Larsson and Gígja, 1959). Another beetle which lives near water, stagnant and flowing, is the dryopid *Dryops* cf. *similaris* Bollow (Koch, 1989), a wet moss dweller, associated with small pools in bogs (Bilton, 1988) and has a near threatened status (NT) in Norway (Artsdatabanken, 2021). *Rhizophagus* cf. *ferrugineus* (Payk.), recovered from the site, is a woodland species, living under the bark of rotting deciduous and coniferous trees, with the adults feeding on the sap and the larvae on fungi and bark beetle larvae and eggs (Lane, 2021). The mycophagous *Phalacrus substriatus* Gyll. also prefers damp habitats both meadows and woodland openings and margins and has been observed from asphodels, smutted *Carex* and sedges (Koch, 1989; Marsh, 2019). *Rhopalomesites tardyi* (Curtis) a xylophagous species, recorded from dead wood of a variety of trees (Hyman, 1992) was also part of the Kvitsøy assemblage. It is found in coastal areas, probably dispersed in driftwood (Denton and Loxton, 2012). It is among the critically endangered (CN) species in Norway, with two records from ash stumps in western Norway, Suldal in Rogaland, although the lack of data is probably a result of lack of entomological surveys (Artsdatabanken, 2021). At the present day, it is believed to be a relic from warmer climate in southern Scandinavia (Blom et al., 2004).

Emergence holes in a hazelnut indicates the possible presence of *Curculio nucum* L., the hazel nut weevil, which can be a pest on hazel and hawthorn (Atty, 1983). The larvae feed in developing kernels, and then through an exit hole, they move out to pupate in the soil (Morris, 2012). The signs of infestation of a wild apple, *M. sylvestris*), with visible remains of frass, insect excrement, indicates infestation by the moth *Cydia pomonella* (L.), currently a cosmopolitan pest of apples, pears, and other fruit trees (Mahi et al., 2024; Pajac et al., 2011). The larvae feed on the fruit and bore into it, and they result in the premature ripening of infested fruits (Maggi and Chreil, 2023). In addition to the Coleoptera, flesh flies, calliphorids, including *Protophormia* sp., which breeds in vertebrate carcasses (Rognes, 1991), were recovered from the site. There were also sphaerocerids, which breed in a variety of environments from carcasses to dung and rotten vegetation (Buck, 1997), heleomyzids which are cold tolerant protein feeders (Skidmore, 1996), and muscids, which can be saprophagous, haematophagous, or predatory and can develop in a variety of materials including rotting plant debris (Skidmore, 1997).

Table 4
Local vegetation units inferred from the botanical results of the present study at Kvitsøy, Norway. Only taxa represented in the pollen and macrofossil records are listed. The classification of units follows Fremstad (1997).

Vegetation unit[a]	Characteristic plant taxa[a]	Macrofossils	Pollen and spores
Upland vegetation			
Low-herb forest	*Betula pubescens, B. pendula, Corylus avellana, Pinus sylvestris, Quercus* sp., *Viburnum opulus, Melampyrum* sp., *Fragaria vesca, Ajuga* sp. and ferns like e.g. *Athyrium filix-femina* and *Dryopteris filix-mas* (Polypodiaceae spores)	*Betula pubescens, B. pendula, Betula* sp., *Corylus avellana, Pinus sylvestris, Quercus, Fragaria vesca, Ajuga*	*Betula, Corylus, Pinus, Quercus, Viburnum, Melampyrum,* Polypodiaceae
Thermophilous deciduous woodland	*Prunus padus*, *Tilia cordata* (possibly local), *Ulmus glabra* (possibly local), *Malus sylvestris*, *Rubus idaeus* and *Moehringia trinervia*	*Prunus padus, Malus sylvestris, Rubus idaeus, Moehringia trinervia*	*Tilia, Ulmus,* Rosaceae
Alnus glutinosa seashore woodland	*Alnus glutinosa, Salix* spp., *Comarum palustre, Filipendula ulmaria* and *Galium aparine*	*Alnus glutinosa, Comarum palustre*	*Alnus, Salix, Potentilla*-type, *Filipendula, Galium*-type
Woodland border shrub	*Crataegus* sp., *Hippophaë rhamnoides*, *Malus sylvestris*, *Prunus padus*, *Rosa* spp., *Hypericum perforatum* and *Lamium purpureum*	*Crataegus, Malus sylvestris, Prunus padus, Rosa* cf. *canina, Hypericum perforatum, Lamium purpureum*	*Hippophaë,* Rosaceae, Lamiaceae
Rock wall/edge vegetation	*Potentilla argentea, Sedum* spp. (e.g. *S. annuum, S. anglicum*), *Silene* spp. (e.g. *S. rupestris*), Brassicaceae spp. (*e.g. Draba incana*) and *Polypodium vulgare*	*Potentilla argentea, Silene* sp.	*Potentilla*-type, *Sedum*-type, *Lychnis*-type, Brassicaceae, *Polypodium vulgare*
Coastal heath	*Arctostaphylos uva-ursi, Calluna vulgaris, Vaccinium* spp. (e.g. *V. uliginosum*), *Polygala vulgaris, Carex nigra, Huperzia selago* and *Sphagnum* spp.	*Arctostaphylos uva-ursi, Polygala vulgaris, Carex nigra*	*Calluna, Vaccinium-type,* Cyperaceae, *Huperzia selago, Sphagnum*
Poor carpet/mud-bottom fen	*Equisetum* spp. *(e.g. E. fluviatile)*, *Sphagnum* spp. and sedges (Cyperaceae, *e.g. Carex* spp., *Eriophorum angustifolium*)	*Carex* sp.	*Equisetum, Sphagnum,* Cyperaceae
Water horsetail-sedge swamp	*Eleocharis palustris, Equisetum fluviatile, Carex* spp.	*Eleocharis palustris, Carex* sp.	Cyperaceae
Sea-shore vegetation			
Sublittoral, salt marsh and brackish swamp	*Schoenoplectus lacustris, Suaeda maritima, Rhinanthus minor, Lychnis flos-cuculi* and several species in common with drift-wall communities	*Schoenoplectus lacustris, Suaeda maritima, Rhinanthus minor*	Chenopodiaceae, *Rhinanthus*-type, *Lychnis*-type
Annual orache drift-wall	*Atriplex prostrata, Stellaria media, Galeopsis bifida, G. speciosa, Persicaria* spp. (*lapathifolia* ssp. *lapathifolia* most likely). Several perennial species may also be included, like *Honckenya peploides* and *Argentina anserina*	*Atriplex, Stellaria media, Galeopsis bifida/speciosa, Honckenya peploides, Argentina anserina*	Chenopodiaceae, *Cerastium*-type, *Potentilla*-type
Perennial grass/herb-rich drift-wall	*Fallopia convolvulus, Arrhenatherum elatius* var *bulbosum* or *Phleum pratense* ssp. *nodosum, Artemisia* spp. and a variety of species common with other seashore communities	*Fallopia convolvulus, Arrhenatherum elatius* var *bulbosum/Phleum pratense* ssp. *nodosum*	Poaceae, *Artemisia*
Drift-wall influenced by freshwater seepage	*Persicaria hydropiper* and *Ranunculus sceleratus*	*Persicaria hydropiper, Ranunculus sceleratus*	*Persicaria*
Rocky shore and coastal bird-manured vegetation	*Armeria maritima, Cerastium fontanum* ssp. *vulgare, Cochlearia officinalis, Matricaria maritima, Plantago lanceolata, Plantago maritima, Sedum* spp. (e.g. *Rhodiola rosea, Sedum anglica, Sedum acre*), *Rumex acetosa, Rumex crispus, Silene* (e.g. *S. dioica, S. uniflora*), Violaceae (e.g. *Viola tricolor*) and *Valeriana sambucifolia*	*Cochlearia* cf. *officinalis, Rumex acetosa, Rumex crispus, Rumex* cf. *longifolius*	*Armeria maritima, Cerastium*-type, Brassicaceae, *Achillea*-type, *Plantago maritima, Plantago, Sedum*-type, *Rumex acetosa*-type, *Lychnis*-type, *Violaceae, Valeriana*

[a] Vegetation unit (Fremstad, 1997) and characteristic taxa represented in the subfossil flora as inferred from taxa observed in the bark structure and peat lenses.

The insect assemblage, although rather limited, provides an overview of the surrounding environments, which according to the beetle remains consisted of woodlands with open areas and water pools. Evidence of infested hazelnuts and wild apples could either be random infestations of the natural assemblages or perhaps a result of consumption of fruits and nuts, including infested ones. The flies could be associated with rubbish which perhaps included excrement, and decaying material. The fossil insects could be associated with various materials, resulting from accidental accumulation, animal, and even human activity. However, both the nature of the assemblages and the limitations of suboptimal sample size and preservation do not allow for a secure interpretation.

Although the ecology of oribatid mites is rather poorly known, according to Weigmann (2006), some information is available. *Carabodes subarcticus* Tragardhcan be found mainly in moist acidic forests and bog soils*, Puntoribates punctum* (C. L. Koch) in various meadows and forest soils with medium moisture, *Ceratozetes gracilis* (Michael) in forest soils and *Oribatula interrupta* (Willmann) in mountain to alpine environments, in moss and woody soils (Weigmann, 2006). The most interesting finds are *Trichobates incisellus* (Kramer), which occurs in moist and fresh meadows and reeds but is also tolerant to salt, and *Ameronothrus marinus* Banks which occurs only in the intertidal zone (Weigmann, 2006). *A. marinus* was found in basal material (8006) and *T. incisellus*, tolerant to salt, in the top material (8002). Other species are rather common in acidic forest and meadows, living beneath soil, but oribatids may occasionally also be found in tree hollows and canopy under tree bark, in streams and animal nests as they disperse via wind, water and may be carried accidently by animals.

4.2.3. Human impact

Anthropogenic impact on the Mesolithic environment is hard to trace from plant and animal assemblages unless strong indicator species or other indicative proxies are recorded. However, this study demonstrates that it is possible to indicate human presence from a small site, given a multidisciplinary approach. The pollen record shows a relatively high presence of microscopic charcoal, that may derive from local hearths or other forms of human activity. Human presence is confirmed by the find of Middle Mesolithic type flint artifacts and Late Mesolithic settlement remains close to the study site (Dugstad et al., 2018, Dugstad 2022). The presence of spores from ascomycetes including coprophilous species, which feed on animal dung, may add to the picture of human activity at the site. This assumption is valid also for several of the identified insects, that may be associated with humans as well as natural materials. A verification of the bark structure as an artifact, like a sleeping mat, is however not feasible based on the available data.

Archaeobotanical research criteria for plant use include for example carbonisation, high frequency and high concentrations of particular plants, their areal distribution in relation to quantity and presence in hearths (Out, 2009). The high frequency of carbonised hazel nut shells and concentrated distribution that may be related to remnants of a hearth (Dugstad, 2022) are thus the most convincing evidence of human activity at the present study site. The potential of local plant use is wider. Fruits of several other recorded species are edible and gain improved taste and storage capability after roasting or boiling. The find of a couple of charred hawthorn fruits is thus supportive, but it might be expected to find a higher portion of carbonised specimens if the structure is a remnant of an occupation site. However, many plants are edible in raw condition and there is no need of preservation other than for storage, in which case drying would be an appropriate method. The use of carbonisation as a major criterion for plant use is in that sense not exclusive. On dry sites only carbonised plant macrofossils may be preserved, and there is no control with respect to uncarbonized presence of the species in the original context.

Corylus nuts are the most recorded macrofossil among seeds and fruits in the structure and occur in all analysed samples in carbonised as well as waterlogged states; some are entire nuts or kernels without shells. A distribution analysis based on the weighing of all hazelnuts finds from the structure, except the topmost layer, rendered c. 530 g and with the majority of finds in the central and upper half of the structure (Dugstad et al., 2018). Numerous and common finds of nutshells are generally considered as waste from consumption. The nuts possess a high nutritional value and are easily stored when dried or roasted. Burnt hazelnuts found in an occupation layer with Mesolithic artifacts on the coastal mainland at Solavika were directly dated to 8500 ± 240 BP (Haraldsen, 1984). *Quercus* nuts, acorns, have a high nutritional value and are edible for humans after roasting. They leave behind little waste which may be a reason of few subfossils find (Out, 2009). Acorns are commonly found on Mesolithic and Neolithic sites in Denmark, some with evidence of human harvesting as the evidence for *Corylus* nuts (Robinson, 2007). Around two hundred and fifty-five waterlogged fruits and seeds of *Crataegus* sp. and two carbonised examples are recorded, which makes it one of the most common plant macrofossils. Carbonised fruits of *Crataegus* are commonly found on archaeological sites in the southern part of Scandinavia and Northwest Europe and are regarded as having been consumed. The taste of the fruits improves after cooking and frost. One of the *Malus sylvestris* fruits was intact, while the rest were fragmented. Whole fruits of wild apple may indicate natural dispersal or human collection for immediate consumption, not storage. Apples for drying need to be cut to avoid rotting, but it cannot be ascertained that the recovered apple fragments were cut by humans. Apple wood is suitable for tools, as evidenced by the two axe shafts found in the Late Mesolithic Tybrind Vig material (Malmros, 2013). Two uncharred grass tubers are found in the upper layer of one square of the bark structure. Tubers formed by *Arrhenatherum elatius* ssp. *bulbosum* (false oat grass) and *Phleum pratense* ssp. *nodosum* (timothy-grass) are very similar, as elaborated by *e.g.*, Tutin et al. (2010) and Wacnik et al. (2014). The tubers are vegetative reproductive organs rich in starch and may well have been collected as food. *Phleum pratense* ssp. *nodosum* is considered as native on sandy soil and dry meadows in southern Scandinavia, while *Arrhenatherum* ssp. *bulbosum* grows on semi-natural grassland and as weed in arable fields. It is not regarded as naturalized in the Norwegian flora (Lid and Lid, 2005; Artsdatabanken 2021. Charred tubers identified as *A. elatius* ssp. *bulbosum* are, however, found as far back as the Neolithic in Denmark and Southern Sweden (Roehrs et al., 2013). The finds include graves, hearths and house structures associated with agricultural settlements. Thus, based on available empiric evidence, the tubers from the Middle Mesolithic context more likely originates from *Phleum pratense* ssp. *nodosum*. Abundant finds of waterlogged fruits from *Atriplex* spp.(saltbush) and *Suaeda maritima* (L.) Dumort. (herbaceous sea-blite) are recorded. Some of the fruits identified as *Atriplex* may be *S. maritima* and these taxa are considered together since they grow in similar habitats. *Atriplex* identified to species level are *A. patula* (L.) and *A. littoralis* (L.)/*A. prostrata* (Moq.). The species are edible, and consumption of young leaves and fruits is reported. One fruit of *Schoenoplectus lacustris* (L.) Palla (common clubrush), several *Juncus gerardii* (Loisel.) (saltmarsh rush) and *Juncus* sp. fruits were found. The species may be used to make ropes or plaiting (Out, 2009). Roots, rhizome buds and fruits of *S. lacustris* are also edible.

The results of this study show that there existed a more varied natural habitat on Kvitsøy in the Mesolithic than is the case today. Plants that could be harvested from early spring to late autumn grew locally. In particular, the presence of forest communities, lush scrub vegetation by the seashore and freshwater sources provided exploitation of local resources for long-term stays. Several of the local plant taxa has a potential for human exploitation mentioned.

Fossil insect research from other Mesolithic sites, in the British Isles and other areas in Europe provides little insight for the effect of hunter gatherers/hunter fishers on their environments, as, unless directly associated with a specific activity, human impact is often not detectable. This has to do with the relatively slight impact of Mesolithic people on the landscape to the extent that it is often impossible to differentiate from natural change. Assemblages from a variety of sites in the British Isles, ranging from Seamer Carr (Osborne, 1980; Kenward and Large, 1997), Star Carr (Hall et al., 2007; Taylor and Allison, 2018), Westward Ho (Girling and Robinson, 1987), West Heath Spa, Hampstead (Girling, 1989), and London (Elias et al., 2009), tend to provide solely evidence of palaeoenvironments where any effects of occasional light human impact are impossible to separate from natural change. In comparison, the insect taxa from Kvitsøy, were recovered from squares all of which included evidence for hazel nuts, hawthorn and saltbush, and in the case of 8002, wild apple. The insect evidence for mould feeders, pests on nuts and fruits, and flies which are protein feeders would be expected in debris resulting from human consumption or other activities, including those of prey, and together with the plant evidence could argue for the human use of the site.

5. Conclusions

The palaeoecological research from Kvitsøy not only provides new data for the site on past environments but also demonstrates the importance of multidisciplinary research for understanding slight human impact. In brief, the results from this study show that.

- A major part of the organic bark-dominated structure was most likely deposited between 7993 ± 44 BP and 7810 ± 40 BP. Burnt hazel nuts are, however, directly dated as far back as to 8830 ± 46 BP, during the Early Holocene regression minimum with a c. 4 m lower sea level than today, and when a terrestrial surface persisted on the site. It is affected by the subsequential inundation of the site during the early phase of the Early-Mid Holocene Tapes transgression and sealed underneath marine deposits. Based on soil micromorphology and geochemistry it may be concluded that the Middle Mesolithic organic deposits are beach-derived, trampled-in sediments, due to their anomalous unlaminated, poorly sorted and phosphate-enriched character.
- The biological evidence from plant and animal remains support human influence at the site but cannot confirm that the bark-dominated structure was an intentionally made artifact.
- The botanical results give evidence of a local sea-shore environment with plant communities of the tidal zone, drift-walls, and bird-manured habitats. The local upland vegetation consisted of a maritime woodland border shrub community with e.g., *Crataegus* sp., *Malus sylvestris* (L.), *Hippophaë rhamnoides* (L.) and an *Alnus glutinosa* (L.) Gaertn. swamp woodland. Other vegetation on the island included thermophilous deciduous woodland, low-herb forest with pine, coastal heath and fen and swamp communities. Aquatic plants confirm the presence of open freshwater. The high frequency of burnt hazelnuts compared with few other charred plants, supports human influence rather than natural fires. A variety of local naturally growing plants may have been utilized as food resource, including edible leaves, roots, seeds, berries, and fruits, consumed in fresh or dried state. A plant-based component may thus have been available from spring until late autumn and been an important contribution to the local diet during occupation.
- The beetle fauna includes species which live in old wood, *Rhizophagus* cf. *ferrugineus* (Payk.), and also driftwood, *Rhopalomesites tardyi* (Curtis) and in addition to evidence for species which are associated with open areas such as *Calathus melanocephalus* (L.) and moist environments and water, *Hydrobius fuscipes* agg., the insect results show coastal environments with trees, open areas and pools. The combined evidence from mould feeding beetles, infestation in hazelnuts by *Curculio nucum* (L.), caterpillars in wild apples, *Cydia pomonella* (L.), and protein feeding flies, heleomyzids, sphaerocerids and calliphorids, including *Protophormia* sp., implies the presence of carrion or animal food debris indicating possible human food waste on the site.
- The oribatid mite fauna includes species from several ecological niches, like *Ameronothrus marinus* Banks that occur only in the intertidal zone, *Trichobates incisellus* (Kramer) which occur in moist and fresh meadows and reeds but also tolerate salt, and *Carabodes su*barcticus Trägårdh which thrives in moist, acidic forest and bog soils.

Data availability

Data from this study are archived at the Archaeological Museum, University of Stavanger and are available on request.

CRediT authorship contribution statement

Christin Eldegard Jensen: Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Elin Hamre:** Writing – review & editing, Formal analysis, Data curation. **Mia Lempiäinen-Avci:** Writing – review & editing, Formal analysis. **Eva Panagiotakopulu:** Writing – review & editing, Formal analysis. **Richard Macphail:** Writing – review & editing, Formal analysis. **Riikka Elo:** Writing – review & editing, Formal analysis.

Declaration of competing interest

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

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