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ORIGINAL ARTICLE

From deciduous forest to open landscape: application of new approaches to help understand cultural landscape development in western Norway

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Abstract Development of the cultural landscape in a village situated by the inner fjords of western Norway is investigated by pollen analysis and quantitative reconstruction methods. Pollen samples from lake sediments and a soil profile were analysed and represent different spatial scales. The Landscape Reconstruction Algorithm (LRA) is applied to a large and a small lake to convert pollen percentages from the small lake into estimated local vegetation cover in selected time periods starting from 2800 cal BC (Middle Neolithic A). This reconstruction shows that estimated forest cover has fluctuated through time, and changes in openness related to human impact are distinct from the Early Bronze Age (1800–1200 cal BC). Pollen analyses from the soil profile indicate forest clearances from the Late Neolithic (2300–1800 cal BC). Gradual intensification of farming is recognized in both pollen diagrams throughout the Bronze and Iron Ages with increasing openness and spatial differentiation in land-use practices. Presence of pollen of cereals and flax record the cultivation of these plants from the Iron Age, and intensification of land-use may have caused erosion and re-sedimentation in the lake in medieval times. To identify a possible landscape in the past, HUMPOL software has been used with the Late Neolithic as a case study. The LRA-based estimates of forest cover are supported by the HUMPOL simulations, but several solutions to the Late Neolithic landscape pattern exist. The results clearly demonstrate how implementation of LRA and HUMPOL improve the understanding of cultural landscape development.

Introduction

The cultural landscapes of Europe document the diversity of past and present land-use practices (e.g. Behre 1988; Birks et al. 1988; Berglund 1991; Krzywinski et al. 2009). These landscapes depend on human impact, and are strongly associated with the nature of an area and the potential for farming. Climate, topography, soil and elevation have all been decisive in the relationships between cultivation and animal husbandry, and the resulting vegetation and landscape. The introduction and development of farming altered the vegetation, but when and how farming was established in Scandinavia differs among regions, and is still debated (e.g. Bakka and Kaland 1971; Berglund 1991; Prescott 1991; Høgestøl and Prøsch-Danielsen 2006; Hjelle et al. 2006; Sørensen and Karg 2014; Mehl and Hjelle 2015). In western Norway the farming economy became established at the end of the Neolithic, c. 2300 cal BC, and gradually changed the vegetation into heathlands along the coast, and into cultivated fields, meadows and pastures in the fjord regions (Kaland 1986; Hjelle 1999a). Archaeological data reflect expansion into the fjord regions at the end of the Neolithic (Bakka and Kaland 1971; Diinhoff 1999; Hjelle et al. 2006) and these areas have

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been important farming communities up to modern times. The long-term development of agriculture in the fjord areas of western Norway has, however, not been fully investigated, mainly due to the fairly steep terrain, resulting in few sites suitable for pollen analytic studies. In Herand by the Hardangerfjord, a small lake is centrally located in a village rich in archaeological remains from the Mesolithic as well as from the Bronze Age onwards (Fett 1954; Bergsvik and Hufthammer 2009; Wrigglesworth 2011). It is therefore a suitable site when aiming to reconstruct vegetation associated with the development of farming by the inner fjord.

Pollen analysis is the main method to reconstruct vegetation development through time, but the method is not straightforward; the relationship between pollen composition in a sample and the surrounding vegetation is not linear (Sugita 1994; Davis 2000). Relying on pollen percentages when reconstructing past vegetation thus has uncertainty. The Landscape Reconstruction Algorithm (LRA) is an approach developed to deal with the challenges—differences in pollen production and dispersal between species—and convert pollen percentages into vegetation cover (Sugita 2007a, b). So far, estimates achieved from this approach are found to be representative of the vegetation in Denmark, Switzerland, Sweden, Estonia and Norway (Hellman et al. 2008; Nielsen and Odgaard 2010; Soepboer et al. 2010; Fredh 2012; Cui et al. 2013; Overballe-Petersen et al. 2013; Poska et al. 2014; Hjelle et al. 2015), and it has been applied to reconstruct vegetation cover on different spatial scales (e.g. Nielsen et al. 2012; Fyfe et al. 2013; Cui et al. 2014; Marquer et al. 2014; Hultberg et al. 2015; Trondman et al. 2015).

In LRA, vegetation reconstructions are based on counted pollen records. Another approach is to simulate a landscape and a pollen composition from this landscape through the simulation package HUMPOL (HUll Method of POLlen simulation: Bunting and Middleton 2005) and compare the simulated and counted pollen assemblages. Reasonable scenarios of past landscapes may then be identified (Fyfe 2006; Caseldine and Fyfe 2006; Caseldine et al. 2007; Bunting et al. 2008; Gaillard et al. 2008; Waller et al. 2012). Application of this method has shown the potential for interpretation of past landscapes but has also clearly shown the large number of possible landscapes that may produce the same pollen composition.

In the present study, vegetation history with a special focus on human impact in Herand is investigated based on pollen analysis of lake sediments (Herandsvatn) and a soil profile (Samland). The combination of analyses of lake sediments and soil profiles provides an opportunity to investigate vegetation development on different spatial scales (Birks et al. 1988; Sugita 1994; Overland and Hjelle 2009). Lakes of a similar size to Herandsvatn are estimated

to have a relevant source area of pollen (sensu Sugita 1994) of 900–1,100 m radius in modern vegetation in the region (Hjelle and Sugita 2012), whereas pollen assemblages from moss polsters in southern Sweden are found to have a pollen source area of 400 m (Broström et al. 2005). However, for both investigated sites the relevant source area of pollen has probably changed through time, depending on vegetation composition and patchiness of the vegetation (Sugita 1998; Bunting et al. 2004; Hellman et al. 2009). LRA is used to reconstruct vegetation cover through time based on the lake sediments, and simulations of past landscapes and pollen assemblages using HUMPOL are compared to pollen assemblages from the lake and the soil profile. With the transformation of pollen percentages into estimated vegetation cover and simulation of possible landscape scenarios in the past, both a direct reconstruction of the relationship between open and forested landscape (Sugita 2007a, b), and a visualization of this potential landscape for a selected time period (Caseldine and Fyfe 2006; Caseldine et al. 2008) are given.
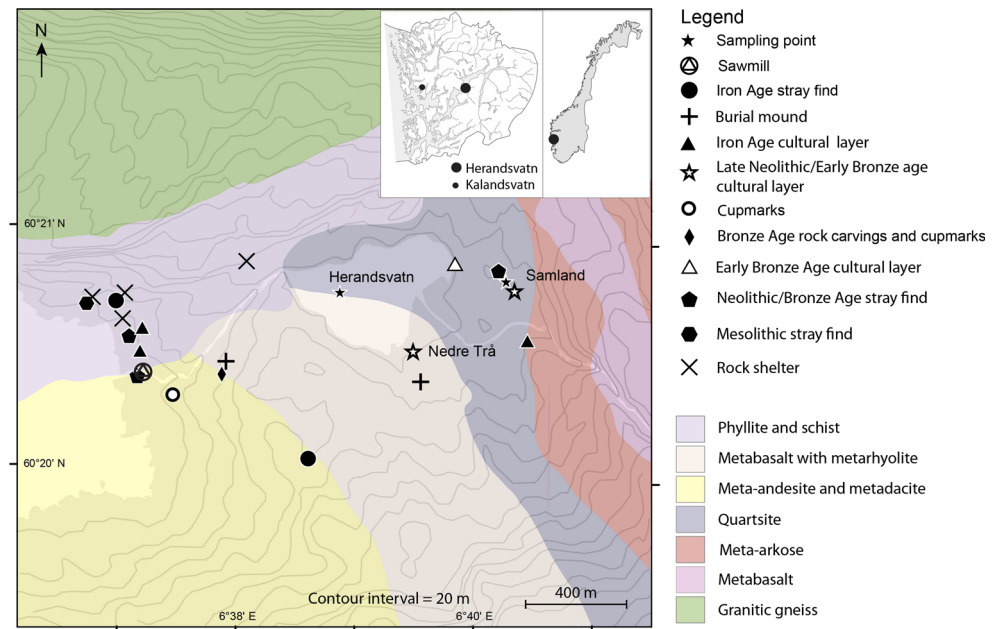
The aims of the present study are to reconstruct the local vegetation development associated with land-use in Herand from the Neolithic until today based on pollen data from a lake and a soil profile, to use LRA to study vegetation cover in archaeological time periods and potential changes connected to these periods, and to use simulations within HUMPOL to increase the understanding of how openings in the forest are reflected in pollen diagrams within the Late Neolithic as a case study. Finally, an aim of the paper is to evaluate the potential of using LRA and HUMPOL in palaeoecological studies of cultural landscape development. The reliability of the methodology was tested by simulating pollen deposition in the lake based on the AD 2003 landscape and the result was compared with the counted pollen assemblage.

Study area

The study area is in Hordaland County in western Norway (Fig. 1). A pollen diagram from the large lake Kalandsvatn (5.4°0.6′ E, 60°27′ N, 340 ha) is used to estimate regional vegetation using the REVEALS model (Mehl and Hjelle 2015). This provides the basis for local vegetation reconstruction in Herand using the program LOVE plus pollen assemblages from lake Herandsvatn (6.3°9′ E, 60°34′ N, 24 ha). The distance between the two lakes is c. 55 km. In addition to Herandsvatn, a pollen diagram is analysed from a soil profile at Samland, c. 640 m east of the coring point in the lake (Fig. 1).

Herand is a village by the Hardangerfjord in Jondal municipality, a region that is diverse with an elevational gradient from sea-level to mountains higher than 1,000 m

Fig. 1 Map showing Herand in western Norway with the two sampling sites Herandsvatn and Samland, and the recently excavated site Nedre Trå. Distribution of archaeological finds and overview of geological features are shown. The site used for REVEALS, Kalandsvatn is shown on the small map, and is situated c. 55 km west of Herandsvatn

Legend

★ Sampling point
⌂ Sawmill
● Iron Age stray find
+ Burial mound
▲ Iron Age cultural layer
✶ Late Neolithic/Early Bronze age cultural layer
○ Cupmarks
◆ Bronze Age rock carvings and cupmarks
△ Early Bronze Age cultural layer
⬠ Neolithic/Bronze Age stray find
⬟ Mesolithic stray find
✕ Rock shelter

Phyllite and schist
Metabasalt with metarhyolite
Meta-andesite and metadacite
Quartsite
Meta-arkose
Metabasalt
Granitic gneiss

Contour interval = 20 m

a.s.l. within short distances. The village itself is surrounded by mountains up to 700 m a.s.l., forming a small valley where Herandsvatn at 76 m a.s.l. is quite centrally located between the fjord and the mountains. Mean winter temperature is 0.5 °C and mean summer temperature 13.1 °C. Yearly precipitation is c. 2,150 mm (DNMI 2014).

The bedrock in Herand consists of a band of phyllite from the fjord eastwards along the northern side of Herandsvatn (Fig. 1), whereas other hard rocks dominate in other parts of the village (Sigmond 1985). Herand is situated in the southern boreal vegetation zone, which implies dominant coniferous trees with frequent deciduous trees (Moen 1999). *Pinus* is common in the hills surrounding Herand, whereas *Picea* has been planted since AD 1960 (Losnegård 2006), and today is found in patches on the northern, eastern and southern slopes at some distance from the lake. Most of the forest stands of *Picea* are young and thus still non-pollen producing. Warmth-demanding species such as *Fraxinus*, *Ulmus*, *Corylus* and *Tilia* grow on calcium-rich soil and characterize the south-facing slopes north of Herandsvatn. Today, the village is dominated by arable land, pastures and fruit gardens.

Herand is among the places by the inner Hardangerfjord where the earliest traces of human activity are found, dated to c. 7000 cal BC when people used and lived in rock shelters (Bergsvik and Hufthammer 2009). So far, activity in the rock shelters has also been dated to the Bronze and Iron Ages (Bergsvik and Hufthammer 2008), and stray finds of Neolithic, Bronze Age and Iron Age artefacts (Fett 1954) are found in the village. A recent archaeological investigation (spring 2014) discovered Late Neolithic and Early Bronze Age (EBA) cultural layers at Nedre Trå close

to Herandsvatn (Fig. 1; Narmo, personal communication). More than 85 rock carvings of Bronze Age origin connected to the South Scandinavian farming societies as well as cup marks from the Bronze or Iron Age (Dodd 2010; Wrigglesworth 2011) indicate a long agricultural history in the area. The farm name "Samland", from where the soil profile is investigated, probably has its origin in the Migration period or the Late Iron Age (Losnegård 2006). In the early 17th century a sawmill was established, which made Herand important in the trade of building material, and which is also an indication of the existence of forests suitable for timber exploitation in the region at that time. Herandsvatn is centrally located in relation to the archaeological data from the village (Fig. 1).

Methods

Palaeoecology

Fieldwork was carried out between 2005 and 2011. In 2005 surface sediments from Herandsvatn were collected using a HTH sediment corer (Renberg and Hansson 2008), and in 2006 sediment cores were collected with a Russian corer (diameter 11 cm). Unfortunately, the sediment cores only covered c. 2,000 years so a new core (4.06 m long) was collected in 2010 using a piston corer for lacustrine and marine sediments (Nesje 1992). At the same time the lake bed was mapped by seismic surveys that located the thickest sediment sequence in the basin at c. 12 m water depth (Bakke unpublished). This was chosen as the coring point and was found to be in the same area as the 2006 core. In 2008,

archaeological investigations, with digging of trenches at selected sites within the infields of farms in the village, were carried out. The thickest accumulation of layers was found at Samland, and pollen samples as well as material for radiocarbon dates were collected directly from the profile wall.

In the laboratory, pollen samples were extracted at constant volume (1 cm³), and treated by acetolysis and hydrofluoric acid following standard procedures (Fægri and Iversen 1989). Four *Lycopodium clavatum* tablets were added to enable calculation of concentration and pollen accumulation rates (PARs) (Stockmarr 1971). A light microscope with phase contrast was used for analysis and c. 1,000 pollen grains counted in each sample. General pollen identification followed Fægri and Iversen (1989), whereas the identification of cereals followed Beug (2004). The reference collection at the University of Bergen was used in cases of doubt. Pollen type taxonomy follows (Lid and Lid 2005). Microscopic charcoal >10 µm was counted.

The results are presented in pollen diagrams using the program Core2.0 (Kaland and Natvig 1993). The pollen sum includes all terrestrial pollen ($\sum$P). Spores and other microfossils are calculated on the basis of the pollen sum and the sum of the microfossil in question ($\sum$P + X). Loss-on-ignition was measured by drying the samples at 105 °C for 12 h, followed by combustion at 550 °C for 6 h (Heiri et al. 2001). The results are given as percentages of dry weight.

Radiocarbon dates and ^{210}Pb-dates

Eighteen radiocarbon samples were dated by AMS (Accelerator Mass Spectrometry) using the radiocarbon dating laboratory at the Norwegian University of Science and Technology in Trondheim in collaboration with the Svedberg laboratory in Uppsala, Sweden, and by Beta Analytic Inc., Miami, USA. The upper sediments in Herandsvatn were dated by the ^{210}Pb method at the University of Liverpool.

The dates were calibrated using Clam, R code for classical age-depth modelling version 2.2 (Blaauw 2010) using the IntCal13 calibration curve (Reimer et al. 2013). The age of each sample from Herandsvatn is based on the best fit of the calibrated ages within 2 σ. Linear interpolation was used to make the age-depth model. The age of samples from the soil profile at Samland follows the date of the respective stratigraphic layer (10 dated layers). Three layers were not dated and the age was interpreted in relation to dated layers below and above the layer in question. The chronology follows archaeological periods and is given as cal BC/AD (Table 1).

Numerical analyses

CANOCO for Windows 4.5 (ter Braak and Šmilauer 1997–2009) was used to identify gradients in the datasets. Principal Component Analysis (PCA) was applied as a linear relationship (gradient length <2.0) was found by running DCA (Detrended Correspondence Analysis). Pollen percentages were square-root transformed to decrease the effect of high pollen producers. Centring/standardization by species were carried out. Charcoal and loss-on-ignition were treated as passive environmental variables in the PCA. The results are plotted using Canodraw for Windows 4.14 (Šmilauer 1999–2009). Zonation of the pollen diagrams are based on the methods SPLITLSQ and SPLITINF (Birks and Gordon 1985) in the program Zone 1.2 (Juggins 1991) as well as on PCA which generally gave the same results. Palynological richness was estimated using the programs RARECEP and RAREPOLL (Birks and Line 1992), where the calculation is based on the lowest (rarefied) pollen counts: 627 out of 58 samples from Herandsvatn and 573 out of 30 samples from Samland. This means that the two sites must be interpreted separately.

Reconstruction of past vegetation cover using LRA

The LRA (Sugita 2007a, b) was applied to estimate local vegetation cover in Herand for eleven time intervals. LRA consists of two sub-models: REVEALS (Regional Estimates of VEgetation Abundance from Large Sites) and LOVE (LOcal Vegetation Estimates) (Fig. 2a). The REVEALS model estimates regional vegetation cover from large sites, ≥100–500 ha (Sugita 2007a), whereas the LOVE model applies to smaller sites for reconstruction of vegetation cover within the Relevant Source Area of Pollen (RSAP) (Sugita 2007b). RSAP is defined as the area beyond where the relationship between pollen loading and vegetation does not improve (Sugita 1994). LRA is based on the Ring-Source model (Sugita et al. 1999); assuming that the basin is a circular opening in the landscape, pollen is dispersed predominantly by wind within a certain distance from all directions over the canopy. Relative Pollen Productivity Estimates (PPEs), which are input parameters to the model, are assumed to be species-specific constants.

The regional vegetation was estimated by running the model REVEALS on pollen data from a large lake, Kalandsvatn, situated c. 55 km from Herandsvatn (Figs. 1, 2a). Kalandsvatn reflects the regional vegetation for Herandsvatn (Hjelle et al. 2015), and the estimated regional vegetation is used as an input parameter in the LOVE model together with pollen data from Herandsvatn. In the LOVE model, the regional pollen component common for both sites is recognized, and the local vegetation cover within the RSAP in Herand is estimated. Pollen counts grouped into 200–700 year intervals following archaeological periods (Table 1), radius of the basin, fall

Table 1 Chronology of archaeological periods following Bergsvik (2002) for the Neolithic and Bronze Age, and Solberg (2003) for the Iron Age

Archaeological periods (abbreviations)	Age (BC/AD)	Kalandsvatn # Samples/pollen sum	Herandsvatn # Samples/pollen sum
Recent time	1900–2010	8/6,637	3/2,760
Historic time (HT)	AD 1536[a]–1900	4/3,630	3/2,648
Medieval time (MT)	AD 1030–1536[a]	6/5,705	28/25,945
Late Iron Age (LIA)–Viking period (VP)	AD 800–1030	4/3,820	6/5,718
Late Iron Age (LIA)–Merovingian period (MVP)	AD 570–800		
Early Iron Age (EIA)–Migration period (MP)	AD 400–570	4/3,769	3/2,452
Early Iron Age (EIA)–Roman Iron Age (RIA)	1 BC/AD–AD 400		
Early Iron Age (EIA)–Pre-Roman Iron Age (PRIA)	500 BC–1 BC/AD	3/2,725	2/1,746
Late Bronze Age (LBA)	1200–500 BC	4/3,904	2/1,948
Early Bronze Age (EBA)	1800–1200 BC	4/3,240	4/3,828
Late Neolithic (LN)	2300–1800 BC	3/2,928	2/1,909
Middle Neolithic B (MNB)	2600–2300 BC	1/1,017	2/1,816
Middle Neolithic A (MNA)	3300–2600 BC	1/914	3/2,838
Early Neolithic (EN)	4000–3300 BC		
Mesolithic	9200–4000 BC		

Number of samples and included pollen sum in LRA from the two lakes in relation to archaeological time periods

[a] The pollen samples are categorized up to or from AD 1600

Fig. 2 a Schematic presentation of LRA (Sugita 2013), **b** schematic presentation of landscape reconstruction using HUMPOL software, modified from Bunting and Middleton (2009)
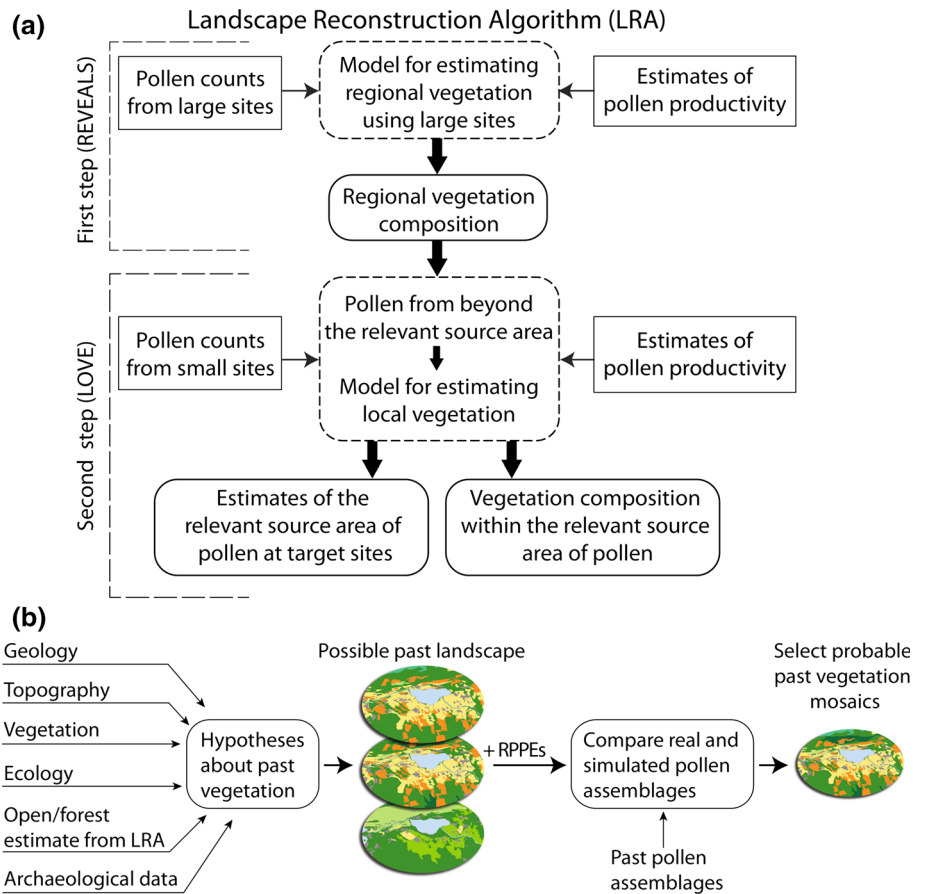
speed of pollen, and relative PPEs with their error estimates are input parameters. Eighteen mainly anemophilous taxa (Table 2) are used in the reconstructions. As PPEs for several taxa are lacking from western Norway, a combination of regionally derived estimates (Hjelle and Sugita 2012), PPE for Cerealia from Denmark (Nielsen 2004), and mean values from the LANDCLIM project (Mazier et al. 2012) are used. These PPEs are found to perform well in our region (Hjelle et al. 2015). REVEALS.v.4.5 and LOVE.v.4.6.2 were used (Sugita unpublished). In this version of the LOVE model, rare taxa are down-weighted resulting in a smaller estimated RSAP than in earlier versions of the program (Sugita, personal communication). The 18 taxa used in the LOVE reconstructions from Herandsvatn represent 86–96 % of $\sum P$, whereas 95–100 % of the total tree pollen is used.

Simulation of landscapes using HUMPOL

The HUMPOL (HUll Method of POLlen simulation) software (Bunting and Middleton 2005) was used to simulate pollen dispersal and deposition from a given landscape with the aim to identify potential past landscapes (Fig. 2b). Landscape scenarios were made for two time periods: (1) modern time to enable evaluation of the results given by the model, and (2) the Late Neolithic (2300–1800 cal BC) as a case study to enable understanding of the changes in the landscape taking place in this time period. The simulated pollen assemblages at the coring points in Herandsvatn (both time periods) and at Samland (Late Neolithic) for the different scenarios, are compared

to the counted pollen assemblages from the same sites and time periods.

Input parameters to HUMPOL are vegetation maps, relative PPEs, and fall speed of pollen (Table 2). Land-cover maps (AR50-maps available at http://skogoglandskap.no) with grid cells 3 × 3 m provided the basis for the landscape scenarios using ArcGIS (ArcMap 10.2), and were further transformed to be imported into HUMPOL. In HUMPOL, concentric rings of 10 m intervals from the coring point and the Sutton-Prentice dispersal model (Prentice 1985) are used. Assuming stable wind conditions during the flowering season, the wind speed was set to 3 m/s.

Two maps are combined in HUMPOL: a 20 × 20 km map representing the background pollen, and local maps representing the possible RSAP around Herandsvatn. Based on the LOVE-estimates for the 11 time intervals in Herandsvatn, an RSAP of 500 to 1,500 m was indicated. Several lakes are, however, needed to estimate RSAP (Sugita 2007b) and the results based on one lake only give an indication of the range of the RSAP. 900–1,100 m was estimated using the extended R-value (ERV) model on similar-sized lakes in the region (Hjelle and Sugita 2012). From this as well as the results from LOVE, a map with a radius of 900 m was made for AD 2003. Based on LOVE, maps of radius 1,500 m was made for the Late Neolithic. Within these radii, the vegetation classes are more detailed than outside the RSAP. The results of REVEALS-based estimates of forested and open vegetation based on the pollen data from Kalandsvatn form the vegetation of the 20 × 20 km map beyond the RSAP, whereas LOVE-based estimates from Herandsvatn make the basis for some of the

Table 2 Pollen productivity estimates (PPE) and fall speed of pollen for 18 taxa used in REVEALS and LOVE

Taxa	PPE	SE	Fall speed (m/s)	References
Alnus	3.22	0.22	0.021	Hjelle and Sugita (2012)
Betula	3.09	0.27	0.024	Mazier et al. (2012)
Calluna vulgaris	0.87	0.05	0.038	Hjelle and Sugita (2012)
Cerealia	0.747	0.039	0.060	Nielsen (2004)
Corylus	1.99	0.20	0.025	Mazier et al. (2012)
Cyperaceae	1.37	0.21	0.035	Hjelle and Sugita (2012)
Filipendula	2.81	0.43	0.006	Mazier et al. (2012)
Fraxinus	1.03	0.11	0.022	Mazier et al. (2012)
Juniperus	0.79	0.21	0.016	Hjelle and Sugita (2012)
Picea	1.20	0.04	0.056	Hjelle and Sugita (2012)
Pinus	5.73	0.07	0.031	Hjelle and Sugita (2012)
Plantago lanceolata	1.04	0.09	0.029	Mazier et al. (2012)
Poaceae	1	0	0.035	
Quercus	1.30	0.10	0.035	Hjelle and Sugita (2012)
Rumex acetosa	0.39	0.10	0.018	Hjelle and Sugita (2012)
Salix	0.62	0.11	0.022	Hjelle and Sugita (2012)
Tilia	0.80	0.03	0.032	Mazier et al. (2012)
Ulmus	1.27	0.05	0.032	Mazier et al. (2012)

Fig. 3 Age-depth model for the sediment cores from Herandsvatn in cm below water surface: **a** core 2010 showing stable sedimentation rate, **b** core 2006 showing increased sedimentation rate from AD 1000. The cores are combined at the level AD 1000
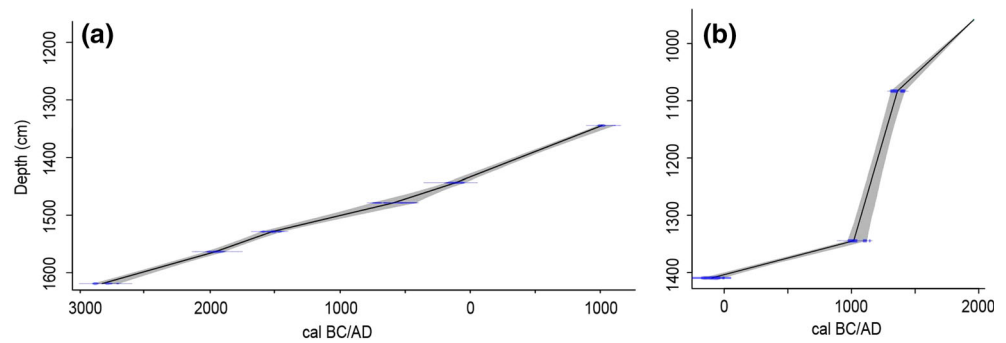
Table 3 Radiocarbon dates from Herandsvatn and Samland soil profile (Bergsvik and Høeg 2013) calibrated using clam (Blaauw 2010) within 2 σ

Lab. number	Depth/layer	Material dated	Age ^{14}C year BP	Age cal year BC/AD
Herandsvatn	Depth (cm)			
Beta-338800	958.5–959.5	Bulk sediments	128.4 ± 0.3pMC	–
TRa-1054	1,083–1,089	Plant remains	570 ± 30	AD 1305–1422
TRa-1053[a]	1,344.5–1,350	Plant remains	1,015 ± 30	AD 972–1148
TUa-6447A	1,409.5–1,410.5	Plant remains	2,075 ± 25	173–39 BC
TRa-2959[a]	1,344.5–1,345.5	Plant remains	1,015 ± 25	AD 979–1117
Beta-338802	1,443.5–1,444.5	Plant remains	2,090 ± 30	192–44 BC
Beta-338803	1,478.5–1,479.5	Plant remains	2,450 ± 30	753–412 BC
TRa-2958	1,528.5–1,529.5	Plant remains	3,245 ± 30	1610–1448 BC
Beta-338801	1,563.5–1,564.5	Plant remains	3,600 ± 30	2028–1889 BC
Beta-285577	1,619–1,620	Plant remains	4,230 ± 40	2912–2679 BC
Samland	Stratigraphic layer			
TUa-7973	104-2	Chracoal, birch	830 ± 35	AD 1060–1271
TUa-7974	104-4	Charred *Hordeum*	1,360 ± 30	AD 617–762
TUa-7975	104-6	Charcoal, birch	1,605 ± 30	AD 398–537
TUa-7976	104-7	Charcoal, birch	1,725 ± 35	AD 241–393
TUa-7977	104-8	Charcoal, birch	1,855 ± 35	AD 79–237
TUa-7978	104-9	Charcoal, birch	2,265 ± 35	399–209 BC
TUa-7979	104-10	Charcoal, birch	3,030 ± 30	1395–1136 BC
TUa-7980	104-11	Charcoal, birch	3,115 ± 35	1487–1282 BC
TUa-7981	104-12	Charcoal, birch	3,610 ± 35	2117–1886 BC
TUa-7982	104-15	Charcoal, birch	4,940 ± 40	3792–3648 BC

The top four dates for Herandsvatn are from a core collected in 2006, whereas the bottom six dates are from a core collected in 2010

[a] Dates from cores 2006 and 2010 are correlated at this point

maps and simulations using HUMPOL. In addition to the land-cover maps, bedrock, soil, slope, vegetation knowledge and archaeological data provide input for defining vegetation types in different areas in the Late Neolithic.

To evaluate the simulation models, the vegetation in the village was studied and compared to aerial photographs and a land-cover map. Field surveys were carried out and plant abundance (percentage cover) was recorded for principal taxa at c. three points within each of the seven vegetation types, and a mean value calculated for each taxon and vegetation type.

For the Late Neolithic landscape, 10 m higher sea-level was corrected for (Romundset et al. 2009) and four different landscape scenarios are presented: (i) only openings outside Herand (10 % as estimated from REVEALS for that time period) to test how background pollen is reflected in Herandsvatn and at Samland, (ii) openings at Samland and Nedre Trå, the two sites documented through archaeological investigations, and 10 % openings outside the RSAP, (iii) 10 % openness as reflected from REVEALS and LOVE reconstructions both within and outside the RSAP, (iv) two openings and an open forest within the
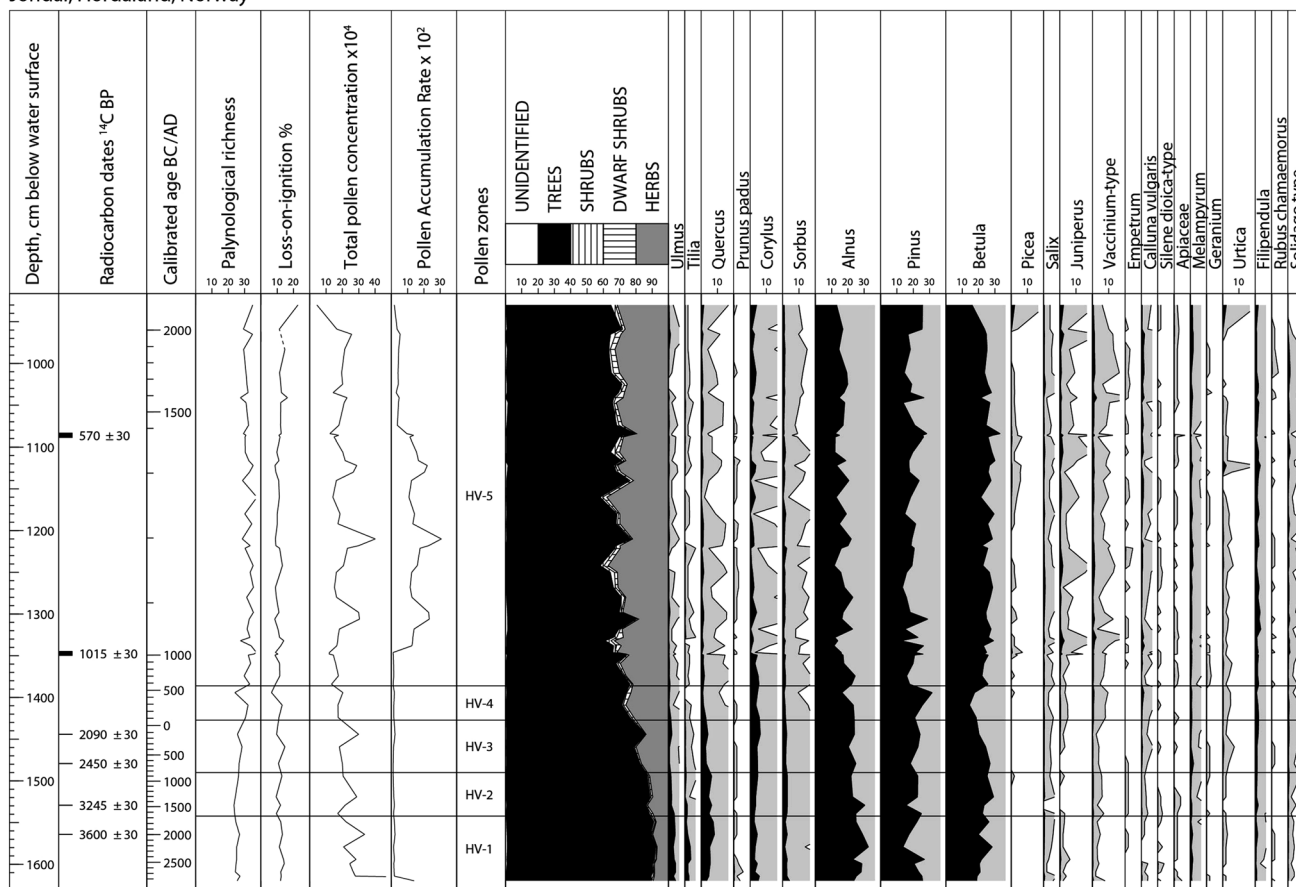
Fig. 4 Pollen percentage diagram from lake Herandsvatn given in calibrated age BC/AD. On the left hand side are curves showing palynological richness, loss-on-ignition, total pollen concentration and pollen accumulation rate. *Black curves* show percentages, *shaded curves* ×10 exaggerations. The scale for taxa not given in the figure is 10 %. Charcoal particles of size >10 μm were counted

RSAP (giving c. 9 % openness), 10 % openness outside the RSAP. In addition to the open vegetation type, five different forest types are used: mixed oak forest to the east and south of the lake, broadleaved forest north of the lake, pine forest on the hills north of the lake, deciduous forest with pine in most parts of Herand, and mixed regional forest as a general forest type outside the RSAP.

The results of the simulated pollen assemblages for the two time windows were compared to counted pollen from Herandsvatn in the level ^{210}Pb-dated to AD 2003, and to the mean of the two analysed samples from the Late Neolithic (cf. Table 1).

Results and interpretation

Investigated deposits and chronology

The investigated sediments from Herandsvatn are gyttja containing some plant macro remains and minerogenic

particles, but with small changes throughout the cores, as reflected in the loss-on-ignition (Fig. 4). Loss-on-ignition cannot therefore be used to support the dating chronology of the two separate fieldwork years. The age-depth model for the 2006 and 2010 cores from Herandsvatn using linear interpolation is shown in Fig. 3. Both cores had two identical dates for two levels taken at intervals of 95 and 97 cm in the respective cores (2006 core: 1,015 ± 30 and 2,075 ± 30 BP, 2010 core: 1,015 ± 25 BP and 2,090 ± 30 BP, see Table 3). Based on this, the two cores are combined at the level dated 1,015 ± 30 BP from the 2006 core and the comparable date 1,015 ± 25 BP from the 2010 core. Sediments below this level represent the 2010 core, above the 2006 core. Depths of the 2010 core samples are adjusted according to the 2006 core. Also the depths from the two samples included from the HTH core, dated to AD 2003 and 1960 respectively, are adjusted to the 2006 core.

Figure 3 shows a relatively constant sedimentation rate of c. 0.06 cm/year, up to the level dated 1015 ± 30 BP. This is followed by a marked increase in sedimentation,
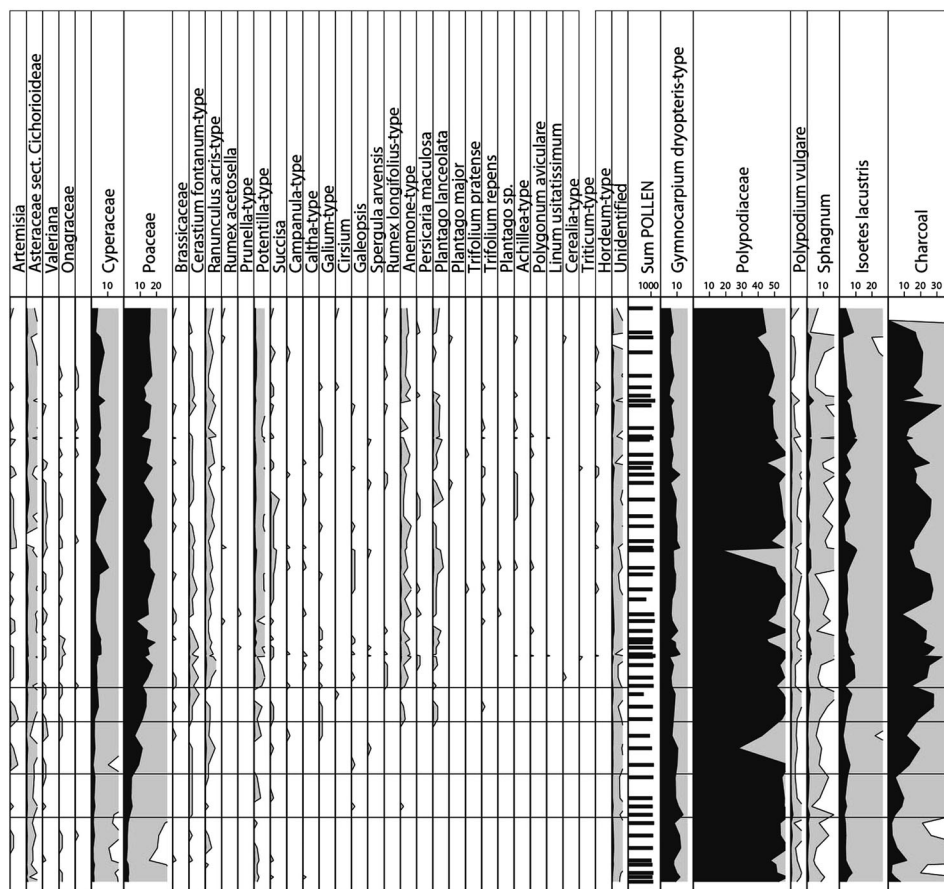
Analysis: Ingvild K. Mehl 2011

Fig. 4 continued

together with increases in the pollen accumulation rate and pollen concentration. Increase in all these parameters may be an indication that erosion has taken place.

The investigated site at Samland comprises different stratigraphic layers where some are natural and others highly influenced by human activity. Charred plant material (including one cereal grain) from 10 of the 16 stratigraphic layers is dated, reflecting the cultural origin of these layers. The chronology of the analysed samples follows the respective layers (Fig. 5).

Pollen diagrams and vegetation development

The pollen diagram from Herandsvatn is divided into five pollen assemblage zones (Fig. 4; Table 4). PCA illustrates the vegetation development from forest to open landscape (Fig. 6), as also recognised in the pollen diagram and LOVE reconstruction. The first axis explains 46.3 % of the species distribution and reflects forest versus open vegetation, whereas the second axis explains only 7.7 %

probably reflecting different vegetation types and land-use practices.

Zone HV-1 is found at the right-hand side of the PCA biplot (Fig. 6) and is clearly separated from the other zones and strongly associated with the deciduous broadleaved trees *Tilia*, *Ulmus*, *Alnus*, *Quercus* and *Corylus*. Zones HV-2 and HV-3 are also forest dominated zones correlated to deciduous trees, but a change in vegetation development and openness is indicated by their respective positions closer to the centre of the ordination plot. A further change in openness and also a change in forest composition are indicated in the position of zone HV-4, influenced by the higher values of *Pinus*. Zone HV-5 is mainly found on the negative side of the first axis, but spread along the second axis. This probably indicates that several vegetation types are represented, but without a temporal differentiation within the zone. In the upper part of Fig. 6 (left panel), species reflecting outfield pastures, such as *Juniperus*, *Calluna*, *Vaccinium*-type and Cyperaceae are found, whereas cereals and common arable weeds (cf. Behre

Samland
Jondal, Hordaland, Norway
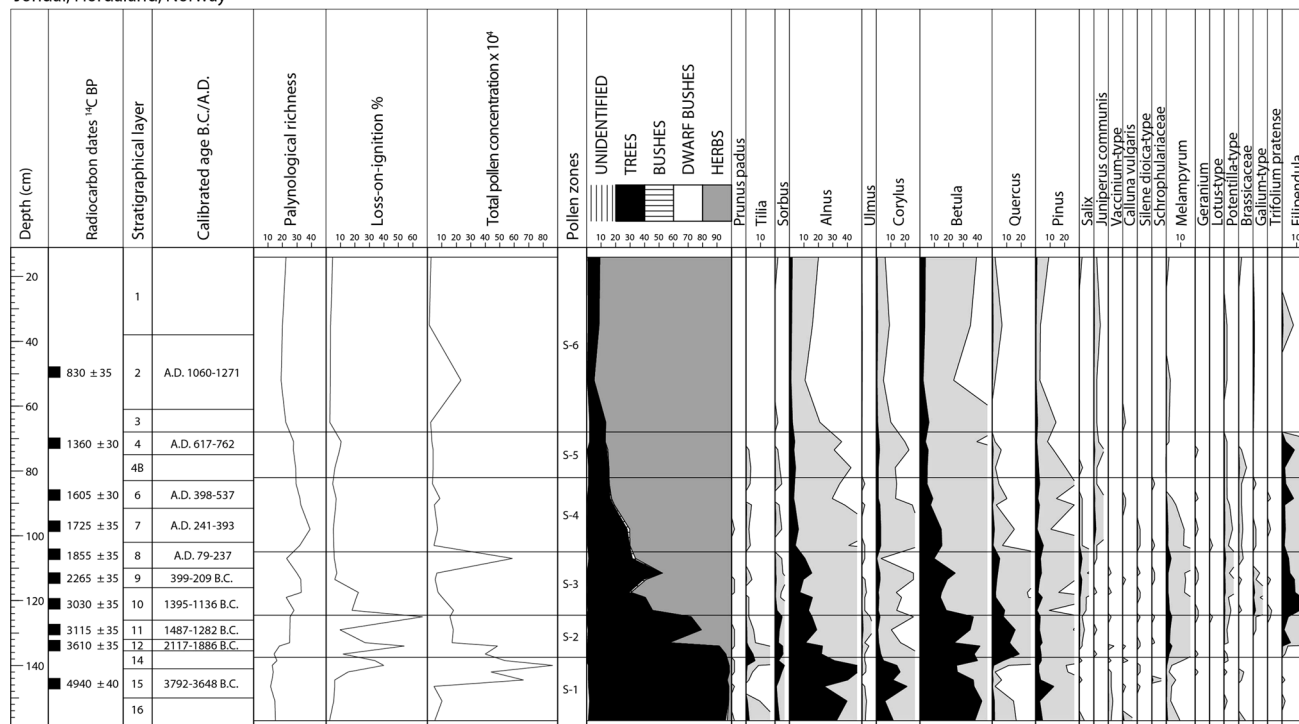
Fig. 5 Pollen percentage diagram from the soil profile at Samland given in calibrated age BC/AD within archaeological layers. At the *left, curves* for palynological richness, loss-on-ignition and total pollen concentration are shown. *Black curves* show percentages, *shaded*

curves ×10 exaggerations. Stratigraphical layers: Silt and sand 15, 16; Peat 14; Silt and sand layers with macroscopic charcoal 12–1. The scale for taxa not given in the figure is 10 %. Charcoal particles of size >10 μm were counted

1981) such as Chenopodiaceae are found in the lower part of the diagram. *Plantago lanceolata*, Poaceae, *Anemone*-type, *Cerastium fontanum*-type and *Ranunculus acris*-type are strongly correlated to the first axis and characterize this zone together with charcoal. The position of LOI on Fig. 6 may indicate that zone HV-5 is more minerogenic than the previous zones.

The pollen diagram from Samland is divided into six pollen assemblage zones (Fig. 7; Table 5). The first PCA axis explains 65.6 % of the species distribution, reflecting forest versus open landscape, while the second axis explains 12.8 % and may reflect different human influenced vegetation types and land-use practices (Table 5).

Zone S-1 is found at the lower right hand side clearly separated from the other zones. Forest trees such as *Corylus, Alnus, Pinus, Tilia, Betula* and *Sorbus* are found connected to this zone. Zone S-2 is also found on the right hand side, but at the upper part connected to *Quercus, Ulmus* and *Melampyrum,* and may represent more light-open conditions than S-1. Zone S-3 is found next to S-2 and closely correlated to *Filipendula, Potentilla*-type, *Galium*-type and *Salix,* which point to open and humid conditions. Zone S-4 is found at the left hand side of the first axis, representing an open cultural landscape with species such

as *Rumex acetosa*-type, *Cerastium fontanum*-type, Poaceae, *Ranunculus acris*-type, *Urtica* and Chenopodiaceae. Zones S-5 and S-6 are found closely related to *Plantago lanceolata, Anemone*-type and Asteraceae sect. Cichorioideae, and are correlated to charcoal.

LOVE-based estimates of vegetation cover based on pollen records from Herandsvatn

The LOVE-based estimates of vegetation cover indicate that *Alnus, Betula* and Poaceae have been important in the vegetation in Herand through all archaeological time periods (Table 1; Fig. 8). *Alnus* and *Betula* have c. 20–30 % and 5–25 % estimated cover, respectively, except that *Betula* is estimated to have no or very low cover within the time period 2800–2300 cal BC. Between 2800 and 2600 cal BC estimated forest cover is c. 75 %, where *Alnus* (30 %), *Pinus* (<10 %) and broadleaved trees such as *Corylus* (10 %), *Tilia* (15 %) and *Ulmus* (10 %) dominate. Poaceae has c.10 % LOVE-estimated cover. Some changes are seen from 2600 cal BC, with no estimated cover of *Pinus*, >10 % cover of *Quercus*, and maximum cover of *Tilia* (c. 25 %). Poaceae has c. 10 % cover. The most visible change in the period 2300–1800 cal BC is the strong
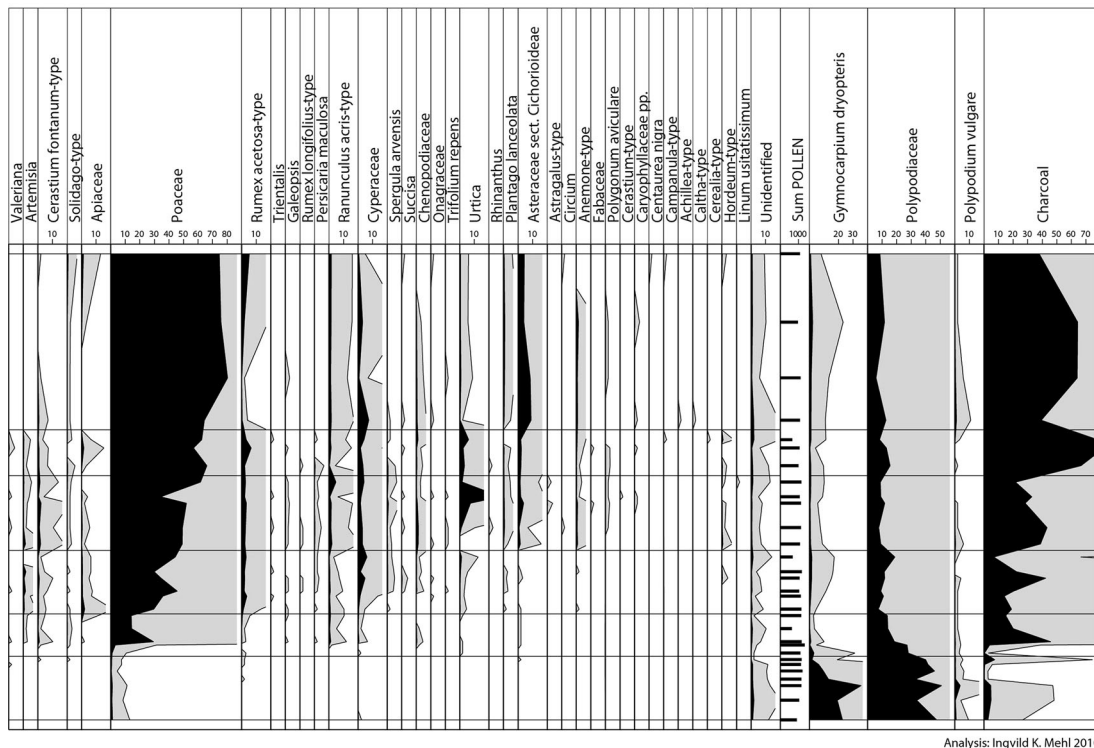
Analysis: Ingvild K. Mehl 2010

Fig. 5 continued

increase of *Betula* that is estimated with c. 20 % cover. *Alnus* and *Quercus* show small increases, whereas *Tilia* and *Ulmus* decrease. Poaceae decreases to its minimum cover of c. 5 %. Most forest trees decrease between 1800 and 1200 cal BC, except *Betula* and *Quercus* that have maximum cover of c. 25 and 15 %, respectively. Poaceae increases to >10 % estimated cover. All deciduous trees decrease between 1200 and 500 cal BC, whereas Poaceae shows a strong increase (to c. 25 %). There is a change in forest composition from 500 cal BC onwards, as *Pinus* changes from almost no cover, to 10 % estimated cover. In addition, *Ulmus* increases to 5 % from no estimated cover in the period 1200–500 cal BC. There are also small increases of cover for *Betula* and *Corylus*, whereas the estimated cover of Poaceae decreases to c. 15 %. In the last 2000 years forest cover is at its lowest, while open vegetation cover is estimated to 30–40 %, dominated by Poaceae. Cerealia has a low estimated cover from AD 1600.

According to the LOVE model, *Tilia*, *Ulmus*, *Quercus* and open-land taxa have been more important in the vegetation than their pollen percentages indicate, whereas *Pinus* has been less important in the vegetation surrounding Herandsvatn.

RSAP varies through all time periods (Fig. 8) and is at a maximum of c. 1,500 m between 2300 and 1800 cal BC and between AD 1030 and 1600, and at a minimum of c. 500 m 2800–2600 cal BC.

Simulation of different landscape scenarios

Simulations of pollen deposition in Herandsvatn based on the AD 2003 vegetation map (Fig. 9, Table 6) show a good agreement with counted pollen from the lake. Although the map is a simplification of the vegetation in Herand today, the results indicate that the approach may be applied also to the Late Neolithic time period. In this time period, the pollen percentages from the soil profile at Samland indicate more opening of the vegetation than the pollen percentages from the lake indicate. The four scenarios presented (Fig. 10, Table 6) are an aid to understand this difference.

The simulation of no openings within the RSAP but 10 % openings within 20 × 20 km (scenario i) as estimated by REVEALS on the large lake, shows that openings outside the RSAP have little impact on the pollen composition in Herandsvatn and Samland. The presence of cultural layers dated to the Late Neolithic suggests an

Table 4 Pollen assemblage zones (PAZ) and interpretation of the pollen diagram from Herandsvatn

| PAZ	Depth, age, archaeological period	Pollen zone features	Interpretation
HV-5	939.5–1386 cm, c. AD 550–1960 Migration period–recent time	AP between 60–80 %. *Alnus* 10–15 %, *Pinus* 10–25 %, *Betula* 20–25 %. Decrease of *Ulmus*, *Quercus* and *Corylus*. Nearly continuous curve for *Picea* in the upper part. Increase of *Salix*, *Juniperus*, *Vaccinium*-type, *Calluna vulgaris*, *Rumex acetosa*-type, *Urtica*, *Ranunculus acris*-type, *Potentilla*-type, *Anemone*-type, *Plantago lanceolata*, Cyperaceae and Poaceae (15 %). First occurrences of *Triticum* and *Hordeum*-type, *Persicaria maculosa*-type, *Rumex longifolius*-type, *Polygonum aviculare*. *Linum usitatissimum* at two intervals; between AD 972–1148 and 1305–1422. Increase of palynological richness. Charcoal between 10 and 30 %. Strong increase in pollen accumulation rate c. AD 1000–1400	*Intensive farming with cultivation of cereals and flax*
HV-4	1386–1427 cm, c. AD 50–550, Roman Iron Age–Migration period	AP decrease from c. 75 to 70 % at c. AD 300, then increase to 75 %. C. 20 % *Alnus*, *Pinus* increases from 20 to 30 %. *Betula* c. 15 %, decreases to 10 %, increases to >20 %. Small increase of *Vaccinium*-type, *Calluna vulgaris*, *Artemisia* and *Cerastium fontanum*-type. First occurrences of *Plantago lanceolata*, *Trifolium*-type and Chenopodiaceae. Noticeable increase of Cyperaceae and Poaceae. Small increase of palynological richness. Charcoal increases to c. 30 %	*More extensive forest clearances, further intensification of human activity*
HV-3	1427–1490 cm, c. 850 cal BC–AD 50 Late Bronze Age–Roman Iron Age	AP decrease from c. 85 to 75 % at 350 cal BC, increase to 85 % at c. 150 cal BC, followed by decrease to c. 75 %. *Alnus* and *Pinus* c. 20 and 25 %, respectively. *Betula* decreases from c. 25 to 15 %. Slight increase of *Ulmus* and *Corylus*, decrease of *Tilia* and *Quercus*. Small increase of *Calluna vulgaris*, *Melampyrum*, *Solidago*-type, *Urtica* and *Ranunculus acris*-type. Noticeable increase of Poaceae from c. 5 to 10 %, decrease at 350 cal BC to 5 % followed by increase. Increase of charcoal	*Some forest clearances, intensification of human activity* *Erosion*
HV-2	1490–1542 cm, c. 1650–850 cal BC Early Bronze Age–Late Bronze Age	AP decrease from c. 88 to <85 % c. 1500 cal BC, followed by increase to >85 %, then gradual decrease. *Alnus*, *Pinus* and *Betula* dominate by c. 20, 20 and 30 %, respectively. *Ulmus* and *Tilia* decrease, *Corylus* <5 % and increases slightly. *Quercus* c. 5 %. Slight increase of *Solidago*-type, Cyperaceae and Poaceae. *Cerastium fontanum*-type continuous curve. Increase of charcoal	*Small forest clearances and increase of human activity*
HV-1	1542–1620 cm, c. 2750–1650 cal BC Middle Neolithic A–Early Bronze Age	AP around 90 %. *Alnus*, *Pinus* and *Betula* dominate. Slight decrease of AP c. 2000 cal BC *Ulmus* and *Corylus* <5 %, decrease of *Tilia*, increase of *Quercus* to >5 %. Continuous curves for Apiaceae, *Melampyrum*, *Rumex acetosa*-type, *Urtica*, *Filipendula*, *Solidago*-type, Asteraceae sect. Cichorioideae and Cyperaceae. Poaceae c. 3 %, slight decrease c. 2500 cal BC, increases at the end of the zone. Charcoal varies	*Forested landscape*

opening at Nedre Trå (Narmo, personal communication) in addition to Samland. However, simulated pollen deposition for this landscape (scenario ii) gives higher values of tree pollen at both Herandsvatn and Samland than the counted pollen, indicating that there should be more open patches in Herand. When 10 % openings are simulated both within and outside the RSAP, as reflected from the LRA-estimated cover for this period (scenario iii), as well as two openings and one open forest type within the RSAP (scenario iv), the simulated pollen assemblages are more comparable to the counted pollen assemblages. The results indicate that openings of the forest at Samland may result in less tree

pollen deposited at this site than in Herandsvatn, in accordance with the counted pollen assemblages.

Discussion

Development of farming in the Neolithic (4000–1800 cal BC)

The pollen source area depends on the size of the investigated basin and, in forested time periods, lake sediments will reflect a larger area than a soil profile/forest hollow
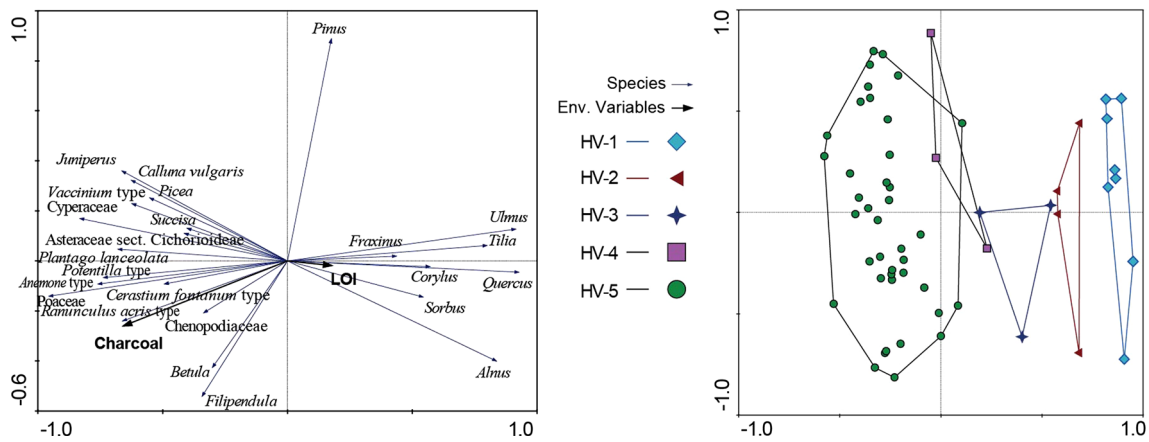
Fig. 6 Principal Component Analysis (PCA) of samples from Herandsvatn. Pollen zones HV-1 to HV-6 refer to the pollen diagram. The gradient from the *right* to the *left* reflects forest versus open vegetation. Eigenvalue of the *first axis* is 0.463 and for the *second axis* 0.076
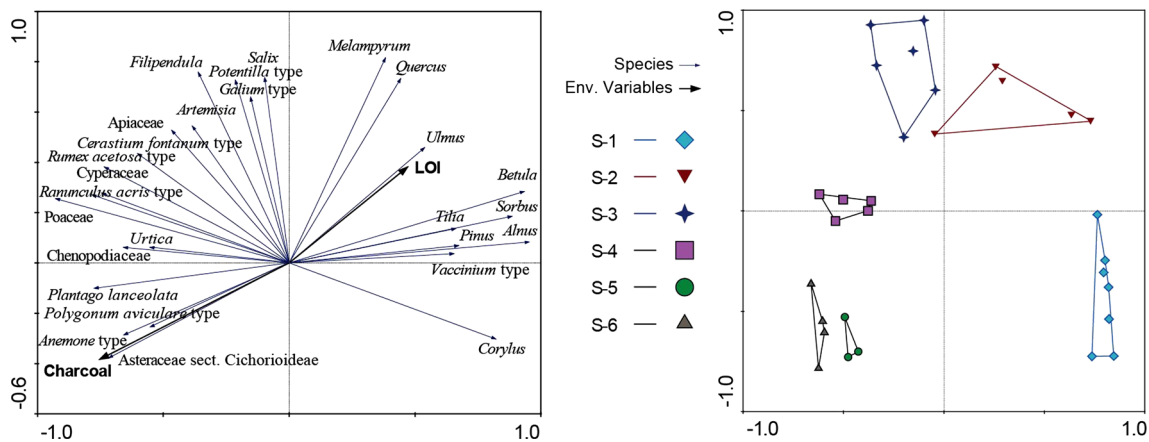
Fig. 7 Principal Component Analysis (PCA) of samples from Samland. Pollen zones S-1 to S-6 refer to the pollen diagram. The gradients show forest versus open vegetation and differences in land-use. Eigenvalue of the *first axis* is 0.656 and for the *second axis* 0.128

(Sugita 1994). Following this, pollen in Herandsvatn originates from a larger area compared to Samland during the Neolithic time period. As indicated by the pollen percentage diagram from Samland (Fig. 5) and the corresponding PCA-plot (Fig. 7), Herand was probably densely forested from the Late Mesolithic (LM) through the Early Neolithic (EN) and Middle Neolithic (MN) time periods. *Alnus* and *Betula* were important, and some *Corylus* and *Pinus* may have been present. The same species are important in the pollen percentage diagram from Herandsvatn, whereas the LOVE reconstruction (Fig. 8) suggests that *Alnus* dominated, while *Betula* hardly had any cover until c. 2300 cal BC. A minor decrease in trees and increase in herbs and charcoal is inferred from the pollen percentages at Samland in the Early Neolithic, possibly caused by human activity. There are no archaeological finds in the rock shelters dated to the Neolithic, which may

indicate that human activity took place in other parts of Herand. In this period, only stray finds of anthropogenic indicators (Behre 1981), such as *Filipendula, Potentilla*-type and *Melampyrum* are registered. The nearest finding of *Plantago lanceolata* dated to the EN is just across the Hardangerfjord in relation to Herand (Prøsch-Danielsen 1984). A slight decrease in forest and registration of *Plantago lanceolata* are noted for the regional vegetation cover from Kalandsvatn (Mehl and Hjelle 2015), suggesting human activity and the existence of small grazed areas within the region from the Early Neolithic time period. More data are needed to support this interpretation of vegetation and human activity in Herand.

Relatively high LOVE-estimated cover of broadleaved trees based on the pollen data from Herandsvatn in the Neolithic (between 35 and 45 % altogether for *Corylus, Tilia* and *Ulmus*) reflects favourable soil and climate.

Table 5 Pollen assemblage zones (PAZ) and interpretation of the pollen diagram from Samland

PAZ	Age, depth	Pollen zone features	Interpretation
S-6	0–68 cm, Migration Period– Medieval time	AP decrease from c. 12 to 10 %. Poaceae c. 75–80 %, Cyperaceae nearly 10 % in the earliest part, decreases to c. 2 %. *Rumex acetosa*-type c. 0.5–5 %, Asteraceae sect. Cichorioideae c. 10–5 %. Apiaceae continuous curve in the upper part; *Solidago*-type, *Plantago lanceolata* and *Urtica* continuous curves throughout the zone. Chenopodiaceae and *Anemone*-type high values. *Hordeum*-type present in the upper sample. Further decrease in palynological richness. Charcoal 35–60 %. LOI c. 5 %. Increase of pollen concentration	Intensive farming
S-5	68–82 cm, Migration period– Merovingian period	AP decrease from c. 15 to 12 %. *Betula* c. 5 %, *Alnus* <5 %. Poaceae between 55 and 65 %, *Filipendula* and *Rumex acetosa*-type a peak of nearly 10 %. *Ranunculus acris,* Asteraceae sect. Cichorioideae, Apiaceae, Chenopodiaceae, *Cerastium fontanum*-type, *Artemisia* and *Urtica* relatively high values. *Plantago lanceolata, Persicaria maculosa, Spergula arvensis, Hordeum*-type, Brassicaceae, *Polygonum aviculare* and *Solidago*-type present. Decrease in, but still high palynological richness. Charcoal >70 %. LOI >10 %	Intensive farming with cultivation of cereals
S-4	82–105 cm, Roman Iron Age– Migration period	AP decrease from c. 30 to 15 %. *Betula* decreases from c. 15 to 5 %, *Corylus* c. 2 %, *Pinus* and *Quercus* decrease. Continuous curves of *Juniperus* and *Salix*. Cyperaceae decreases from c. 5 to 2 %. Poaceae around 50 %. Relatively high values of *Filipendula*, *Rumex acetosa*-type, *Ranunculus acris*-type, *Potentilla*-type, Asteraceae sect. Cichorioideae, Brassicaceae, *Cerastium fontanum*-type, *Galeopsis*-type, Chenopodiaceae, *Persicaria maculosa*, *Spergula arvensis* and *Plantago lanceolata*. *Hordeum*-type appears frequently and one pollen grain of *Linum usitatissimum*. Max. palynological richness. Charcoal between 8 and 40 %. LOI c. 8 %	Forest clearances, intensification of farming, cultivation of cereals and flax
S-3	105–124.5 cm, Late Bronze Age– Roman Iron Age	AP decrease from c. 60 to 30 % in the first part, then c. 50 % until another decrease to 30 %. *Betula* c. 10–25 %, *Alnus* 5–15 %, *Pinus* 2–3 %. *Quercus* <10 %. *Filipendula* decreases from c. 12 to 5 %. Cyperaceae increases to nearly 5 %. Poaceae c. 30–45 %. Relatively high values of *Rumex acetosa*-type, *Ranunculus acris*-type, *Potentilla*-type, Apiaceae, *Cerastium fontanum*-type, *Galium*-type, *Melampyrum,Urtica, Spergula arvensis* and *Artemisia. Plantago lanceolata,* Chenopodiaceae and *Persicaria maculosa* present. First occurrence of *Hordeum*-type. Further increase in palynological richness. Charcoal a peak of c. 40 % in the middle of the zone. LOI decreases from c. 20 to 5 %. Increased pollen concentration in the upper part	Farming with cereal cultivation
S-2	124.5–137.5 cm, Late Neolithic–Late Bronze Age	>95 % AP at the onset of the zone, small decrease followed by an abrupt decrease to <60 % and new increase to c. 75 %. *Betula* 30–40 %, *Alnus* from 25 to 12 %, *Corylus* decreases to c. 2 %. *Quercus* max. of >15 %, decreases gradually to <10 %. *Tilia* c. 5 % in the onset of the zone, decreases to c. 1 %. Max. values of *Ulmus* and *Sorbus*. *Filipendula* around 5 %, Poaceae from 1 to nearly 30 % in the earliest part, decreases to c. 12 %. More or less continuous curves of *Rumex acetosa*-type, *Ranunculus acris*-type, *Urtica, Potentilla*-type, Asteraceae sect. Cichorioideae, *Cerastium fontanum*-type, *Melampyrum, Solidago*-type and *Artemisia*. First occurrences of Chenopodiaceae and *Persicaria maculosa*. Increase in palynological richness, decrease in pollen concentration. Charcoal and LOI vary	Broad-leaved forest and human activity
S-1	137.5–157 cm, Early Neolithic– Middle Neolithic	AP >95 %. *Betula* max. of c. 40 % in the first part, then varies. *Alnus* max. around 50 %, *Corylus* max. of c. 20 %, *Pinus* max. of c. 12 %. Low values of *Quercus, Tilia* and *Ulmus*. A few occurrences of *Filipendula, Rumex acetosa*-type, *Potentilla*-type, Brassicaceae and *Silene dioica*-type. *Melampyrum* continuous curve. Charcoal 1–5. LOI increases to nearly 40 %. Increased pollen concentration	Deciduous forest

However, these trees decrease gradually, while LOVE-estimated cover of *Quercus* increases to >10 %. An increase of estimated *Betula* cover from 2300–1800 cal BC at the expense of broadleaved trees reflects forest disturbance. Disturbances are also indicated at Samland, where fluctuations in the *Betula* pollen percentages and a more open
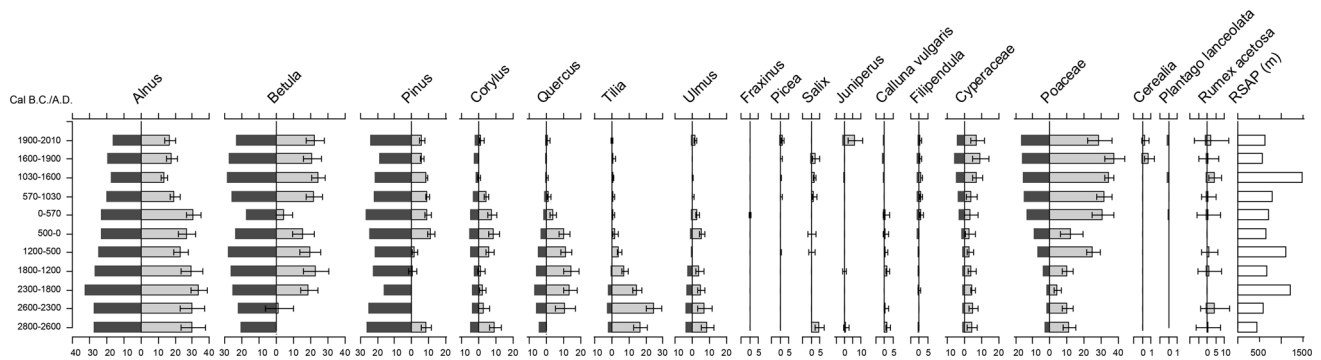
Fig. 8 Comparison of pollen percentages (*dark grey*) and LOVE-estimated cover (*light grey*) for 18 taxa from Herandsvatn in archaeological time periods. The relevant source area of pollen (RSAP) for each time period is shown at the right hand side

forest are indicated in the same time period. *Betula* has high colonizing ability (Rackham 1980; Rasmussen 2005) and was probably a pioneer tree in the cultural landscape in Herand. The LRA-based cover estimates from Herandsvatn and pollen percentages from Samland indicate different forest development in the Late Neolithic in the respective sites. Increased forest cover is inferred from Herandsvatn in contrast to a decrease in forest at Samland. However, the pollen concentration of tree taxa at Samland remains high throughout the Neolithic (results not shown), showing the continued presence of trees. The LOI curve from Samland reflects peat accumulation in the period prior to the LN, which was probably caused by deforestation resulting in groundwater rise (Kaland 1986), supporting the changes seen in tree composition. The pollen diagram from Samland shows continuous curves of anthropogenic indicators (cf. Behre 1981), suggesting improved light conditions, most likely caused by forest clearances, indicating farming activity in the LN.

The potential vegetation in the Late Neolithic is demonstrated by simulations of the LN landscape (Fig. 10). Comparison of scenario (i) against the three other options (ii, iii and iv), demonstrates that openings in the forest within the RSAP have existed. Where these openings were located is, however, more unclear. Openings are documented at Samland and Nedre Trå. From historical sources, Samland was the earliest inhabited farm in Herand (Losnegård 2006), which also stresses the potential cultivation of Samland further back in time. However, as indicated from the simulations (scenario ii), we assume that Samland and Nedre Trå were not the only open areas in Herand. Samland is located c. 80 m a.s.l. at some distance from the fjord, and thus is unlikely to be the first place at which people arrived. Forest clearance with the aim of creating openings for domestic animals and cultivation therefore probably took place at several places in Herand in the Late Neolithic, in line with the development in other areas by

the Hardangerfjord (Halvorsen 2007a, 2009). The LRA-based estimates indicate around 10 % openness both within RSAP and on a regional scale. When 10 % openness is used in the simulations, comparable results for simulated pollen and counted pollen assemblages were found. This is a good indication that the models are reliable. Where these openings were found, and whether it was larger openings without forest or a more open forest, are so far open questions. As shown by the different scenarios, and several scenarios not shown, there are several possibilities for the size of the openings and where these may be found.

Expansion of farming in the Bronze Age (1800–500 cal BC)

Both the pollen diagram (zone HV-2 and beginning of HV-3) and the LOVE-based reconstruction from Herandsvatn reflect increased openness in the EBA compared to the Neolithic. This is further supported by the PCA plot (Fig. 6) which shows changes in species composition probably related to higher openness, grazing and perhaps also cultivation, although not documented. The small-scale farming indicated at Samland in the LN probably expanded in the EBA, a pattern also recognized regionally (Bakka and Kaland 1971; Diinhoff 1999; Øye 2002; Myhre 2004; Overland and Hjelle 2009) as well as in the Hardangerfjord region (Halvorsen 2007b; Hjelle 2008). In Hordaland County, the Hardangerfjord is one among few areas that have relatively large concentrations of rock art connected to Bronze Age farming societies (Dodd 2010; Wrigglesworth 2011). In addition, Bronze Age layers in a rock shelter revealed domestic mammal bones (Hufthammer, personal communication), which supports the existence of pastures interpreted from the botanical data.

Increased palynological richness at Samland seen from the stratigraphic layers (10 and 11) dated to the Bronze Age (Fig. 5) probably reflects larger forest clearances, improved
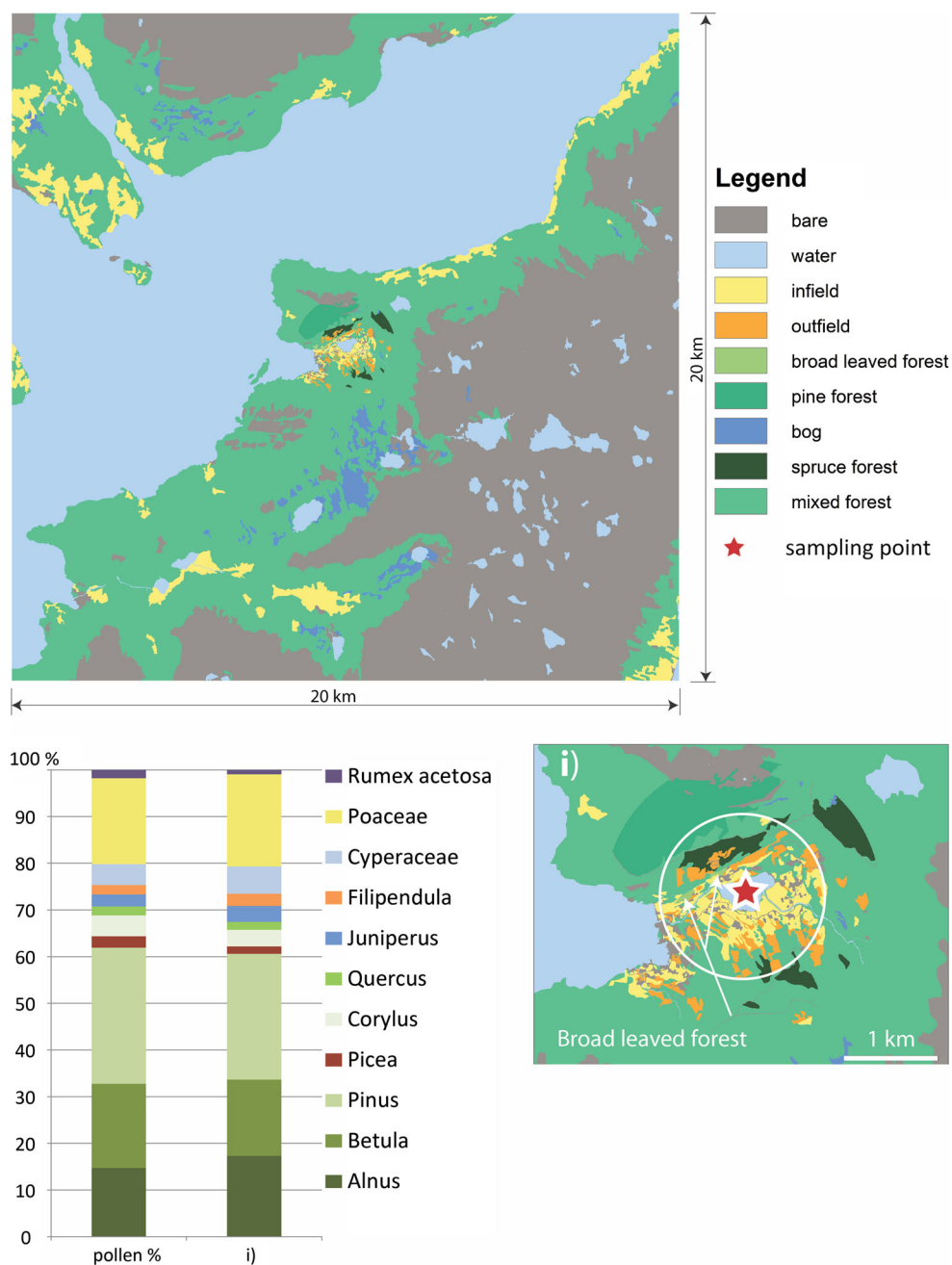
Fig. 9 Simulated landscape at AD 2003 in Herand with seven different vegetation types. More detailed vegetation cover is given within the relevant source area of pollen (RSAP) of c. 900 m, while a general vegetation cover is simulated outside the RSAP. Pollen percentages are compared to simulated pollen percentages for Herandsvatn

light conditions and increased cultivation and grazing. The pollen diagram from Samland suggests, however, that a period during the EBA was a phase with reduced human activity locally as forest taxa increased. The regional pattern of increased tree cover around 1650 and 1000–800 cal BC based on reconstructions from Kalandsvatn (Mehl and Hjelle 2015), may be reflected in the small fluctuations in the diagram from Herandsvatn and thus support that this is a regional signal. This phase is followed by a strong increase in human activity from the upper part of the Late Bronze Age clearly reflected in the increase in LOVE-estimated openness from Herandsvatn, palynological richness, and the presence of anthropogenic indicators (cf. Behre 1981) at both sites.

Table 6 Vegetation cover for vegetation types at AD 2003 and the Late Neolithic used in HUMPOL

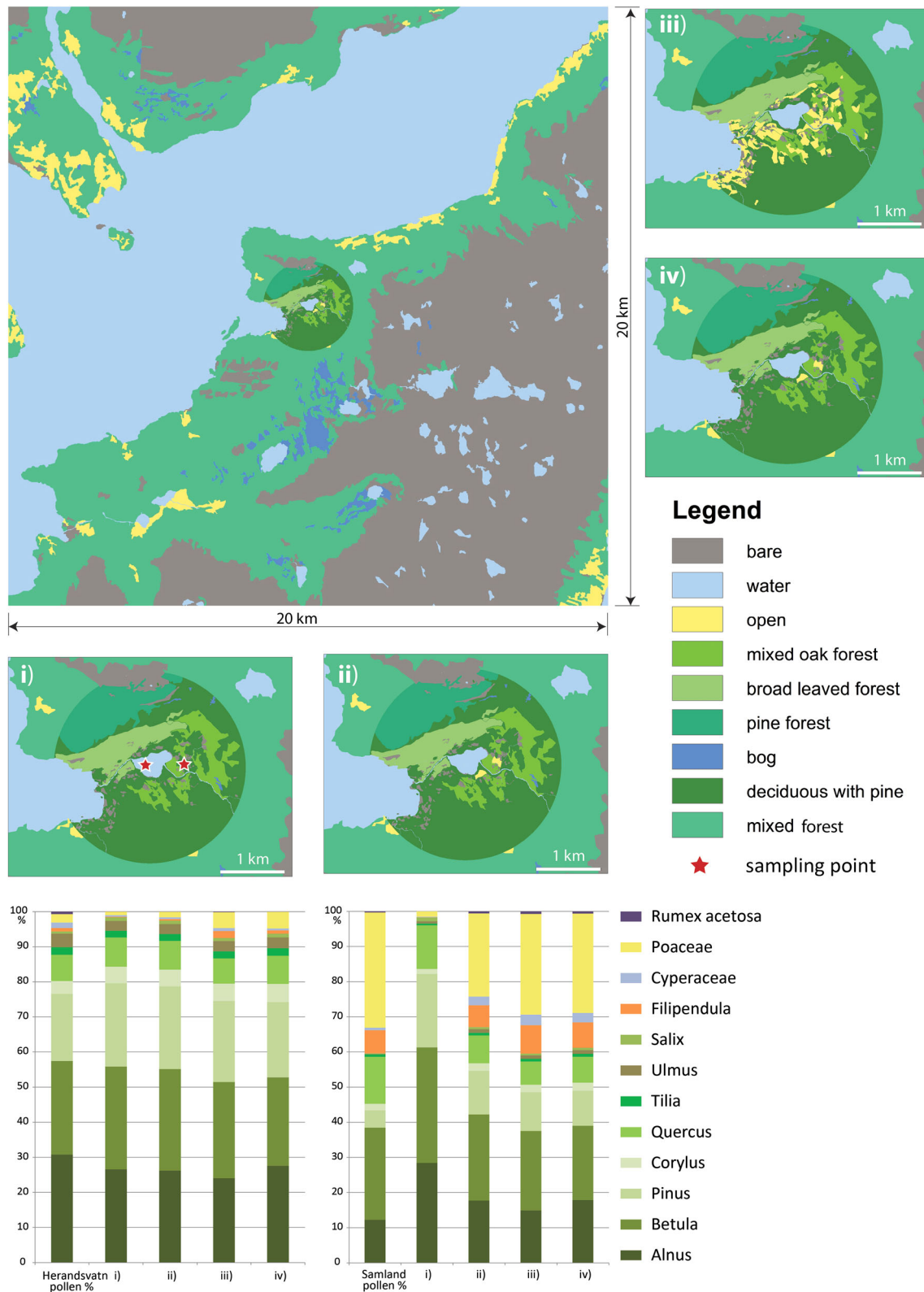| Class	Vegetation cover (%) AD 2003	Class	Vegetation cover (%) Late Neolithic, scenario i, ii, iii	Vegetation cover (%) Late Neolithic, scenario iv
Bare		Bare		
Water		Water		
Infield	Poaceae 85, Cyperaceae 5, *Rumex acetosa* 10	Open	Poaceae 70, Cyperaceae 5, *Rumex acetosa* 5, *Filipendula* 15, *Betula* 5	Identical to scenario i, ii, iii
Outfield	Poaceae 60, Cyperaceae 15, *Filipendula* 10, *Rumex acetosa* 10, *Juniperus* 5	Mixed oak forest	*Quercus* 55, *Alnus* 15, *Betula* 15, *Tilia* 5, *Corylus* 5, *Ulmus* 5	*Quercus* 40, *Alnus* 10, *Betula* 10, *Tilia* 5, *Corylus* 5, *Ulmus* 5, Poaceae 5, *Filipendula* 5
Broad-leaved forest	*Corylus* 30, *Tilia* 20, *Ulmus* 20, *Quercus* 20, *Fraxinus* 10	Broad-leaved forest	*Ulmus* 35, *Tilia* 30, *Corylus* 20, *Alnus* 10, *Betula* 5	Identical to scenario i, ii, iii
Pine forest	*Pinus* 70, *Betula* 5, *Juniperus* 5, *Calluna* 20	Pine forest	*Pinus* 75, *Betula* 20, *Salix* 5	Identical to scenario i, ii, iii
Bog	Cyperaceae 60, Poaceae 5, *Calluna* 10, *Juniperus* 10, *Pinus* 10, *Betula* 5	Bog	Cyperaceae 75, Poaceae 10, *Pinus* 10, *Betula* 5	Identical to scenario i, ii, iii
Spruce forest	*Picea* 100	Deciduous with pine	*Betula* 30, *Alnus* 25, *Quercus* 25, *Pinus* 10, *Salix* 5, Poaceae 5	*Betula* 20, *Alnus* 25, *Quercus* 25, *Pinus* 5, *Salix* 5, Poaceae 20
Mixed forest	*Betula* 15, *Alnus* 15, *Corylus* 5, *Quercus* 5, *Salix* 5, *Pinus* 10, *Picea* 2, *Juniperus* 10, Poaceae 20, Cyperaceae 10, *Filipendula* 2	Mixed forest	*Betula* 25, *Alnus* 20, *Corylus* 10, *Quercus* 10, *Tilia* 10, *Ulmus* 5, *Salix* 5, *Pinus* 15	Identical to scenario i, ii, iii

Development of the traditional cultural landscape from the Iron Age onwards (from 500 cal BC)

In the Pre-Roman Iron Age (PRIA), the LOVE-estimated forest cover increases and the estimated cover of Poaceae decreases. Among the trees *Pinus* increases most, from almost no estimated cover to 10 %. Increases in tree pollen (*Alnus* and *Betula*) are also seen at Samland in the layer (9) dated to this time period. Quite low simulated cover of broadleaved trees may reflect clearance, but also utilization of leaves for fodder (Troels-Smith 1960).

Zone S-3 contains samples from both the Bronze Age and the PRIA (Fig. 7), which may indicate similar land-use in these periods. Despite the possible increase of forest cover, the first registration of *Hordeum* at Samland is also found in this time period. The PRIA has been suggested to have been a period of intensive farming and changes in settlement patterns (Tesch 1991; Diinhoff 1999), which may explain the present results.

In Herandsvatn, more extensive openings are shown in the time periods 0-AD 570 and AD 570–1030 when estimated cover of Poaceae increases to >30 %, a level that continues up to the last century. These pollen zones (HV-4 and HV-5) are also separated on the PCA plot (Fig. 6) and an increase in pollen percentages of several taxa as well as in palynological richness is seen in HV-5 compared to HV-

4. High palynological richness also characterizes Samland in these time periods, with the presence of *Hordeum*-type and either an increase of or the first appearance of several anthropogenic indicators. The herb composition in a pollen assemblage is strongly connected to the management (Gaillard et al. 1994; Hjelle 1999a; Overland and Hjelle 2009). In the time period 0-AD 570 (HV-4, S-4), cereals and arable weeds (cf. Behre 1981) point to cultivation whereas high values of Poaceae and grazing indicators/meadow plants (cf. Hjelle 1999b) indicate the existence of mown meadows. The more intensified use may indicate the establishment of an infield/outfield system, a division that probably took place from the Roman Iron Age (Øye 2002). The infield consisted of arable land and meadows, whereas the outfield was used for grazing. The increased percentages of Poaceae at Samland in the Late Iron Age (S-5) probably indicate increased importance of mown meadows, at a time when the scythe became common (Solberg 2003). *Hordeum*-type is registered throughout the Late Iron Age, but not in medieval time at Samland. In comparison, *Hordeum*-type is not registered earlier than medieval time in Herandsvatn and stray finds of *Triticum*-type are also registered in the same period. The relatively late presence of pollen from cereals in the lake is most likely caused by the low pollen production and dispersal characteristics of *Hordeum*- and *Triticum*-type (Vuorela 1973).

Legend

- ⬛ bare
- 🟦 water
- 🟨 open
- 🟩 mixed oak forest
- 🟩 broad leaved forest
- 🟩 pine forest
- 🟦 bog
- 🟩 deciduous with pine
- 🟩 mixed forest
- ★ sampling point

- 🟪 Rumex acetosa
- 🟨 Poaceae
- 🟦 Cyperaceae
- 🟧 Filipendula
- 🟩 Salix
- 🟫 Ulmus
- 🟩 Tilia
- 🟩 Quercus
- 🟩 Corylus
- 🟩 Pinus
- 🟩 Betula
- 🟩 Alnus

Pollen from flax (*Linum usitatissimum*) is registered both in the lake and at Samland in the Iron Age and medieval time. Its presence during these archaeological time periods coincides with other records from western Norway (Torske 1995; Bakkevig et al. 2002; Danielsen and Halvorsen 2009), where it is mostly interpreted as

◄ **Fig. 10** Four possible landscape scenarios in the Late Neolithic (2300–1800 cal BC) in Herand simulated with seven different vegetation types. More detailed vegetation cover is given within the relevant source area of pollen (RSAP) of c. 1,500 m, while a general vegetation cover is simulated outside the RSAP. Four different scenarios are simulated; (i) only openings outside Herand (10 % as estimated from REVEALS for that time period, (ii) two openings within Herand as documented from Samland and Nedre Trå, and 10 % openings outside the RSAP, (iii) 10 % openings both within and outside the RSAP as estimated from REVEALS and LOVE, and (iv) opening at Samland and Nedre Trå with a more open forest type within the RSAP (see vegetation composition in Tables 2, 6), and 10 % openings outside the RSAP. Pollen percentages are compared to simulated pollen percentages in each scenario at both Herandsvatn and Samland

connected to textile production. The earliest registrations of flax pollen in western Norway date back to the PRIA (Torske 1995; Kvamme 1997; Bakkevig et al. 2002). Flax pollen production and dispersal is very scarce, therefore the finding of its pollen most probably documents local cultivation. It has, however, been suggested that findings of flax pollen may also originate from the retting process and not solely from cultivation (Viklund 2011).

The farming society with cultivated fields, mown meadows and pastures indicated in the pollen record, may be supported by a large variety of archaeological data from the Iron Age (cf. Fig. 1) reflecting settlement and human activity in different parts of Herand.

In medieval time, LOVE estimates up to c. 35 % cover of Poaceae (Fig. 8) from Herandsvatn and a Poaceae pollen percentage of nearly 80 % is reached at Samland. The medieval period thus reflects further expansion of farming activity, even though some farms were abandoned due to the Black Death and other plagues (Losnegård 2006). It is difficult to detect phases of regression of human activity from Herandsvatn, as the pollen percentage diagram shows several fluctuations, including a maximum in tree pollen around AD 1400, that are difficult to interpret at this stage. More dates and application of LRA on a more detailed temporal scale may add information to this. The LOVE reconstruction from Herandsvatn indicates that the period AD 1600–1900 was a phase with further expansion of human activity, a general pattern recognized in northern Europe (e.g. Berglund 1991; Lagerås 2007; Nielsen et al. 2012). The lower estimates of *Pinus* cover from AD 1600 until modern time are probably connected to different activities in Herand, such as a sawmill (Fig. 1), used for processing material for boat building, which existed from AD 1603 (Losnegård 2006).

Intensive farming may result in erosion and redeposition in lakes (cf. Dearing 1991; Rasmussen and Bradshaw 2005). A marked increase in PAR from c. AD 1000 (Fig. 4) may indicate that this was the case in Herandsvatn. In spite of this, the pollen diagram is probably also reflecting the vegetation from c. AD 1000–1600. This interpretation is

based on the fact that the pollen composition indicates a more open cultural landscape than in the previous time periods, and that the dates are in the right chronological order.

Evaluation of the methodological approach

The data presented—pollen analyses from lake sediments and a soil profile—give information on cultural landscape development through time. The numerical approaches used clarify and support the changes inferred from the pollen diagrams and archaeological data, and thus improve the understanding of the changes in vegetation composition related to human activity (Fig. 11). They also add information about changes in the landscape when there are few or no archaeological finds, for example in the Neolithic. PCA recognizes gradients in the datasets, such as forest versus open vegetation, but also changes in land-use practices. In the PCA plot for Samland (Fig. 7), the pollen assemblage zones are clearly separated, both on forest versus open land, and on a gradient in herb composition. This indicates different land-use practices in the Bronze Age/PRIA (S-3), Roman Iron Age/Migration period (S-4), and the Late Iron Age/medieval time (S5).

The LOVE reconstruction shows that the cultural landscape has been more open than is suggested by pollen percentages alone, which is a general pattern seen when using LRA (Hellman et al. 2008; Nielsen et al. 2012; Cui et al. 2013; Fyfe et al. 2013; Hultberg et al. 2015). There are still challenges in the use of LRA, including the fact that not all of the most commonly registered pollen taxa have PPEs. On the other hand, these are mainly entomophilous taxa which are not suitable for these methods (Sugita 2007a, b; Mazier et al. 2012). A combination of pollen percentages and estimated vegetation cover is therefore recommended for interpretation purposes, where the anthropogenic indicators (Behre 1981; Hjelle 1997) are still important. Rare taxa in the pollen diagram such as Cerealia, *Plantago lanceolata* and *Rumex acetosa* lead to high standard errors in the LOVE-reconstruction, and Poska et al. (2014) recommend that taxa with pollen values of <1 % are not included in the reconstruction. Overall, the use of LRA shows the potential vegetation cover as corrections are made for the discrepancies in pollen production and dispersal between taxa.

The use of HUMPOL adds further information to LRA and is demonstrated to be a powerful tool. In our case we used lakes sediments and a soil profile. These two represent different taphonomical processes following deposition of pollen. In the soil profile, human activity may have resulted in soil mixing as well as supply of pollen through manure in a cultivated field. Vertical movement of pollen due to worms or root channels may also have taken place
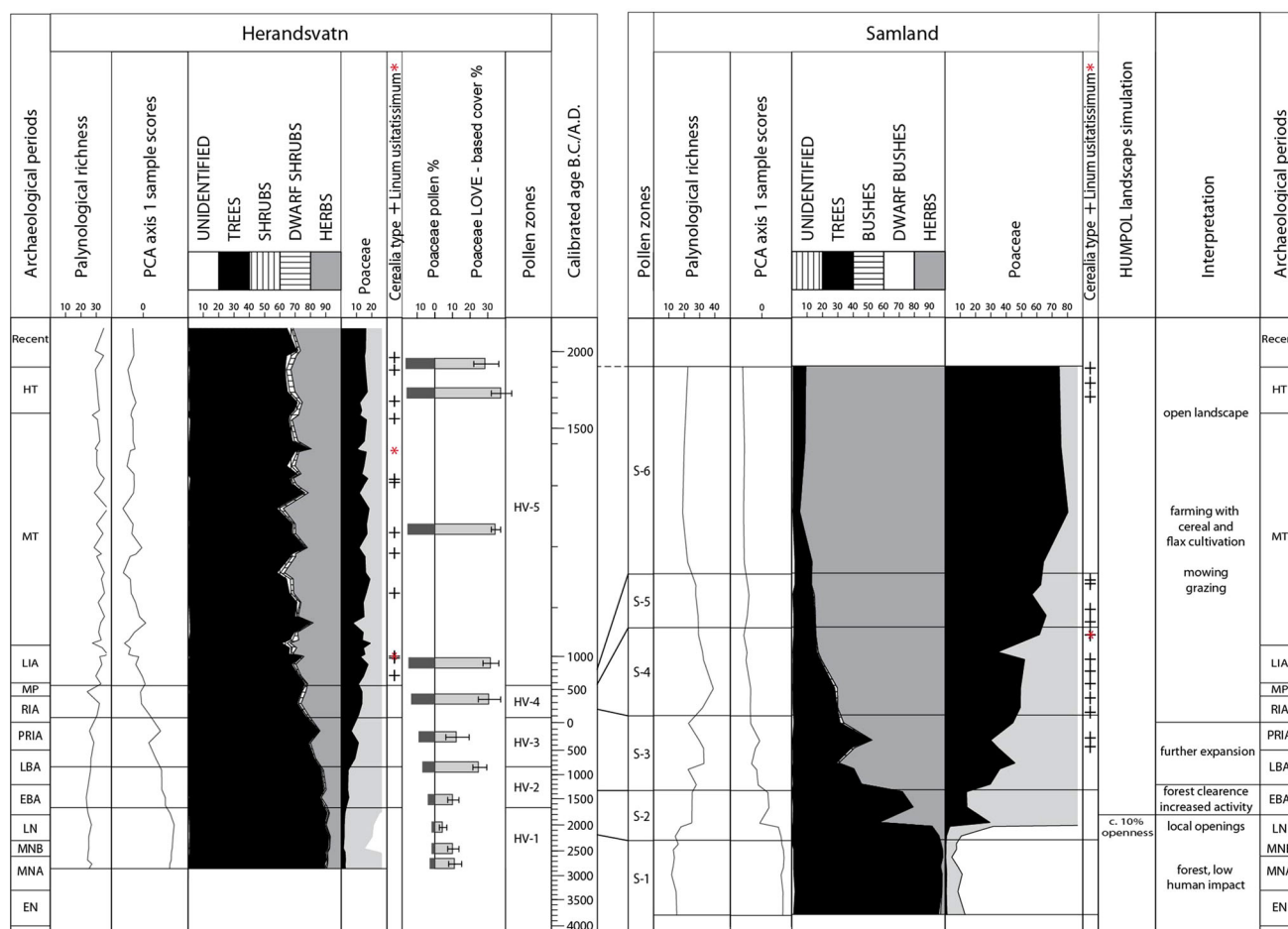
Fig. 11 Synthesis of results from Herandsvatn and Samland given in archaeological time periods showing selected results from the two sites and interpretation of the cultural landscape development in Herand

(Dimbleby 1985). Although mixing may have taken place within different stratigraphical layers, the change in pollen composition through the profile indicates that vertical pollen transport is not a significant problem. An assumption for the pollen dispersal models used both in LRA and HUMPOL is that pollen is transported through the air. With other pollen agencies, sources of error may exist in the soil profile, and perhaps also between AD 1000 and AD 1600 due to potential erosion around Herandsvatn. However, we believe that most of the pollen is contemporaneous with the time of deposition and conclude that both sites may be used to compare simulated and counted pollen assemblages. It is a clear limitation of HUMPOL that several landscapes may produce the same pollen assemblages, but the number of possible landscapes is probably reduced by using more than one site in the simulations. In our study we simulated pollen deposition at two sites (Herandsvatn and Samland), and it was more difficult to get comparable results than by using just Herandsvatn. The simulations helped to demonstrate that different percentages of tree pollen may

be found at different sites and it helped to identify less reasonable landscape patterns. Altogether, the landscape scenarios and simulations give an indication of how difficult it may be to trace early agriculture in a forested landscape from a lake pollen diagram.

The RSAP varies throughout all reconstructed time periods, although these estimates are approximations as long as only one small lake is used in LOVE (cf. Sugita 2007b). However, the good correspondence between the LRA-estimated RSAP of 900–1,100 m (Hjelle and Sugita 2012) and our LOVE-estimated RSAP of 900 m may indicate that the LOVE estimates are reasonable. Our simulations demonstrate that HUMPOL simulations are useful in reconstructing possible openness of past landscapes. In this way, potential landscape scenarios related to disturbances caused by human impact may be detected. Improved similarities between estimated and counted pollen percentages also indicate that adding knowledge of vegetation cover from LRA (REVEALS and LOVE results) increases the potential of simulating a realistic

landscape of the past. Visualization of past landscapes provides the potential to include knowledge from archaeological and historical data to increase our understanding of farming development through time and how people have transformed forests into open cultural landscapes.

Conclusions

The use of pollen percentage diagrams from a lake and a soil profile in combination with the numerical approaches of PCA, palynological richness, LRA and HUMPOL (Fig. 11) are demonstrated to be useful for the study of cultural landscape development. PCA shows the gradients in the pollen assemblages, from forest to open landscape as the main gradient. Forest clearances were followed by increased palynological richness. In the LOVE-based estimates of vegetation cover, increased openness of the landscape compared to the pollen percentages is demonstrated for all time periods. Finally, HUMPOL helps identify possible as well as impossible landscape patterns, and supports the openness estimated from LRA.

Herand was covered by forest until the Late Neolithic, when scattered open patches are inferred to have occurred. Farming developed in the Late Neolithic and a marked expansion took place in the EBA. Further intensification took place in the upper part of the Late Bronze Age and PRIA. Cereal cultivation probably took place in all these time periods, but is not documented until the PRIA. A further intensification of farming is recognized through the Iron Age with increased openness, cultivation of cereals and flax, and also the existence of mown meadows.

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