Long-term changes in regional vegetation cover along the west coast of southern Norway: The importance of human impact

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Abstract
Questions: How open was the landscape prior to agriculture? Did agriculture start earlier in the south than
in the north? How did the vegetation change in different regions after the introduction of agriculture?
Location: Coast of SW and W Norway.
Methods: The REVEALS (Regional Estimates of VEgetation Abundance from Large Sites) model is
applied for pollen-based vegetation reconstruction in 19 time windows over the last 9,000 years. Pollen
data from 63 sites (lakes and bogs) are com- piled and systematically used for data analysis so that the
structure of vegetation change in space and time is captured.
Results: Estimated cover of selected trees, shrubs, *Calluna*, graminids and herbs indi- cate a partly open
outer coast throughout the Holocene. The highest tree cover is estimated for 8,200–6,200 cal. BP. Broad-
leaved trees (*Fraxinus*, *Quercus*, *Tilia* and *Ulmus*) spread from south to north and were present in the
whole region at the end of the Mesolithic (5,950 cal. BP). Larger spatial variation in tree cover and a step-
wise reduction in deciduous trees after 5,700 cal. BP is concordant with increases in open-land taxa
indicating human activity. Vegetation changes caused by agriculture are indicated in the very south from
ca. 5,950 cal. BP. Distinct human-induced vege- tation changes with spatial differentiation took place from
4,200 to 1,700 cal. BP, when most of the areas earlier covered by deciduous woodland had been trans-

formed to cultivated fields, grasslands and heathlands. Increased Poaceae cover from 1,700 cal. BP probably reflects the expansion of mown meadows in addition to pastures.

Conclusions: Capturing continuous changes of vegetation structure in space and time elucidates open areas along the western coast prior to the introduction of agriculture. Agriculture started earliest in the very south and spread rapidly along the whole coast prior to the Late Neolithic. Differences within the study area have existed in all time periods, reflecting different land-use practices adapted to different natural conditions.

1 INTRODUCTION

After the deglaciation, trees spread from south to north in western Norway. Forest composition changed from early successional trees in the early Holocene to late successional deciduous trees in the mid-Holocene (Fægri, 1940, 1944; Moe et al., 1996; Prøsch-Danielsen, 1996; Mehl & Hjelle, 2015). With the spread of agriculture to Northern Europe around 6,000 years ago, new species of plants were introduced, and human impact became an increasingly more important driver of vegetation change (e.g., Behre, 1988; Berglund, 1991; Odgaard, 1994; Gaillard, Dutoit, Hjelle, Koff, & O'Connell, 2009; Reitalu et al., 2013). Palaeo-records, which elucidate and give evidence to human impact on vegetation changes on long-term time scales (centuries to millen- nia), are also valuable for conservation planning and practices (e.g., Birks, 1996; Willis & Birks, 2006; Reitalu, Kuneš, & Giesecke, 2014). This paper aims to quantify the changes in vegetation cover through ca. 9,000 years in southwestern and western Norway to demonstrate how people affected their environment.

People were present in Norway more than 10,000 years ago (Bjerck, 2008) and agriculture became widespread around 4,250 cal. BP (Myhre, 2004; Høgestøl & Prøsch-Danielsen, 2006; Hjelle, Hufthammer, & Bergsvik, 2006; Prescott, 1996, 2009; Olsen, 2012). Timing of the arrival of the first farmers, as signalled by anthropogenic indicators such as *Plantago lanceolata* (Behre, 1981), and the open- ing of vegetation based on pollen percentages, is still debated for the time period 5,950–4,250 cal. BP. Biases connected to different pollen production and dispersal among species and size of the investigated pollen site affect the pollen–vegetation relationship (Prentice, 1985; Sugita, 1993, 1994; Davis, 2000). Without correction of such biases, it is hard to objectively interpret vegetation openness and compare palaeo-records among sites and regions. Sugita (2007a, 2007b) de- veloped the Landscape Reconstruction Algorithm (LRA) that aims to correct for these biases and convert pollen percentages to vegetation cover. This study aims to demonstrate overall trends in the plant cover of the region by applying the REVEALS model (Regional Estimates of VEgetation Abundance from Large Sites; Sugita, 2007a) – the first step of the LRA – for reconstruction of regional vegetation within a 50–100-km radius of pollen sites. REVEALS has been evaluated (e.g., Hellman, Gaillard, Broström, & Sugita, 2008; Sugita, Parshall, Calcote, & Walker, 2010; Soepboer, Sugita, & Lotter, 2010; Abraham, Oušková, & Kuneš, 2014; Hjelle, Mehl, Sugita, & Andersen, 2015) with encour- aging results. Regional vegetation has been estimated using REVEALS (e.g., Fyfe et al., 2013; Marquer et al., 2014; Kuneš et al., 2015; Mehl & Hjelle, 2015), and all papers point to more open vegetation during the Holocene,

than indicated by pollen percentages.

Naturally open vegetation, such as bogs and seashore plant com- munities, existed before human impact intensified. However, the extent to which European forests were influenced during the Mesolithic has been debated. Areas may have been maintained open through grazing and browsing by wild animals (Vera, 2000) or through fire manage- ment (Selsing, 2016). High *Calluna* cover has been estimated along the European coasts (Nielsen et al., 2012; Fyfe et al., 2013; Mehl, Overland, Berge, & Hjelle, 2015). *Calluna* seems to have had northern glacial re- fugia (Rendell & Ennos, 2002) that could explain the Late Glacial (LG) and/or early Holocene appearances in coastal areas of NW Europe (e.g., Paus, 1989; Berglund et al., 2005; Overballe-Petersen, Nielsen, Hannon, Halsall, & Bradshaw, 2013). On Utsira Island, ca. 20 km off the coast of SW Norway, *Calluna* formed dwarf-shrub heaths around 10,500 cal. BP (Paus, 1990). Most probably, this reflects a bridgehead for the later *Calluna* migration to the Norwegian mainland. After the introduction of animal husbandry, *Calluna* became an important winter fodder and the heathland ecosystem was maintained through regular burning and graz- ing (Kaland, 1986, 2014). In SW Norway, the heathlands have developed since the Neolithic (5,950 cal. BP), with main expansions around 4,450, 2,750 and 2,250 cal. BP (Prøsch-Danielsen & Simonsen, 2000). Further north, the oldest heathland connected to grazing is dated to 4,850 cal. BP, with main expansions around 1,700 and 1,050 cal. BP (Kaland, 1986). In the present paper, we use REVEALS to compare the degree of forest cover/openness through time along a south–north gradient in southwestern and western Norway (Figure 1). This area has previ- ously been central in the discussion about introduction of farming in Norway. The development of agriculture (husbandry and cultivation) has earlier been synthesized using pollen percentage data, reflecting heathland development and opening of the landscape in the southern part (Høgestøl & Prøsch-Danielsen, 2006), and presence of anthro- pogenic indicators in the northern part (Hjelle et al., 2006). REVEALS application enables us to transform pollen percentages into vegetation cover and thus allows a more profound discussion about vegetation prior to agriculture and the transformation from forests to open cul- tural landscapes along the coast. Our specific aims – assuming reliable cover estimates – are to test the following hypotheses: (1) the west- ern coast was partly open prior to the introduction of agriculture; (2) the introduction of agriculture started earlier in the south than in the north; and (3) after introduction of agriculture, timing of significant changes in vegetation structure and openness at the regional scale was not synchronous along the coast, reflecting human impact as the
main driver of the landscape change.

2 | METHODS

2.1 | Study area

The study area comprises the counties of Hordaland, Rogaland and Vest-Agder (Figure 1, Appendix S1). It covers the coastal heathland
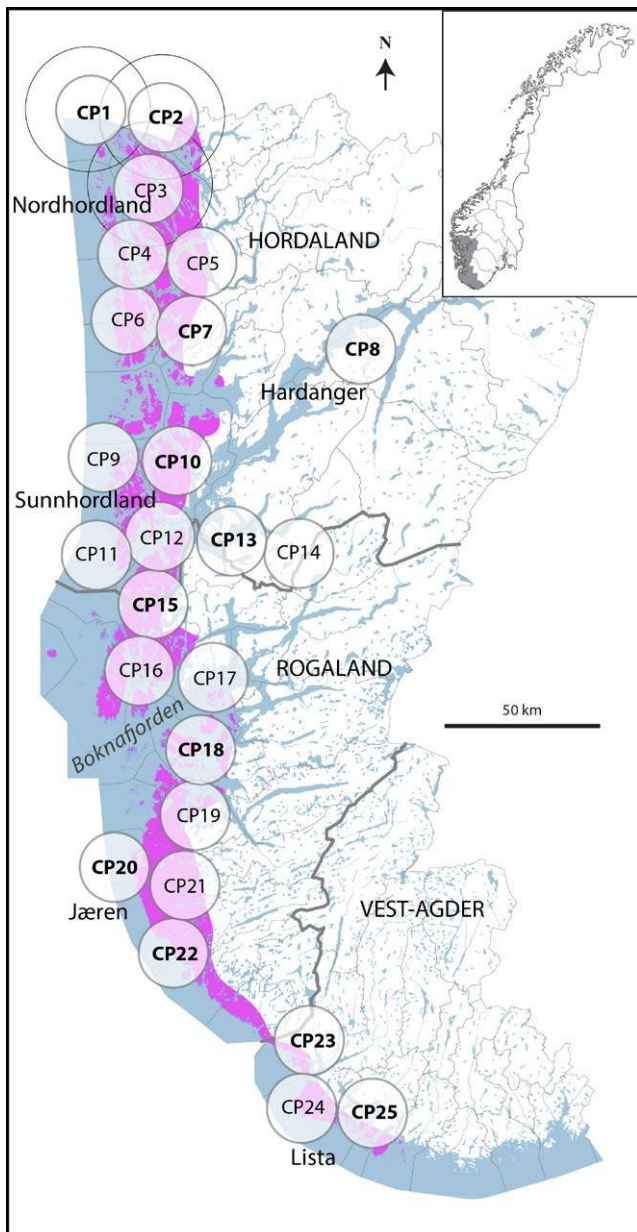
FIGURE 1 Map showing cross-points (CPs, see text) with estimated regional vegetation cover and the distribution of coastal heathland within the counties of Hordaland, Rogaland and Vest- Agder. Circles with a radius of 20 km (shown for CP1–CP3) overlap, and smaller circles are used in Figure 3 and Appendix S5. Bold text shows the 12 CPs with no overlapping sites used in Figures 2 and 4

and parts of the fjord areas: from flat, low-lying landscapes in the SW to relatively flat islands in the NW, to fjords and mountain landscapes to the east. The bedrock is mainly Precambrian or Caledonian. Areas with phyllite, mica schists and limestone provide nutrient-rich soils in the Boknafjord and Hardanger areas (Figure 1). From the Lista and Jæren regions to the fjords and coastal areas further north, overly- ing Quaternary deposits also contribute to the deep soil development well suited for cultivation (Moen, 1999: Maps 14, 15). The climate is oceanic, with a gradient from high precipitation and mild winters in the west, to lower winter and higher summer temperatures in the east (Moen, 1999: Map 88). The large topographic variation from sea level to 1,000 m a.s.l. within a few kilometers enhances the west–east cli- mate gradient. This study focuses on vegetation development in the lowland area with surrounding hillsides using sites situated from 2 to 250 m a.s.l.

The study area covers five vegetation zones. The boreonemoral zone to the west includes the most oceanic coastal heathlands and contains coniferous (*Pinus sylvestris*) and broad-leaved (*Corylus avel- lana*, *Ulmus glabra*, *Fraxinus excelsior*, *Quercus robur* and *Tilia cordata)* woodlands. To the east and

with increasing altitude, the southern, middle and northern boreal zones occur. These include coniferous woodland (*P. sylvestris*), deciduous trees (*Betula pubescens*, *Alnus glu- tinosa*, *A. incana*, *Populus tremula*, *Salix* spp. and *Sorbus aucuparia*) and scattered mires. The nemoral zone with the thermophilous *Q. petraea*, *Q. robur* and *T. cordata* occurs sparsely in the very south (Moen, 1999: Map 70). The southern part of the study area, covering the coun- ties of Rogaland and Vest-Agder, exhibits the best agrarian potential with more than 50% of the area in the nemoral (only Vest-Agder), boreonemoral and southern boreal zones, compared to ca. 25% in Hordaland county (Moen, 1999: Map 71).

2.2 | Pollen data

Pollen records from 63 sites (Appendix S1) are from the pollen da- tabases at the University Museums of Bergen and Stavanger or **obtained** directly from the authors. Sites with available pollen counts and reliable chronology (minimum three radiocarbon dates from the analysed cores) were selected. In a few cases, sites with fewer dates were accepted when additional dates were available from region- ally well-defined pollen stratigraphic levels. All radiocarbon dates were calibrated using linear interpolation within the Clam package, R-code for classical age–depth modelling version 2.2 (Blaauw, 2010; R Foundation for Statistical Computing, Vienna, AT). Based on the best age estimates available for each pollen record, pollen data were pooled in 500-year intervals from 9,700 to 700 cal. BP and a time window from 700 to 350 cal. BP.

Twenty-three mainly wind-pollinated taxa (Appendix S2) were selected for analysis. Pollen productivity estimates – important input parameters to REVEALS – for 19 of these have been evaluated against vegetation maps from western Norway (Hjelle et al., 2015). We pres- ent cover estimates of *Plantago lanceolata*, cereals (pollen productiv- ity separated into Cerealia (*Avena*, *Hordeum* and *Triticum* types) and *Secale*), *Calluna* and Poaceae separately, whereas cover estimates for individual tree and shrub taxa were combined into tree cover, forest (trees and shrubs) cover and thermophilous tree cover. Entomphilous taxa show limited pollen dispersal and tend to be problematic in re- gional vegetation reconstruction (Mazier et al., 2012). Except for Cerealia, such herbs were excluded from our data analysis.

2.3 | Regional vegetation reconstructions

The REVEALS model (Sugita, 2007a) corrects for biases caused by the inter-taxonomic differences in pollen production and dispersal in pollen-based vegetation reconstruction. Pollen records from large lakes (50–100 ha) are ideal for the model application. However, simulations and empirical works have demonstrated that using pol- len data from several smaller sites is sufficient for reconstruction of the regional vegetation in general (Sugita, 2007a; Sugita et al., 2010; Mazier et al., 2012; Fyfe et al., 2013; Hjelle et al., 2015; Trondman et al., 2016). The present data set includes pollen records from 28 lakes and 35 bogs ranging in size from <0.5 to 47ha, and one large lake of 340ha (Appendix S1). The sizes are within the range used in previ- ous investigations; the smallest size used by Fyfe et al. (2013) was 0.03 ha and by Nielsen et al. (2012) 0.4 ha. Mazier et al. (2012) used basins of size 0.04–28ha and found small differences of REVEALS estimates for one large site *vs* the mean of (four and six) sites with size 1, 10 and 28 ha. 55 out of 63 sites used in this study are smaller than 10 ha. However, the standard errors (SE) of the REVEALS estimates obtained for most of the plant taxa are smaller than their REVEALS estimated vegetation cover for each CP/time window. This is also the case for groups of taxa, apart from a few exceptions for shrubs

(Appendix S3). These results could partly reflect that many of the small sites are surrounded by open vegetation, which make the sizes of sedimentary basins larger than indicated. Accordingly, the estimates appear acceptable (cf. Marquer et al., 2017: Appendix S2).
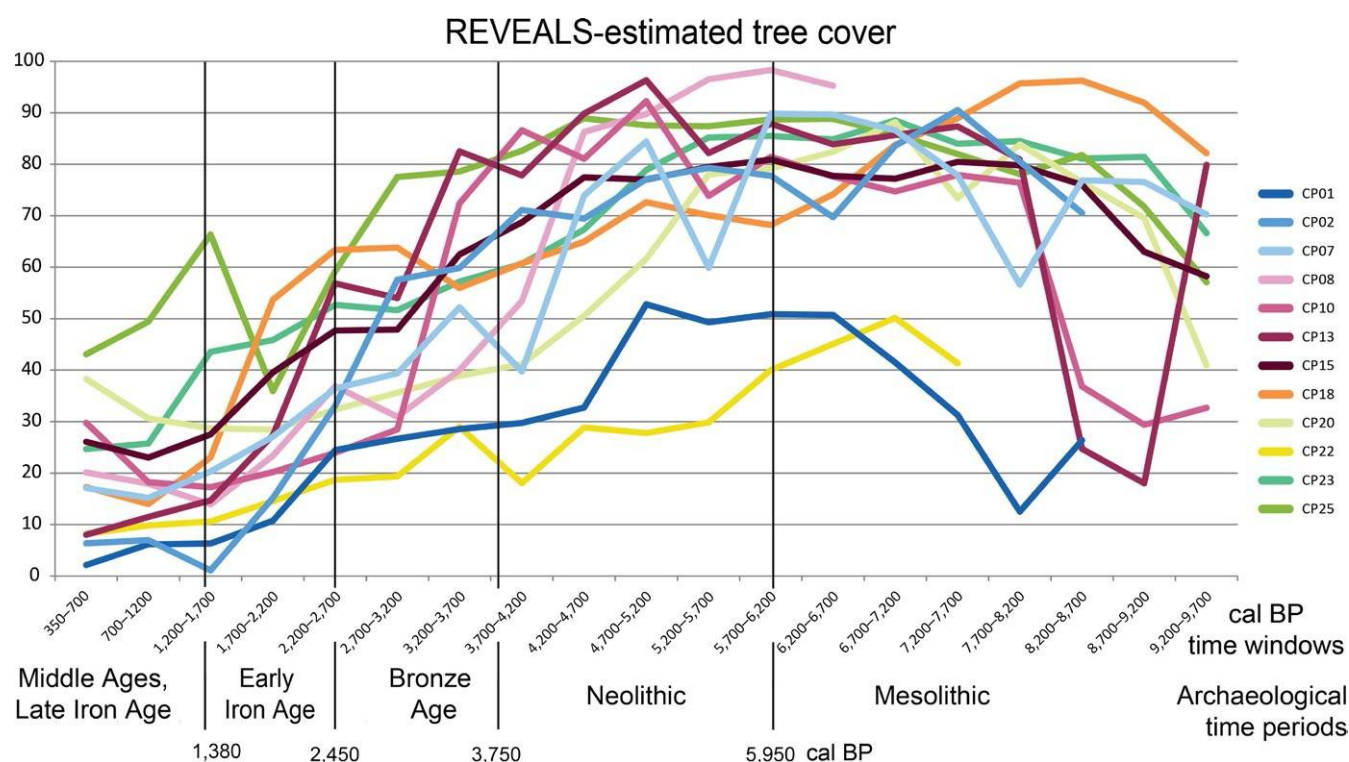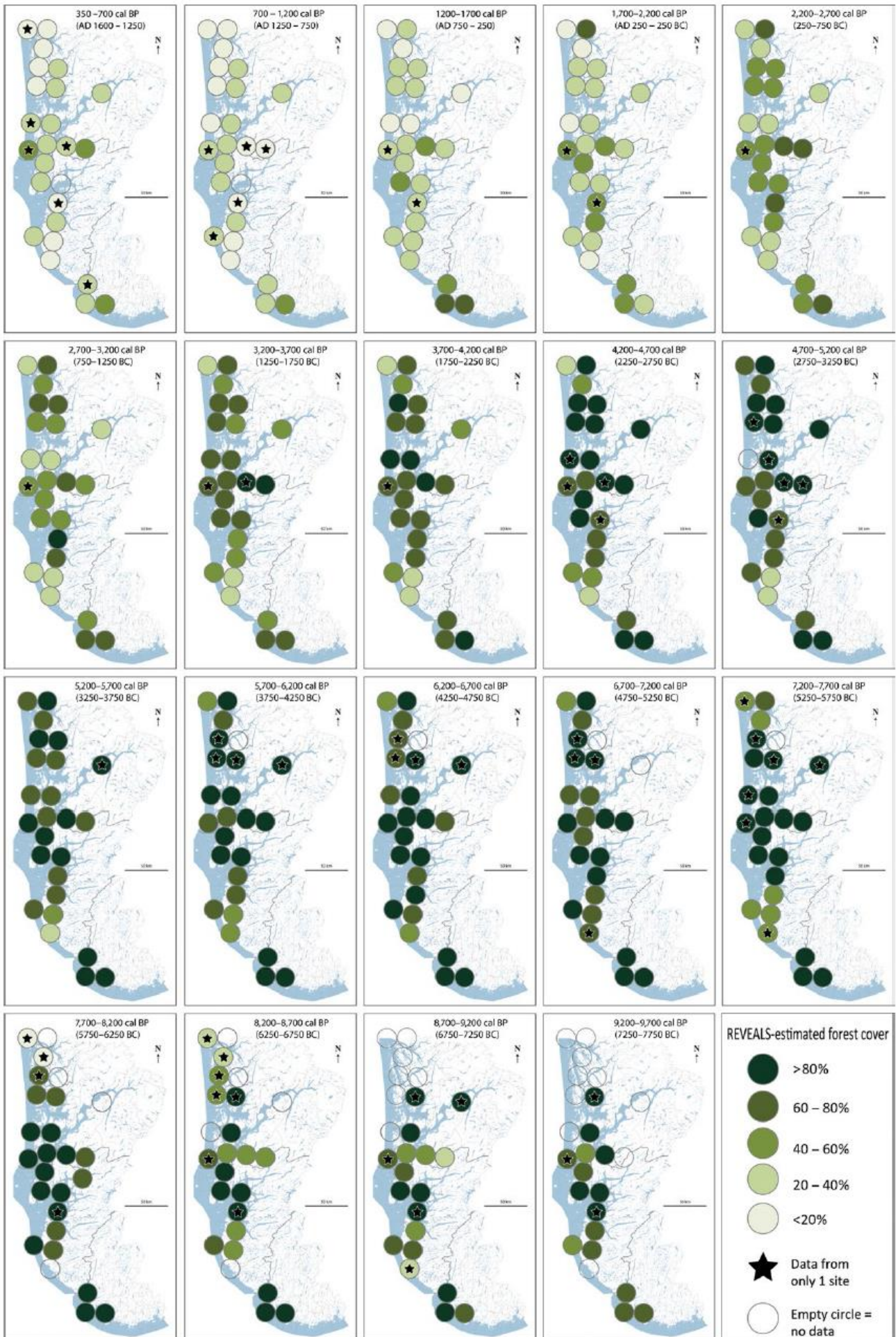

FIGURE 2 REVEALS estimated tree cover for 12 CPs with no overlapping pollen sites (cf. Figure 1) and 19 time windows in relation to archaeological time periods (time windows are not in accordance with archaeological time periods, see Appendix S6). See Appendix S3 for estimated tree cover, shrub cover and NAP (non-tree/shrub) cover with error estimates for all 25 CPs individually

In our study, the regional vegetation was set to 50 km, wind speed to 3 m/s, and atmospheric conditions to neutral. We used Sutton's model of particle dispersal for a ground-level source (Sutton, 1953; Tauber, 1965; Prentice, 1985; Sugita, 1994, 2007a) for the REVEALS application because all the estimates of pollen productivity were obtained using this dispersal model.

The present study applies a new approach to visualize the vegetation gradients. We set up regularly-spaced grid cells of ca. 20×20 km (60.9°N, 60.7°N, 60.5°N, … 58.1°N; 7.0°E, 6.6°E, 6.2°E, … 4.6°E), and used pollen data from available sites located within a 20-km radius around each cross-point (CP). REVEALS estimates of the regional vegetation are obtained at CPs where at least two pollen sites are available (although for individual time windows only one site is present in some cases). In total, this approach results in REVEALS estimates around 25 CPs, i.e., CP1–CP25 (Figure 1). The total pollen count varies from 266 to 35,000 for each CP and time window, with lowest pollen counts in the earliest time windows (Appendix S4). Even though some pollen sites are included in two or three CPs (Appendix S1), this approach is useful to capture the con- tinuous nature of the long vegetation gradient in western Norway. The analysis is done separately for each CP, thus autocorrelation among the REVEALS results is not critical. Results for 12 CPs with no overlapping sites are shown in addition to the continuous vegeta- tion gradient using 25 CPs. We use REVEALS.C.v1.5.1.exe (S. Sugita, unpubl) for regional vegetation reconstruction. This program en- ables selection of CPs with specific predetermined coordinates and uses

pollen data from bogs and lakes in a single model run. The pro- gram estimates the mean regional vegetation composition and its SE for each taxon in each CP with available pollen data for given time windows. We calculate the SE of trees, shrubs and NAP (non-trees /shrubs) using the delta method in the program Plant.PFT.conversion.v.1.1.exe (S. Sugita, unpubl).

				REVEALS-estimated forest cover
350–700 cal BP (AD 1600–1250)	700–1,200 cal BP (AD 1250–750)	1200–1700 cal BP (AD 750–250)	1,700–2,200 cal BP (AD 250–250 BC)	2,200–2,700 cal BP (250–750 BC)
2,700–3,200 cal BP (750–1250 BC)	3,200–3,700 cal BP (1250–1750 BC)	3,700–4,200 cal BP (1750–2250 BC)	4,200–4,700 cal BP (2250–2750 BC)	4,700–5,200 cal BP (2750–3250 BC)
5,200–5,700 cal BP (3250–3750 BC)	5,700–6,200 cal BP (3750–4250 BC)	6,200–6,700 cal BP (4250–4750 BC)	6,700–7,200 cal BP (4750–5250 BC)	7,200–7,700 cal BP (5250–5750 BC)
7,700–8,200 cal BP (5750–6250 BC)	8,200–8,700 cal BP (6250–6750 BC)	8,700–9,200 cal BP (6750–7250 BC)	9,200–9,700 cal BP (7250–7750 BC)	

REVEALS-estimated forest cover

- >80%
- 60 – 80%
- 40 – 60%
- 20 – 40%
- <20%

★ Data from only 1 site

◯ Empty circle = no data

3 | RESULTS

3.1 | Vegetation cover prior to ca. 5,950 cal. BP (ca. 4,000 cal. BC)

Changes in tree cover through time for 12 CPs indicate that the coastal Nordhordland and Jæren (CP1, CP22) deviate from the other areas by reflecting partly open vegetation (Figure 2, Appendix S3). The main group shows large variation in tree cover among sites in the first part of the Holocene. For a few, e.g., CP13 from 9,200 to 8,200 cal. BP, local dominance of Cyperaceae causes extremely low tree cover esti- mates. Between 7,700 and 6,200 cal. BP, the variations between CPs are smaller, but a decrease in tree cover is found both in the south (CP18, CP22) and north (CP2). Figures 3 and 4 further elaborate this, with the highest estimated cover of trees and shrubs between 8,200 and 6,200 cal. BP (Figure 3). Thermophilous trees (*Fraxinus*, *Quercus*, *Tilia* and *Ulmus)* reached 20–60% in parts of the study area, open areas with *Calluna* and Poaceae existed along the coast, but with differences at temporal and spatial scales, and *Plantago lanceolata* was present with low values in a few areas (Figure 4).

3.2 | Vegetation cover ca. 5,950–ca. 3,700 cal. BP (ca. 4,000–1,750 cal. BC)

A decrease in tree cover is observed in several CPs from 6,700– 6,200 cal. BP to 6,200–5,700 cal. BP (Figure 2), representing the transition to the Neolithic. From 5,700 cal. BP onwards, tree cover distinctly varies, indicating asynchronous opening-up of the forests. Some CPs show a decreasing trend (e.g., CP20, CP22), whereas others decrease 5,700–5,200, increase 5,200–4,700 and decrease 4,700 – 4,200 cal. BP (e.g., CP7, CP10, CP13).

At the start of the Neolithic (6,200–5,700 cal. BP), slightly more open vegetation is indicated in the southern area, and cereal cultivation may have taken place at Lista (CP25; Figures 3 and 4). *Calluna* ex- panded in the Jæren and Sunnhordland regions and remained high in Nordhordland. Forests, mostly deciduous, were important through- out the Neolithic (time windows 5,700–3,700 cal. BP). A step-wise increase of opening is indicated in the south, whereas forest open- ness fluctuated in the north. *Calluna* and/or Poaceae increased in the whole region, especially 4,200–3,700 cal. BP, *Plantago lanceolata* occurred in all CPs in the south and in most CPs in the north, and Cerealia was present prior to the Late Neolithic (CP2, CP18, CP23, CP25). Cultivated fields were present in several areas 4,200– 3,700 cal. BP, but with higher cover in the south than in the north.

3.3 | Vegetation cover ca. 3,700–ca. 350 cal. BP (ca. 1750 BC–AD 1600)

In the Early Bronze Age, a large variation in tree cover was found, with a decrease compared to the previous time window for some CPs (e.g., CP8, CP10, BP15) and increase in others (e.g., CP7, CP22; Figure 2). Generally, the landscape became more open in the next time windows. With two exceptions, all CPs have <50% tree cover from 2,200–1,700 cal. BP onwards.

During the Bronze Age and beginning of the Iron Age (3,700– 2,200 cal. BP), forest cover declined (Figures 3 and 4). With some exceptions, the cover of broad-leaved trees was <10% at the Bronze Age/Iron Age transition. *Calluna* expanded and from 2,700– 2,200 cal. BP, its cover reached > 40% (CP1, CP22). Also Poaceae increased, with highest values in areas of low *Calluna* cover. *Plantago*

*lanceolata* was present and the cover of cultivated fields (cereals) increased.

In the Early Iron Age and start of the Late Iron Age (2,200– 1,200 cal. BP), forest cover was <40–60% within most of the study area (Figure 3). *Calluna* and/or Poaceae became common every- where, and *Plantago lanceolata* and cereals had higher cover than in the previous periods (Figure 4).

In the Late Iron Age and Middle Ages (1,200–350 cal. BP), the coastal landscapes showed maximum Holocene openness, with both tree and forest cover <40% in nearly all areas and <20% in some. Patches of broad-leaved forests still existed, particularly in the south. *Calluna* heathlands were widespread and grasslands expanded, reflected in high Poaceae and *Plantago lanceolata* cover. The highest cover of cereal fields occurred within this time period, with highest estimates in the southwestern region (CP18).

4 | DISCUSSION

4.1 | Vegetation openness at the western coast prior to the introduction of agriculture

Within the study region, the differences in natural environmental conditions have caused distinct variations in vegetation, both prior to and after the introduction of agriculture. Thermophilous broad-leaved trees were common in the south, but also occurred in the inner coast and fjord regions further north and in smaller, favourable patches at the western coast. *Calluna* and *Plantago lanceolata* were probably growing on the coast of Norway already in the Late Glacial and earliest Holocene (Fægri, 1940; Paus, 1982, 1989). Our results support the idea that they have been native species in open plant communities. *Calluna* was present with >5% cover both in the south and north prior to 7,000 cal. BP, showing open heath vegetation. At CP1 and CP22, tree cover never reached 60%, probably explained by flat, low-lying areas that earlier were wet and boggy. According to old maps from Jæren, palaeo-lakes occurred in areas now drained and cultivated (Bang-Andersen, 1985). On the small island of Fedje in northwestern Hordaland, the REVEALS estimates (CP1) are based on sites from the exposed western part as well as more sheltered sites on the eastern side of the island. The pollen diagrams from bogs and acid rocks in the extreme west indicated open vegetation throughout the Holocene (Danielsen, 1986). This contrasts findings of roots of deciduous trees on the eastern side of Fedje (Kaland, 2014; P. E. Kaland, unpubl). Probably prevailing westerlies caused wind and salt abrasion of the soils and vegetation facing the sea. Accordingly, varied topography, peat and shallow nutrient-poor soils not suited for forest establishment, created a semi-open landscape along the outer coast. Additionally, Mesolithic settlement sites along the Norwegian coast (Bjerck, 2008) could have influenced local forest cover (cf. Selsing, 2016; Hjelle & Lødøen, 2017). If reconstructions are based on pollen diagrams close to such sites, human impact may have been exaggerated in the REVEALS estimates.
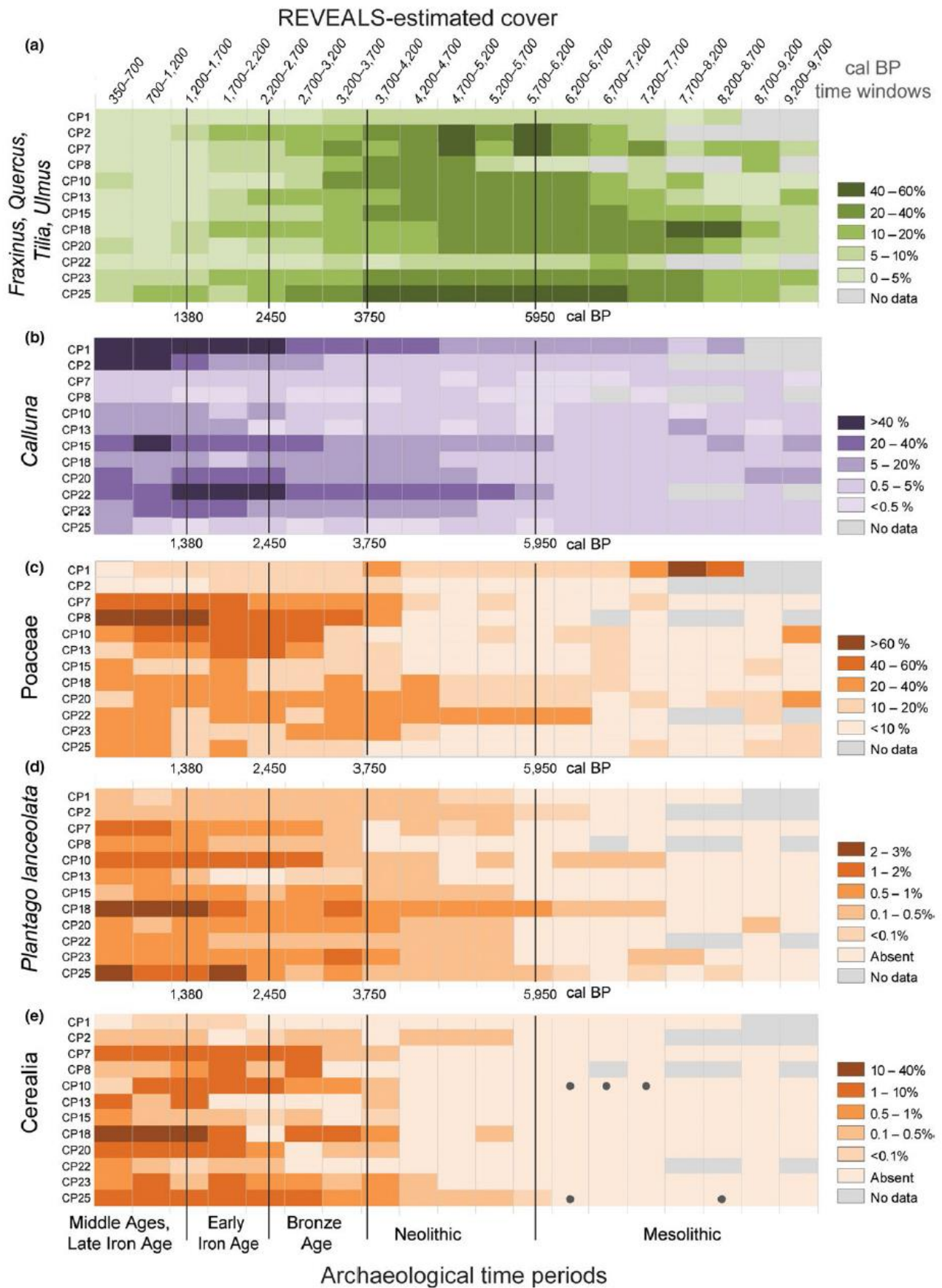
FIGURE 4 REVEALS-estimated cover for 19 time windows in relation to archaeological time periods for (a) thermophilous broad-leaved trees, (b) *Calluna* (Appendix S5), (c) Poaceae (Appendix S5), (d) *Plantago lanceolata* and (e) Cerealia. Grey dots marks presence of large Poaceae interpreted as wild grasses. Study sites are presented along an approximate N–S transect, with CP1 as the northernmost site. Only CPs with no overlapping pollen sites are shown

4.2 | Introduction of agriculture

Human impact on vegetation is clearly indicated in the estimated tree cover through time. Climate, soil properties and dispersal characteristics of plants probably caused the large variation prior to 7,700 cal. BP, followed by more stable conditions in the middle Holocene. We conclude that human impact and the introduction of agriculture caused increasing variation in forest cover since ca. 5,950 cal. BP. However, as the landscape was partly open prior to the introduction of agriculture, not only openness but also the relative change in species composition must be considered when interpreting the effect of human impact. The reconstructed changes in tree cover indicate a distinct reduction in the Neolithic compared to that in the Mesolithic. Around 5,950 cal. BP, when agriculture reached Scandinavia, most of our study regions were forested, as was also the case on the continent (Nielsen et al., 2012). Although already present in some places, *Calluna* heathlands and *Plantago lanceolata* expanded along the whole coast. Their simultaneous increase from early in the Neolithic suggests that these changes were caused by grazing (Kaland, 1986; Odgaard, 1994). There are scattered finds of large pollen grains of Poaceae within the size ranges of Cerealia-type pollen in the Mesolithic (Figure 4). At the moment, we consider all these to represent wild grasses, e.g., *Glyceria* (cf. Høeg, 1995, 1999; Prøsch-Danielsen, 1996, 1997; Overland, 1999).

Lista (CP25) in the very south deviates by a possible presence of cultivated fields and pastures in nearly 90% forest cover already in the Early Neolithic, when agriculture established in Denmark (e.g., Odgaard, 1994; Nielsen et al., 2012; Sørensen & Karg, 2014). Lista is the warmest part of the study region, with optimal conditions for early agriculture, well reflected in the archaeological material (Prescott, 2009). In the northern part (CP2), the estimated presence of cereals is connected to hunting/fishing settlements by the coast between 5,700 and 4,700 cal. BP. Small-scale agriculture was probably practiced at these sites (Hjelle et al., 2006). Pollen data from forests rarely detect Cerealia-type, thus our results probably reflect cases of short distance between pollen sites and cereal fields.

Our results not only support that a farming economy was well established in Norway in the Late Neolithic (e.g., Myhre, 2004; Hjelle et al., 2006; Høgestøl & Prøsch-Danielsen, 2006; Prescott, 2009; Olsen, 2012), but also contribute new information on the extent of forest clearance and a better understanding of the development through the Neolithic. In the southwest, open land increased, with up to 30% from the end of the Mesolithic to the start of the Late Neolithic. In the already open landscape in the very northwest, open land increased by ca. 20% from 5,200–4,700 to 4,700–4,200 cal. BP. The REVEALS reconstruction provides a convincing pattern of a first main change in the Early Neolithic (from 6,200–5,700 to 5,700–5,200 cal. BP), which together with marked changes from south to north before 4,200 cal. BP, is a clear indication that people had started to manipulate the vegetation, probably through the introduction of agriculture.

4.3 | Human impact as main driver of vegetation change – the agrarian landscapes

From 5,700 to 5,200 cal. BP onwards, the opening-up of the landscape is asynchronous, indicating that human activity was the most important factor influencing the vegetation. The marked increases in *Plantago lanceolata*, Poaceae and Cerealia in this time window, with further increases around 4,200–3,700 cal. BP and 3,200–2,700 cal. BP, together with decreases in thermophilous trees, are clear indications that nutrient-rich soils were preferred for farming.

An expansion in land use, which in turn reduced deciduous forests, seems to have taken place all over the region in the Bronze Age. However, reforestation occurred both around 3,700–3,200 cal. BP and 2,700–2,200 cal. BP, probably reflecting societal changes in the farming communities (e.g., Myhre, 2004). Increased openness around 3,200–2,700 cal. BP accords with the pattern found else- where in continental Europe (Nielsen et al., 2012). At the Bronze Age–Iron Age transition (2,700–2,200 cal. BP) farming communities, which utilized areas for cereal cultivation, grasslands and heath- lands were well established, with further expansions in the Iron Age. Heathland management is strongly connected to farm development and the differentiation between utilization of in-field and out-field resources. Here, *Calluna* is an important winter fodder in a management regime involving burning and grazing (Kaland, 1986, 2014). The importance of animal husbandry is also indicated in the expansion of grasslands. This may reflect mown hay meadows in addition to pastures following the development of iron production from around 2,450 cal. BP and increasingly effective iron tools from ca. 1,380 cal. BP (Solberg, 2000).

The number of taxa used in the REVEALS reconstructions is limited, and changes in biodiversity in the region are hard to estimate from our reconstruction of past vegetation. However, our results suggest the development of a landscape-scale mosaic of human- induced patterns of land cover and land use. This can be studied in more detail using the LOVE model in LRA (Sugita, 2007b). Together with the fragmented natural vegetation, high habitat and species diversity were probably maintained within the traditional management regimes until the 20th century.

4.4 | How reliable are our estimates of vegetation cover?

Simulations and empirical studies suggest that the higher the number of sites, the better the REVEALS estimates. This is especially critical using pollen data from "small" sites, as in our study (Sugita, 2007a; Sugita et al., 2010; Fyfe et al., 2013). The results demonstrate that the prescribed 20×20 km grid cells included enough sites around a number of CPs to make results robust, with only small uncertainties (Appendix S3; cf. Trondman et al., 2016). At the same time the spatial patterns of the vegetation gradients through time was captured. We show that the development of coastal heathlands, pastures and cultivated fields and the regional-scale deforestation were distinctly dynamic. This approach was especially informative where the spatial structure of vegetation clearly changed, such as at the eastern border of the coastal heathlands.

Previous studies have shown that REVEALS tends to estimate higher vegetation openness from bogs than from lakes due to locally dominant plants, such as Cyperaceae or *Calluna* (e.g., Mazier et al., 2012; Nielsen et al., 2012; Fyfe et al., 2013; Trondman et al., 2016). One of the major assumptions for the REVEALS model is that source plants of pollen do not grow at the pollen site (Sugita, 2007a). In the present study, most CPs included both lakes and bogs. However, some areas indicating high openness use pollen data only from bogs. Cyperaceae (e.g., CP13) apparently influence the REVEALS estimates, resulting in reduced forest cover in the early Holocene, but in most cases Cyperaceae pollen does not seem to overestimate locally grown plants. Poaceae and *Calluna*, also growing locally on bogs, may over- estimate landscape openness in a few cases (e.g., CP1, CP22). Results from CP5 and CP7, partly based on the same bog sites but with a large lake included in CP7 (Appendix S1), shows that, prior to 2,700 cal. BP, higher forest cover is estimated for CP5 than for CP7 in several time windows. This indicates that the local CP5 woodland communities affected the REVEALS estimates based on small bogs (cf. Trondman et al., 2016). All sites and results considered; the obtained estimates in this study are regarded as good approximations of the regional

vegetation. REVEALS estimates are potentially influenced by the type of pollen dispersal–deposition model used (Theuerkauf, Kuparinen, & Josten, 2013; Mariani, Connor, Theuerkauf, Kuneš, & Fletcher, 2016; Theuerkauf, Couwenberg, Kuparinen, & Liebscher, 2016). Our study uses a Gaussian plume model (GPM) because pollen productivity estimates (PPEs) based on GPM are available from the study region (Hjelle & Sugita, 2012). The Langrangian stochas- tic model (LSM) of Kuparinen, Markkanen, Riikonen, and Vesala (2007) expresses the pollen–vegetation relationship better than GPMs for all pollen types and for heavy pollen types, such as *Fagus* and Cerealia, in particular (Theuerkauf et al., 2016). *Fagus* is of minor importance in our region, whereas Cerealia poses potential biases, both regarding selection of dispersal model and PPE. This study used a PPE of 0.75 for Cerealia obtained from Denmark (Nielsen, 2004). If we had used 0.046, estimated from the Czech Republic (Abraham & Kozáková, 2012), the Cerealia cover would have been higher. Further studies on the effects of the selection of PPEs and the dispersal models are necessary. Theuerkauf et al. (2016) also suggested that the differences in REVEALS estimates using the GPMs or LSMs might increase with increasing basin size. With one exception, this study uses pollen data from relatively small basins. Thus, the basin size issue is not critical in our study.

5 | CONCLUSIONS

The REVEALS estimates of regional vegetation cover using a pre- scribed grid system visualize the spatially continuous changes in vegetation development along the coast of southwestern and west- ern Norway over the last 9,000 years. Our results suggest that tree cover was highest between 8,200 and 6,200 cal. BP. At the same time, areas with <60% cover existed along the western coast, probably due to acid bedrock, flat and moist areas and strong winds.

Agriculture started at the southern coast in the Early Neolithic. From time window 5,700–5,200 cal. BP, human impact increasingly became the more important driver of vegetation change. A marked increase in human-induced vegetation changes took place in the Late Neolithic (time window 4,200–3,700 cal. BP), in line with the accepted theories on development of the farming economy. However, vegetation changes prior to this clearly indicate that small-scale agriculture/ animal husbandry took place along the coast earlier in the Neolithic. Except for the earliest agriculture in the very south, no northward delay in the onset of agriculture is documented. However, the impact on the vegetation may have been larger in the southern part than in the north. Areas of thermophilous forests were reduced dramatically from 4,200 to 2,200 cal. BP as these areas were utilized for agriculture. Open landscapes with less than 50% tree cover have characterized the whole study area over the last 2,000 years.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

APPENDIX S1 Investigated sites in Hordaland, Rogaland and Vest- Agder, Norway

APPENDIX S2 Relative pollen productivity estimates (PPE) and fall

speed of pollen

APPENDIX S3 REVEALS-estimated cover for trees, shrubs, and NAP ± *SE* estimates

APPENDIX S4 Sites/CPs with pollen counts per site/CP per time

window

APPENDIX S5 REVEALS-estimated *Calluna* cover and Poaceae cover

APPENDIX S6 Archaeological time periods