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From landscape description to quantification: A new generation of reconstructions provides new perspectives on Holocene regional landscapes of SE Sweden

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Abstract

The development since the beginning of the 20th century of the pollen-analytical theory and method as a palaeoecological tool for describing landscape development is outlined with reference to southern Scandinavia. Numerical methods applied since the 1980s are discussed. The aim of this paper is to provide a new perspective on the landscape development and human impact during the Holocene by applying the Regional Estimates of VEgetation Abundance from Large Sites (REVEALS) model to the pollen records from the reference site Lake Färskesjön in SE Sweden. The model was applied both to a previously published record (core 1956, entire Holocene until AD 1600) and a newly collected dataset (core 2013, the last 3000 years). The comparison between the REVEALS estimates of vegetation cover and historical landscape maps indicate that traditional, uncorrected pollen percentages significantly underestimate the degree of landscape openness created by long-term farming and pasturing, but that the degree of underestimation varies over time, depending on the species composition of both the forest and the open-land communities. The REVEALS reconstructions are also a useful tool for the quantification of past land-use changes that may have affected the nutrient loading to the Baltic Sea.

Keywords

biodiversity changes, human impact, pollen-analytical theory, pollen-based landscape reconstruction, REVEALS model

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Introduction

The aim of this paper is to present several generations of landscape reconstructions from the same site in southeastern Sweden and in this way illustrate the development of palynology for landscape reconstruction over the last half century. The classical reference site Lake Färskesjön (core 1956, Berglund, 1966b) was revisited, and the original pollen record was complemented with a new record from the top sediments, representing the last 3000 years (core 2013; Åkesson, this paper). The Regional Estimates of VEgetation Abundance from Large Sites (REVEALS) model (Sugita, 2007a) was applied to both pollen records in order to obtain a quantitative reconstruction of the vegetation development of the region, so that we can not only characterize but also quantify the changes in the landscape. Pollen-based REVEALS estimates of plant abundance opens up for new possibilities to further explore and understand the processes and drivers behind the landscape development during the Holocene.

Recent studies have suggested that past land-use changes may also have affected – besides terrestrial ecosystems and biodiversity in general – the marine environment of the Baltic Sea (Funkey et al., 2014; Zillén and Conley, 2010). In order to study the links and to assess the possible impact of human land use on the sea in a long time perspective, the project ‘Managing Multiple Stressors in the Baltic Sea’ (MULTISTRESSORS) was initiated at Lund University (Stadmark and Conley, 2013). The project focuses on reconstructing land-cover changes in coastal regions, and nutrient status in coastal waters of the same regions, based on terrestrial and marine palaeoecological records, respectively. Two of the project’s study regions are northeastern Småland, where land-cover changes reconstructed based on a new pollen record from Lake Storsjön (Åkesson, 2013) are being compared with marine proxies from the nearby bay Gåsfjärden (Ghosh et al., 2012; Nielsen et al., 2013), and southeastern Blekinge, which is the focus area of the present study. In this paper, we present a regional scale landscape reconstruction for the coastal region of southeastern Blekinge, based on the combined pollen records from Lake Färskesjön. This reconstruction will, in an ongoing

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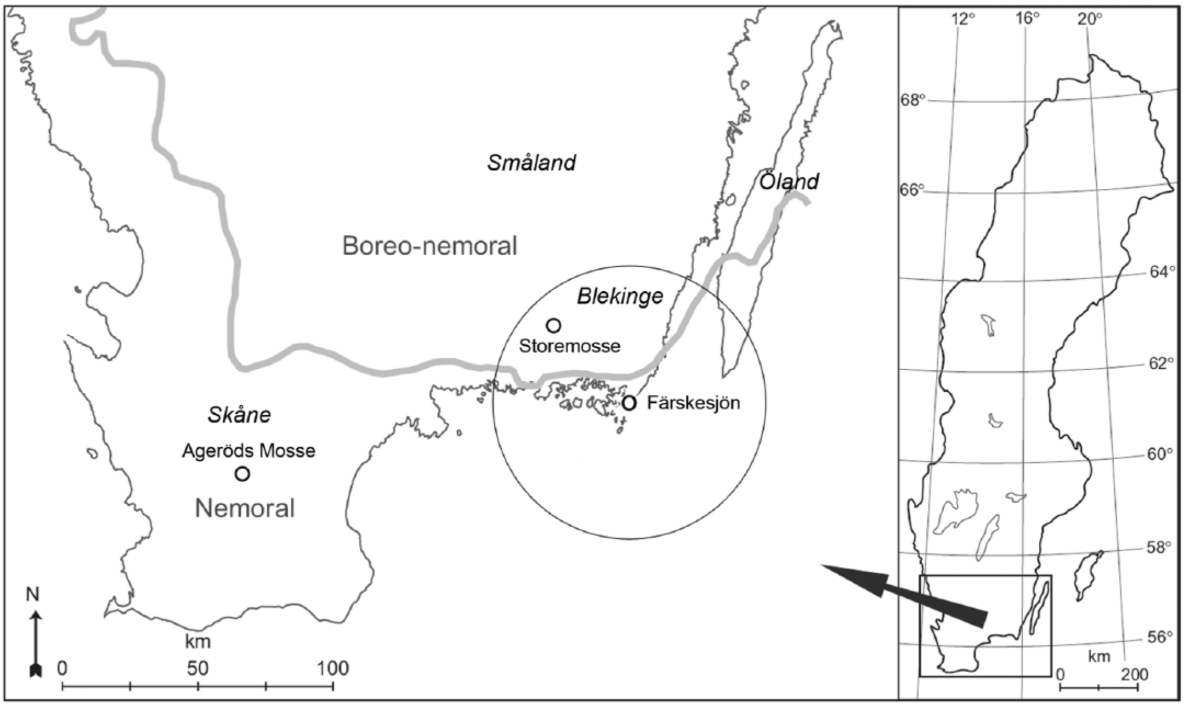

Figure 1. Map of southern Sweden showing the location of the study area Lake Färskesjön and the locations of the two bogs Ageröds Mosse and Storemosse. The provinces of Skåne, Blekinge, and Småland, as well as the island Öland are also shown in the map. The nemoral/boreo-nemoral forest border according to Sjörs (1965) is illustrated.

related study, be used in the interpretation of changes in the coastal environment studied in a core from nearby Karlskrona.

Pollen analysis – From description to quantification

Pollen records extracted from lake sediments or bog deposits have the potential to provide continuous information on past vegetation changes. When pollen analysis was introduced as a palaeobotanical method, the aim was concentrated on forest history, since pollen identifications were restricted to tree pollen (see pioneer works by Erdtman (1921), Firbas (1949), Nilsson (1935), and von Post (1916, 1924)). Iversen's (1941) 'landnam study' in Denmark was a breakthrough for more complete microscopical analyses by identifying even herb and grass pollen. This made it possible to trace land-use types such as forest clearing, cultivation, and grazing. The first textbooks with pollen flora descriptions (Erdtman, 1943) and identification keys (Fægri and Iversen, 1950) were also produced at this time. In south-central Sweden, Florin (1957) and Fries (1951, 1958) were the pioneers of the interpretation of farming history based on pollen analyses, later followed by Berglund (1966b, 1969) in the province of Blekinge and Königsson (1968) on the island of Öland (Figure 1).

Interpretation of pollen records in terms of forest composition was rather superficial in the early studies on Holocene forest history, because they were based on original pollen percentages. However, it was well understood that pollen production and dispersal varied between species. Iversen (1964) proposed correction factors for north European trees, and applied these in a study of the long-term history of Draved Forest in Denmark, and Andersen (1970, 1974) revised these factors based on experimental field studies in the same forest area. These have been widely applied in studies of local forest dynamics in other regions of northwestern Europe, for example, in southern Sweden (e.g. Berglund, 1991). Davis (1963) introduced the concept of the R-value model, that is, a first mathematical expression of the relationship between a plant taxon's pollen percentage and related vegetation percentage. The main conclusions from those early studies were that (1) trees are generally overrepresented and herbs underrepresented in pollen percentage diagrams, in relation to their share in the vegetation, which implies that forest and open-land cover tend to be interpreted as too large, respectively too small, when pollen percentages only are used in the interpretation of vegetation history, and (2) pollen from certain trees, such as *Betula* and *Pinus*, are overrepresented, while those from, for example, *Tilia, Ulmus*, and *Fraxinus*, are underrepresented, which implies that actual forest composition is very different from tree pollen composition.

A comprehensive review of the developments of pollen analysis in the field of human impact and land-use history and quantification of human-induced landscape openness is found in Gaillard (2013). Early studies of human impact on the landscape were based on the 'indicator species approach' (Behre, 1981; Birks and Birks, 1980). The identified pollen taxa were ascribed to modern human-induced and natural plant communities and their ecological characteristics. The presence/absence of these indicator taxa was used to describe the land-use history, and the percentages of the 'pollen land-use groups' were applied to infer relative changes in land use in relation to forest cover. Gaillard (2013) lists *c*. 200 pollen taxa related to five vegetation types within a traditional farming landscape. This method was applied in the so-called Ystad Project in southernmost Sweden, a palaeoecological/archaeological project focused on the long-term history of the cultural landscape (Gaillard, Göransson, Hjelmroos, Kolstrup, and Regnéll in Berglund, 1991). The indicator species approach using 'pollen land-use groups' may be described as a semi-quantitative method and is useful in particular when it is combined with skilled pollen-morphological identifications and botanical knowledge. However, it does not quantify the degree of human impact in terms of actual landscape openness, that is, the cover of human-induced open land.

A complementary method for analyzing the relationship between pollen assemblages and vegetation and/or land use is the 'comparative approach' (Birks and Birks, 1980; Birks and Gordon, 1985) in which contemporary pollen assemblages from different plant communities, for example, in ancient cultural landscapes are numerically compared with fossil pollen assemblages in order to identify modern analogues for the past assemblages, and in this way provide a description of the past vegetation/land use from the modern analogue landscape. A case study with pollen data from traditional farming landscape in southern Sweden (Berglund et al., 1986) was followed by other studies resulting in a large database of modern pollen assemblages and related vegetation, land-use, and soil chemical characteristics from ancient cultural landscapes in southern Sweden. This database was used in reconstructions of past anthropogenic landscapes and land use, and related grazing pressure and soil characteristics using the pollen record from Lake Bjäresjö (within the Ystad project, mentioned above; Gaillard et al., 1992, 1994, 1997). The comparative approach has also been applied in other countries including Finland (Hicks and Birks, 1996), Norway (Hjelle, 1999), and Denmark (Odgaard and Rasmussen, 1998, 2000).

Another, parallel development in the theory of pollen analysis has been the attempts at formulating the pollen-vegetation relationship mathematically/mechanistically with the objective of getting a reliable model to 'translate' pollen assemblages into quantitative estimates of vegetation composition. It has long been understood that the relationship between vegetation abundance and pollen proportion in sediments is non-linear (Fagerlind, 1952), which made it difficult to quantify vegetation cover based on pollen data. However, a theoretical framework gradually developed from the R-value model of Davis (1963), through the relative R-values or correction factors of Andersen (1970) – mentioned above – to the Extended R-Value (ERV) model (Parsons and Prentice, 1981; Prentice, 1985; Sugita, 1994) that takes the non-linear relationship between vegetation and pollen percentages into account. Apart from inter-taxonomic differences in pollen productivity, the representation of vegetation by pollen assemblages is also affected by differences in the properties of pollen dispersal and deposition. The latter was already studied by Tauber (1965, 1977) in Denmark, who applied the relatively simple Sutton equations (Sutton, 1953) to describe wind dispersal. This was later incorporated in the ERV-model framework to obtain a mechanistic model of the pollen-vegetation relationship (Prentice, 1985; Sugita, 1993). This model could then be used to simulate pollen dispersal and deposition to a pollen site (i.e. pollen assemblages in lakes and bogs) within a given landscape, which significantly improved the understanding of fossil pollen records in terms of past vegetation and landscapes (e.g. Bunting, 2008; Bunting et al., 2004; Caseldine et al., 2007; Gaillard et al., 1998; Nielsen, 2004; Nielsen and Sugita, 2005; Sugita, 1994; Sugita et al., 1999).

Based on this theoretical framework, combined with simulations and empirical studies of the relationship between surface pollen assemblages and modern vegetation (e.g. Broström et al., 1998, 2004, 2005), Sugita (2007a, 2007b) developed the Landscape Reconstruction Algorithm (LRA), designed to correct for pollen representation and dispersal biases and quantify vegetation composition based on fossil pollen assemblages. The LRA includes two models, REVEALS to estimate regional vegetation composition (within an area of *c*. 50–100 km radius) using pollen assemblages from large (*c*. 100–500 ha) lakes, or alternatively from multiple smaller sites (Sugita, 2007a), and the LOcal Vegetation Estimation (LOVE) model to estimate local vegetation composition using smaller sites, combined with regional vegetation estimates from REVEALS (Sugita, 2007b). The background for using mainly large lakes for regional vegetation reconstruction with REVEALS is that both simulations and empirical studies have shown that between-site differences in pollen composition within a region are small for large lakes, but large for small lakes (Berglund, 1973; Jacobson and Bradshaw, 1981; Sugita, 1994). Therefore, REVEALS estimates based on pollen records from several small sites generally exhibit larger error estimates than those using records from one or more large lake(s).

The REVEALS model has been empirically validated in, for example, southern Sweden and Switzerland (Hellman et al., 2008a, 2008b; Soepboer et al., 2010), and taxon-specific pollen productivity estimates (PPEs) needed for REVEALS-based vegetation reconstruction are now available for several areas of Europe (reviews in Broström et al., 2008; Mazier et al., 2012). So far, REVEALS estimates of Holocene land cover are available from southern Sweden, Denmark, and Switzerland (Nielsen and Odgaard, 2010; Soepboer et al., 2010; Sugita et al., 2008). In the project LANDCLIM (Holocene LAND-cover-CLIMate interactions in Europe; Gaillard et al., 2010), REVEALS has been applied for selected Holocene time windows to networks of sites within northwest Europe (Fyfe et al., 2013; Mazier et al., 2012; Nielsen et al., 2012; Trondman et al., 2012), and for the entire Holocene at selected sites (Marquer et al., 2014). The major objective of the LANDCLIM project is to assess the potential influence of human-induced land-cover change on the past climate of Europe (Strandberg et al., 2014). Land-cover effects on carbon release to the atmosphere have also been studied by combining REVEALS-based land cover with ecosystem modeling (Olofsson et al., 2013). At a more local scale, the LRA has been applied in southern Sweden to address long-term impact of land use on floristic diversity (Fredh, 2012; Fredh et al., 2013), fire dynamics (Cui et al., 2013), and dissolved organic carbon in lakes (Bragée, 2013). This use of pollen records allows the study of long-term processes in terrestrial and aquatic ecosystems, and the knowledge gained, such as the rate, amplitude, and frequency of changes in the past, has great potential to be useful for management of the environment today and in the future.

Material and methods

Description of the Lake Färskesjön area

Lake Färskesjön is situated in the province of Blekinge, southeastern Sweden, *c*. 16 km east of the city Karlskrona (Figures 1 and 2). The lake is located on the Torhamn Peninsula at an altitude of *c*. 14 m.a.s.l., *c*. 2 km east of the Baltic Sea bay Hallarumsviken and 3 km west of the open Baltic Sea. The lake lies in a depression within the Subcambrian peneplane, composed of gneiss, dipping gently eastwards towards the sea (Kornfält, 2007). A bedrock plateau at 25–35 m.a.s.l. west of the lake separates the basin from the Baltic Sea bay Hallarumsviken. The bedrock is covered by a thin layer of wave-washed, sandy till (Persson and Malmberg Persson, 2014). East of the lake, the till is covered by eolian sand.

The hydrological catchment area of Lake Färskesjön is *c*. 2.5 km^2, and the lake is drained by a brook running southwest towards the sea. The lake area is 0.5 km^2 (Berglund et al., 2008), and the water depth in the central part is 3–4 m (Figure 3). The lake was dammed off in 1964 to be used as a water reservoir. Within a shallow bay northwest of a small island in the lake, pine stumps occur which have been dated to *c*. 4000 BP (Berglund, 1966b). The lake is oligotrophic, and the limnic vegetation is described in Berglund (1966b). The western part of the lake is included in the Färskesjön nature reserve that comprises the bedrock plateau west and southwest of the lake.

Several grave cairns from the Bronze Age occur within a radius of 1.5 km from the lake. A grave field with stone settings dated to the Iron Age is located close to the eastern shore (Figure 4). Small-scale farming still occurs north and southeast of the lake. The sand field east of the lake is covered with planted pine wood. The bedrock-dominated area west of the lake has been used for grazing until the mid-19th century. It was an open *Calluna* heath, now characterized by a woodland succession with birch, pine, oak, and some beech.

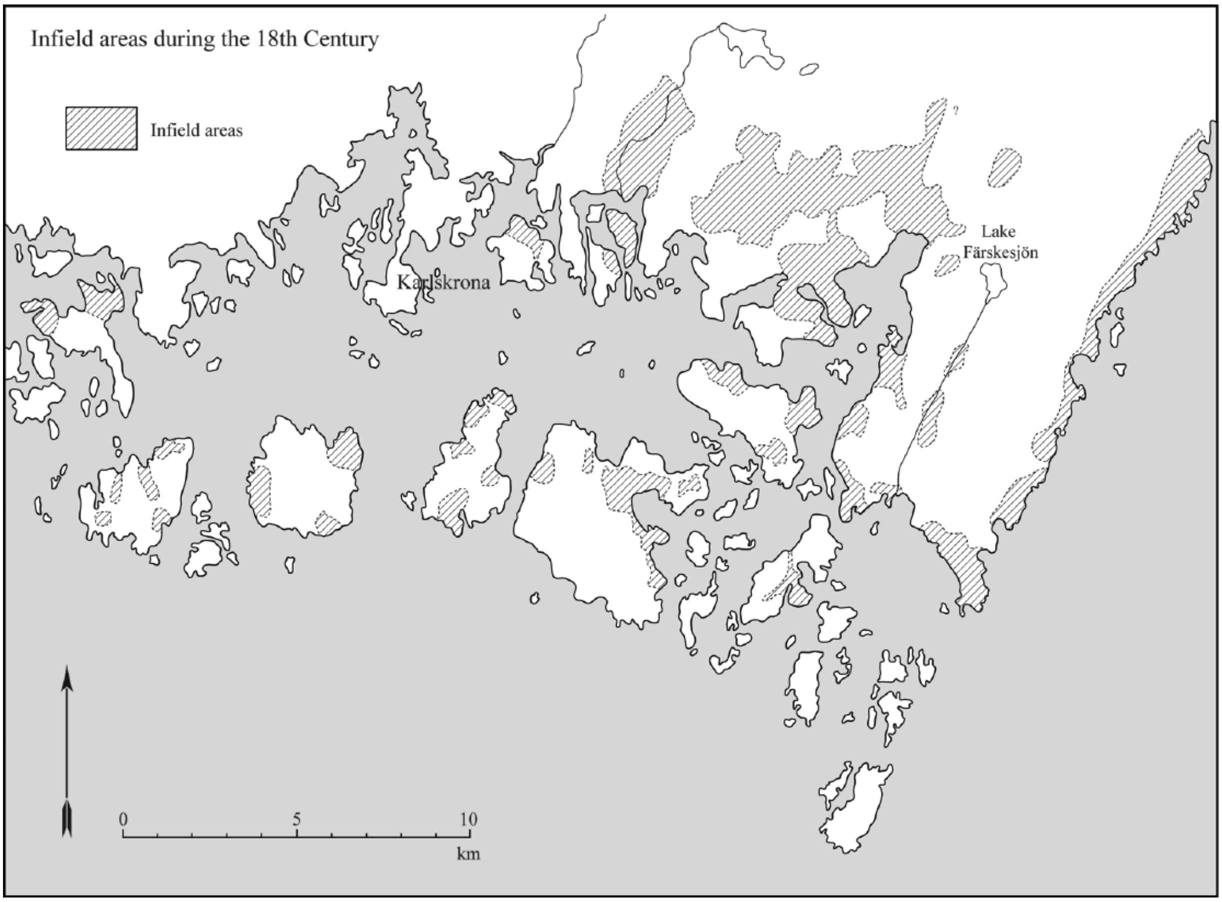

Figure 2. The distribution of farm village infield areas in the coastal area surrounding the city Karlskrona and on the Torhamn Peninsula, where Lake Färskesjön is located. The mainland west of Karlskrona has not been considered. The map is based on enclosure maps from the 18th century.
Source: Land survey documents at the Land Survey Office in Karlskrona, now at the national office in Gävle. From Berglund (1966b).

Field work and laboratory analyses

Core 1956. The first geological field work was performed in the summer of 1956. A sediment core (core 1956) was obtained by using a Hiller sampler in the southern part of the lake (Figure 3) at a water depth of 2.85 m. The sampling technique at that time made it impossible to perform a reliable subsampling of the top sediments (uppermost *c*. 20 cm).

The stratigraphy was as follows:

- *2.85–8.69 m*. Dark green, fine detritus gyttja, slightly clayey below 8.0 m.
- *8.69–8.75 m*. Grayish green, clayey fine detritus gyttja.
- *8.75–10.50 m*. Gray clay.

The sequence was pollen analyzed in 1956–1957, with some complementary identifications made in 1963. The lower boundary for the Holocene (tundra/forest) was identified at the layer 8.69–8.75. Two pollen diagrams were constructed, one for the Late Weichselian and one for the Holocene, both published in Berglund (1966a, 1966b). Later versions based on the same pollen data are discussed in Berglund et al. (2008) and in this paper. All details on pollen preparation and identification of pollen-morphological types are found in Berglund (1966a, 1966b).

Core 2013. In September 2013, a new sediment core (core 2013) with high time resolution for the last millennium was collected, sampled, and analyzed within MULTISTRESSORS and the project 'Linking land-use change to coastal ecosystems in the recent past', to supplement the Lake Färskesjön record with special focus on the uppermost part of the core, which could not be reliably sampled in 1956. The sampling location was situated 180 m from the nearest shore and 120 m southeast of a small island in the lake at a water depth of 3.0 m (Figures 3 and 4). Core 2013 has a total length of 2.8 m (3.0–5.8 m). The loose surface sediments (41 cm) were collected using a gravity corer (Kajak, Renberg, 1991) and sectioned in 1-cm intervals in the field, where the material was sealed in plastic bags. The remaining sediment sequence (3.20–5.80 m) consisted of three overlapping cores (FS1: 3.2–4.2 m; FS2: 4.0–5.0 m; FS3: 4.8–5.8 m), which were retrieved from two holes *c*. 1.5 m apart using a Russian corer (length: 1 m; diameter: 75 mm) and sealed in plastic film in the field. All of the material was stored in a cold room at 5 °C until further analyses.

The stratigraphy is as follows:

- *3.0–5.15 m*. Dark brown, fine detritus gyttja, some silt particles below 4.80 m.
- *5.16–5.18 m*. Brown gray, fine sand with a sharp upper and lower boundary.
- *5.18–5.26 m*: Dark brown, silty fine detritus gyttja, transition zone.
- *5.26–5.80 m*. Light gray, silty sandy gyttja-clay, sharp upper boundary.

Subsamples of 1 cm^3 were collected from the Kajak core and the uppermost Russian core for pollen analysis and loss on ignition (LOI) at an interval of 1 cm. The correlation between the cores was based on the LOI results, which showed similar values and corresponding peaks in both cores (see Figure 8). The subsamples for pollen analysis were prepared and analyzed in 2013 according to standard pollen methodology (Berglund and

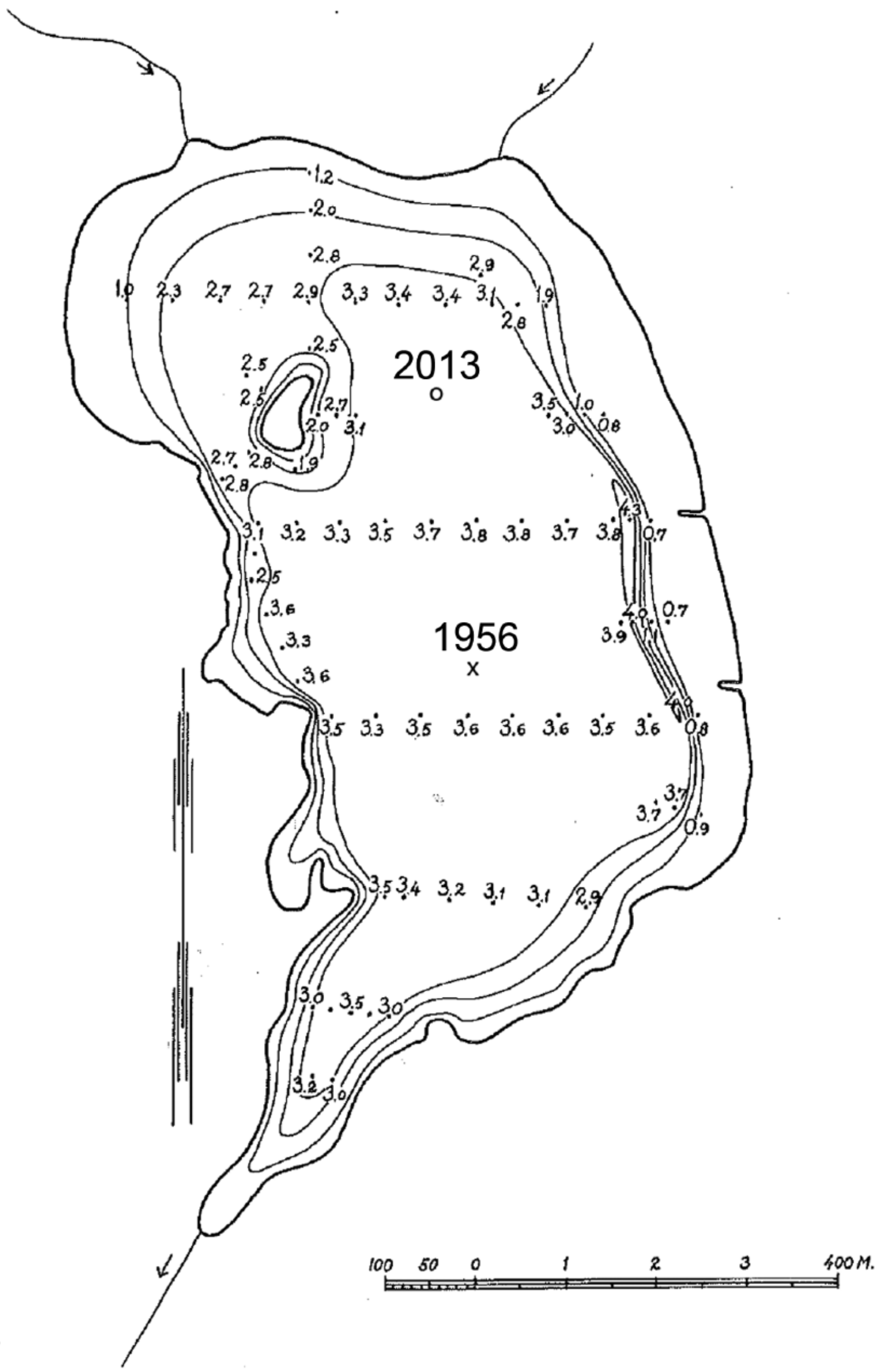

Figure 3. Bathymetric map of Lake Färskesjön based on measurements from the ice in the winter of 1941, by Bergdahl (Berglund, 1966b). Sediment coring sites are indicated with the year for the sediment sampling, 1956 and 2013, respectively.

Ralska-Jasiewiczowa, 1986). Pollen grains were counted and identified to species or family level using a light microscope (Olympus BX41) at 400 times magnification, pollen keys, and illustrations from Beug (2004), Fægri and Iversen (1989), and Moore et al. (1991) and the reference collection at the Department of Geology, Lund University. At least 1000 pollen grains were counted in each sample and the total pollen sum was used for the calculation of the pollen percentage. A P/E ratio of 1.25 was used in order to distinguish *Secale t.* (>1.25) from the other cereals (<1.25; in an equatorial view of a pollen grain, P is the distance between the polar areas and E the size of the grain at the equator). The outer annulus diameter was used in order to distinguish *Triticum/Avena t.* (>12 µm) from *Hordeum t.* (10–12 µm). For REVEALS analysis, *Triticum/Avena* and *Hordeum* types were combined into Cerealia t.

The subsamples extracted for LOI analysis were weighted, oven dried at 50 °C for approximately 12–24 h, and weighted again in order to determine the dry weight of the samples. The samples were then heated to 550°C in a muffle furnace and after cooling weighted again in order to estimate the organic content of the samples.

Chronology

The chronology of core 1956 is based on the pollen-stratigraphical correlation between the pollen record from Färskesjön and the ^{14}C-dated pollen record from Ageröds Mosse in Skåne (Figure 1; Nilsson, 1964) using numerical zonation methods (Birks and Berglund, 1979; for more details, see Berglund et al., 2008).

From core 2013, sediment samples from the Kajak core were freeze-dried and submitted for ^{210}Pb dating at the department of

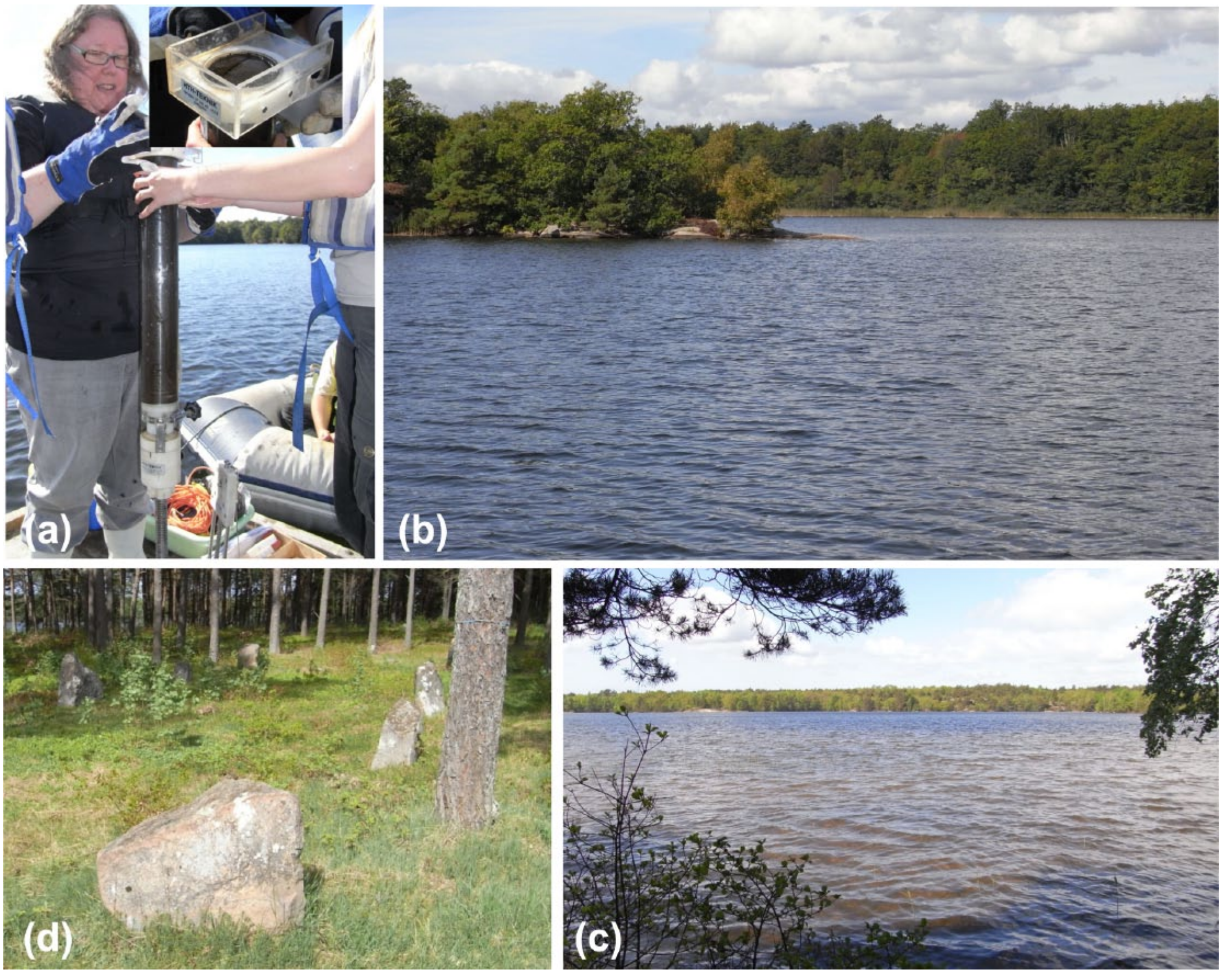

Figure 4. (a) Kajak sampling of top sediments. (b) View towards northwest from the sampling raft with the island and bay in the background. (c) View towards southwest from the eastern, sandy beach of the lake. (d) Iron Age grave field in the pine wood situated east of the lake.
Source: Photo BE Berglund, (a) and (b) in September 2013, (c) and (d) in May 2013.

Geology at Lund University. The age–depth relationship calculated using the constant rate of sedimentation model (CRS; Appleby and Oldfield, 1978) showed that the sedimentation rate was 1.74 mm/yr in the top 11.5 cm of the sediment (after *c*. AD 1951), and 0.80 mm/yr from 16.5 to 11.5 cm depth (*c*. AD 1882–1951).

Sediment samples from selected levels below 41 cm were sieved through meshes of 500 and 250 µm. Macroscopic plant remains from terrestrial taxa, mostly consisting of *Betula* fruits and catkin scales, *Alnus* bud scales, and unidentified leaf fragments, were carefully extracted from the sieve residue using a binocular microscope at 15 times magnification (Olympus SZX12). Three samples were submitted for dating at the ^{14}C-laboratory, Department of Geology, Lund University (Table 1). An additional date was used to construct the age–depth model of core 2013, namely, the ^{14}C age of the increase of *Fagus* pollen from *c*. 1% to 5% in the pollen diagram from Storemosse (Berglund, 1966b) in Blekinge, located 45 km northwest of Lake Färskesjön (Figure 1), a pollen-stratigraphical level also found in core 2013.

The age–depth model (Figure 5) was established based on the calculated ^{210}Pb dates and the ^{14}C dates, using the IntCal09 calibration curve (Reimer et al., 2009) to convert the radiocarbon dates into calendar years, and applying a smoothing spline model using the R-code CLAM (Blaauw, 2010).

Pollen diagrams from Lake Färskesjön – Methodological approaches

The first pollen diagrams from Lake Färskesjön (Berglund, 1966a, 1966b) were constructed in the traditional manner, inspired by the 'Copenhagen Troels-Smith school'. In a special diagram, correction factors were applied – *Betula, Pinus*, and *Corylus* were divided by 4; *Tilia, Acer*, and *Sorbus* were multiplied by 2. Such corrections have not been applied in later versions. A revised and simplified diagram was published together with similar diagrams from other regions in southern Sweden in a survey paper discussing the human impact on the landscape in late Holocene (Berglund, 1969). The Holocene pollen diagram from Lake Färskesjön (core 1956) has more recently been revised for different purposes (e.g. Berglund et al., 1996; 2006).

The high standard of pollen identifications (stratigraphic resolution, number of identified taxa, pollen sum in most samples *c*. 2500) made it suitable for calculation of palynological diversity as a proxy method for plant diversity (Berglund et al., 2008). Berglund et al. (2008) determined the palynological richness in the 1956 core using the rarefaction technique (Birks and Line, 1992) that estimates the expected number of terrestrial pollen taxa (E(Tn)) at a given pollen sum n. A base pollen sum of $n = 2099$ was used. Five 'diversity events', that is, periods of increased palynological richness, were identified and discussed in relation to anthropogenic deforestation and land-use disturbance. Although the relationship between palynological and plant-species richness is known to be complex (Odgaard, 1999, 2001), palynological richness can provide a general measure of diversity changes at the landscape scale (Berglund et al., 2008).

A slightly more simplified diagram, showing 22 key taxa (see below), is presented in this paper (Figure 6b), together with the new pollen diagram of core 2013 (Figure 6a), showing the same 22 taxa. The pollen diagrams were constructed using the computer program Tilia (Version 1.5.12; Grimm, 1992), and the percentages are based on the sum of terrestrial pollen.

REVEALS reconstructions

REVEALS estimates of vegetation cover for 22 selected taxa using the pollen records from core 1956 and core 2013 are presented in Figure 7a and b, respectively. The taxa selected are predominantly wind-pollinated taxa which are common in the pollen record and for which reliable estimates of pollen productivity (PPEs) are available (Broström et al., 2008; Mazier et al., 2012). The REVEALS reconstruction was carried out using the program REVEALS.v4.2.2 (Sugita, unpublished; see Sugita, 2007a for details on the REVEALS model). The values of pollen productivity and fall speed used follow Fredh et al. (2013). The Sugita (1993) lake model for pollen dispersal and deposition was applied, with a wind speed of 3 m/s. The maximum extent of the regional vegetation was set to 50 km (Mazier et al., 2012).

The REVEALS estimates (Figure 7a and b) are expressed in percentage vegetation cover within the spatial scale of the REVEALS model, that is, a *c*. 50–100 km radius. The percentages in the REVEALS diagram are based on the sum of the cover of the 22 selected taxa. However, as the 22 taxa represent >95% of the total sum of terrestrial pollen types, most of the differences seen between the pollen (Figure 6) and REVEALS (Figure 7) diagrams are caused by the correction for the taxon-specific differences in pollen productivity and dispersal function applied by the model. The percentage of the terrestrial pollen sum represented by pollen types not included in the REVEALS analysis is shown for the 2014 core in Figure 8. As seen, this varies slightly over time, and increases in the topmost part of the core. The most common taxa excluded from REVEALS are *Myrica gale* with up to 0.5% pollen and Chenopodiaceae, *Empetrum*, and *Achillea* type each with up to 0.3%. Polypodiaceae spores (up to 0.3%) are also included in this group.

The REVEALS model provides standard error estimates on the estimated percentage cover of each taxon based on the counting errors of the pollen data and the standard deviations of the PPEs (Sugita, 2007a). In Figure 8, the sum of the open-land REVEALS pollen taxa are plotted with their combined standard error.

Table 1. ^{14}C dates.

Sample	Depth	Uncalibrated ^{14}C date
LuS10863	329–330	220 ± 40
LuS10864	349–351	780 ± 40
LuS10865	415–416	2845 ± 45
U447[a]	378–382	1580 ± 80

[a]Date of the increase of *Fagus* pollen at Storemosse (for more explanation, see text).

Results and discussion

Chronology of the pollen diagrams from Lake Färskesjön

When the Holocene pollen diagram from Lake Färskesjön was prepared (1957–1963), it was difficult to obtain radiocarbon dates, and dates based on lake sediments were regarded as less reliable than dates based on bog peat. Nilsson (1964) selected the ombrotrophic peat bog Ageröds Mosse (Figure 1) for a careful stratigraphic study and 33 samples from a 6 m long core covering the entire Holocene were ^{14}C dated. A detailed pollen diagram from the same core was produced, and ages for the

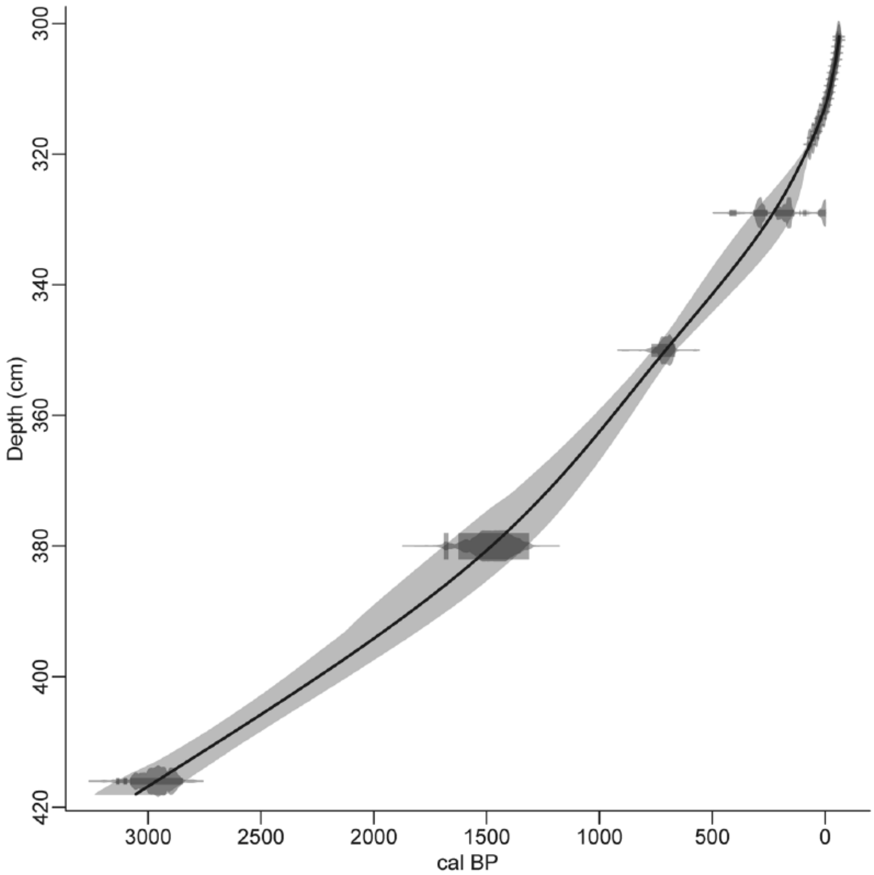

Figure 5. Age–depth model for core 2013 based on ^{14}C dates (Table 1) and ^{210}Pb measurements. The IntCal09 calibration curve and smoothing spline was applied using CLAM (Blaauw, 2010).

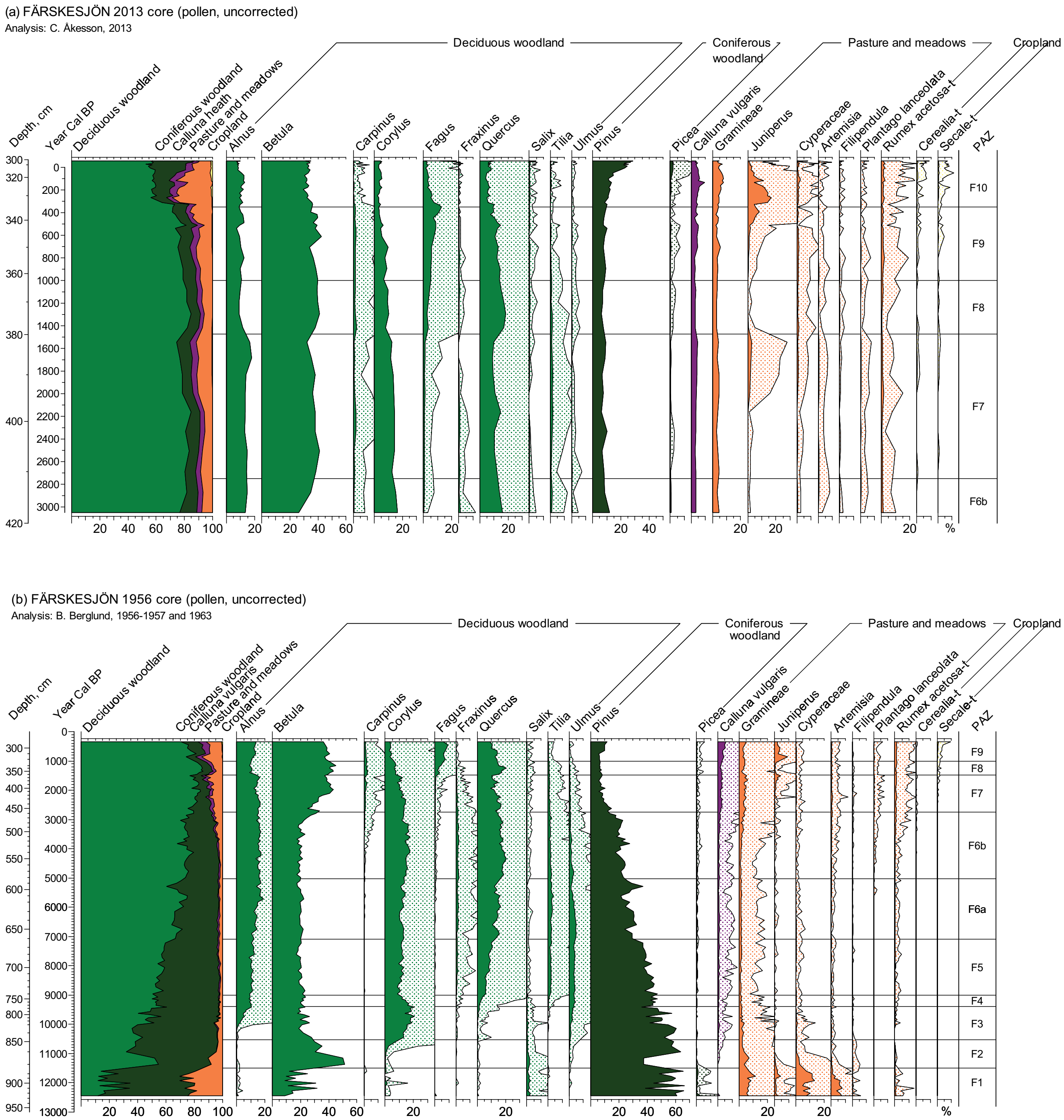

Figure 6. (a) Pollen diagram, original percentages, based on top core sediments 2013, time span 3000 cal. BP to present (AD 2012). (b) Pollen diagram, original percentages, based on full Holocene sediment sequence 1956, time span 12,500–350 cal. BP (AD 1600).

pollen-zone boundaries (Figure 5 in Nilsson, 1964) of the classical zone system for the province of Skåne were inferred from the ^{14}C-dated levels (Håkansson, 1971; Nilsson, 1935). Berglund (1966a, 1966b) focused on the vegetation history of eastern Blekinge and correlated the pollen zones between Skåne and Blekinge (with a distance of *c*. 150 km between the sites) in order to apply the chronology from Ageröds Mosse to the pollen records from eastern Blekinge (Figure 58 in Berglund, 1966b). This chronology was also supported by radiocarbon dates of peat from bogs in Blekinge. Moreover, a comparison of three selected Holocene pollen diagrams from lakes in Skåne (Bjäresjöholmssjön) and Blekinge (Lösensjön and Färskesjön) was later improved by applying four independent numerical zonation methods described by Gordon and Birks (1972): CONSLINK, SPLITINF, SPLITSQ, and PCA (Birks and Berglund, 1979). The zone system from Ageröds Mosse was also included in this comparison, which strengthened the time-space correlation between the two regions.

For the last 3000 years covered by core 2013, it has been possible to establish a chronology based on AMS dates of plant macrofossils (thus overcoming the problems with dating lake sediments), supplemented with one date transferred from the nearby Storemosse. Correlation between the two Färskesjön pollen records indicates that the age of the topmost sample of core 1956 had an age of *c*. 350 cal. BP, that is, slightly older than previously thought (Birks and Berglund, 1979). The chronology for the last 1000 years of core 1956 was adjusted accordingly.

Long-term forest dynamics

The Holocene pollen diagram of Lake Färskesjön core 1956 was subdivided into 10 pollen zones (Berglund, 1966b) comparable

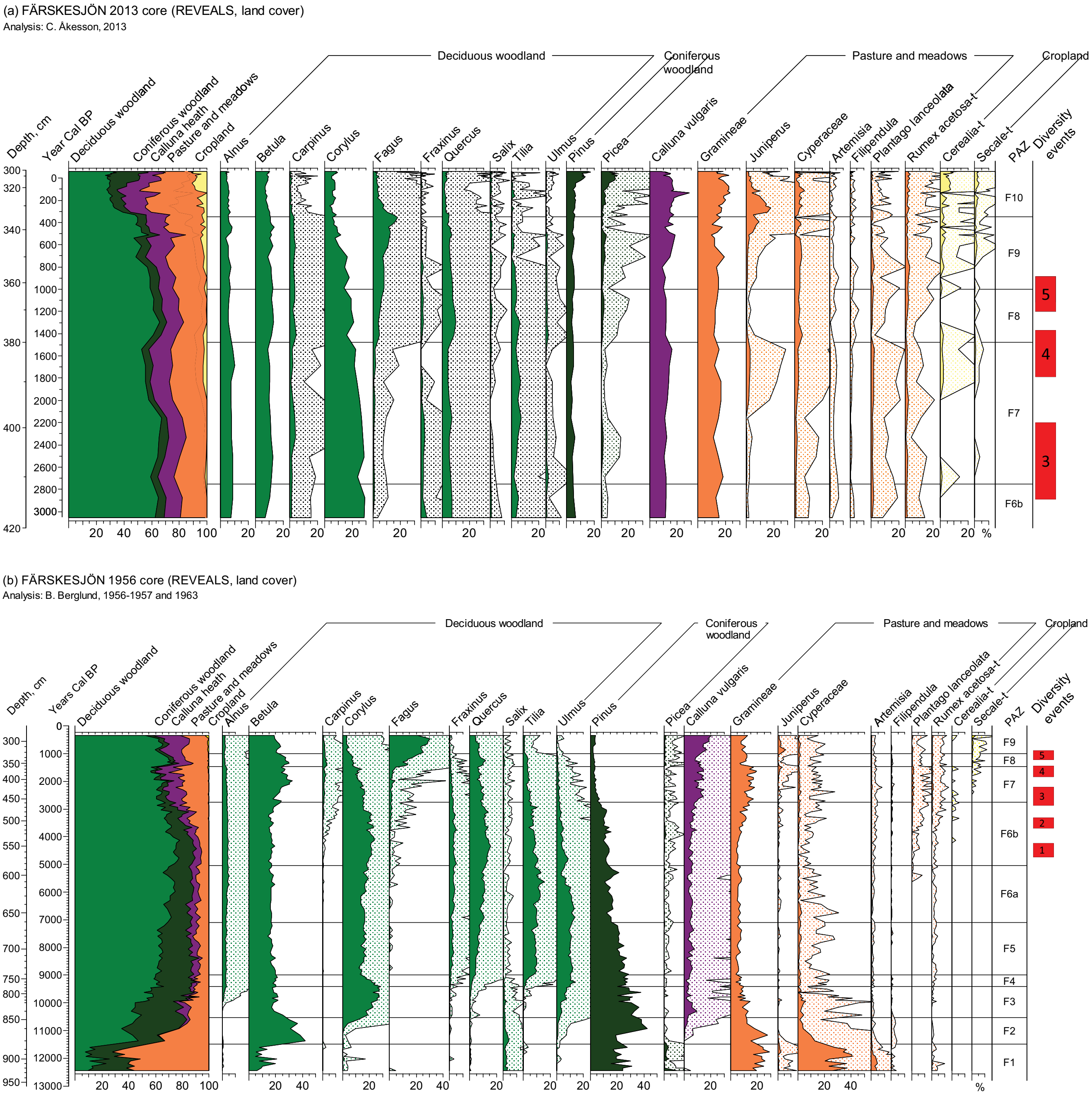

Figure 7. (a) Pollen-based REVEALS estimates for the top core sediments 2013, time span 3000 cal. BP to present (AD 2012). (b) Pollen-based REVEALS estimates for the full Holocene sediment sequence 1956, time span 12,500–350 cal. BP (AD 1600). The diversity events identified by Berglund et al. (2008) are indicated with red boxes.

with the traditional pollen zones in the province of Skåne (Nilsson, 1964). The numerical zonation resulted in nine pollen assemblage zones (PAZ, Birks and Berglund, 1979), and we have transferred these into the new version of the diagram published in this paper (Figure 6b). For the top sediment of core 2013, we have added an additional zone, PAZ 10, covering the time span 350 cal. BP to the present (Figure 6a), which means that this diagram comprises the uppermost part of PAZ 6b, and PAZ 7–10. The pollen diagram from core 1956 exhibits three main phases, which can be correlated with Iversen's classical subdivision of Quaternary interglacials (Berglund, 1966b; Iversen, 1958, Birks, 1986):

- The protocratic stage, PAZ 1–2, 12,500–10 500 cal. BP, with dominance of herbs, grasses, and bushes, interpreted as a vegetation of steppe-tundra character. Climate and soils favored calciphilous, heliophilous, and low-competitive plants. Pioneer woodlands with *Betula, Pinus*, and some *Corylus* and *Ulmus* expanded at the end of this period.
- The mesocratic stage, PAZ 3–6, 10,500–3000 cal. BP, with dominance of broadleaved forests, expansion of *Corylus, Ulmus, Quercus, Tilia, Fraxinus*, and *Acer*, in wetlands *Alnus*. This expansion occurred at the expense of *Pinus* and open-land vegetation as indicated by the retreat of grasses, herbs, and juniper bushes. During the later part, after 5000 cal. BP (PAZ 6b), there are traces of openings in the forest, as indicated by some decrease of broadleaved trees and expansion of grasses, herbs, and some cereals, altogether interpreted as the introduction of small-scaled farming.
- The telocratic stage, PAZ 7–9/10, 3000 cal. BP to present. During this stage, the broadleaved trees as well as *Pinus* decreased in favor of *Betula* and the immigrating new tree species *Carpinus* and *Fagus*, and during the last 200 years

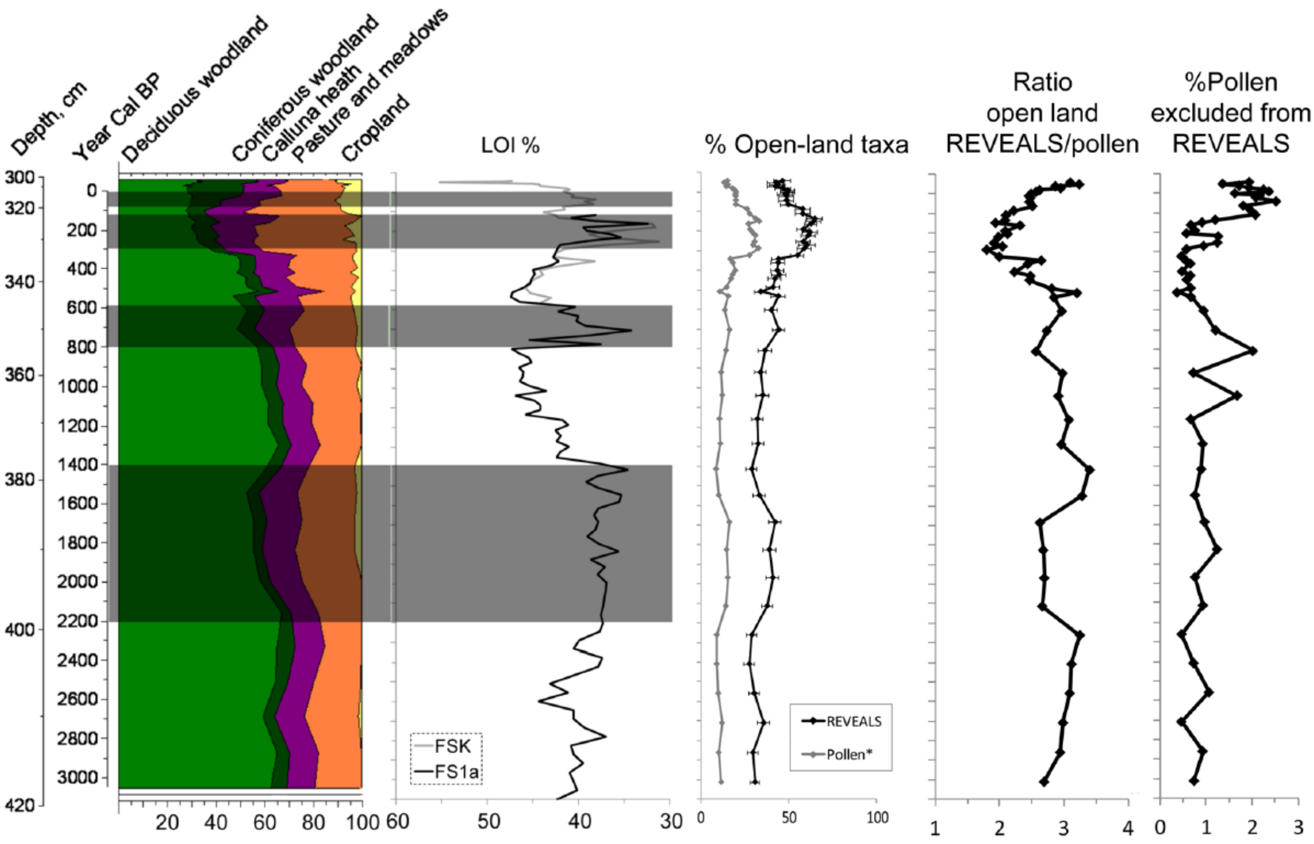

Figure 8. The summary REVEALS-based land-cover categories from the 2013 core (see also Figure 7a) plotted with Loss On Ignition (LOI %) from the Kajak core (FSK) and uppermost Russian core (FS1a). Periods of increased minerogenic content (note inversed LOI axis) and increasing landscape openness are indicated with gray shading. For the open-land taxa (Calluna heath, pasture and meadow, and cropland taxa) included in the REVEALS reconstruction, the sum of their REVEALS cover (with ±1 S.E.), and of their pollen percentages are shown, as it the ratio between these two values for each sample. Also shown is the percentage of the terrestrial pollen sum in each sample represented by taxa not included in the REVEALS analysis.

even *Picea*. The expansion of *Pinus* 150 years ago is partly caused by pine plantations near the lake. Open-land vegetation related to expanding farming characterizes this stage with *Calluna* heaths, grass-juniper heaths, croplands with cereals, and weeds.

When comparing the two diagram types, that is, the uncorrected (Figure 6b) and the REVEALS calibrated (Figure 7b), it is obvious that forests are overrepresented in relation to the open land in the uncorrected diagram. This difference varies over time, with the largest difference seen at 11,800 cal. BP, where the REVEALS estimate of open-land cover is higher than the pollen percentages of the corresponding taxa by 42%. The smallest difference, of just 5.8%, is found at 8400 cal. BP. During the protocratic stage, the REVEALS model reconstructs a mostly open landscape dominated by sedges and grass. The REVEALS reconstruction also indicates that up to 30–40% of the landscape was tree covered (by birch and pine, with low amounts of willow and even spruce). This is the period where the differences in landscape openness indicated by REVEALS and pollen percentages are largest (25–41%). The large difference is because of the dominance among the tree species of highly productive and well-dispersed pollen types like *Pinus* and *Betula*. However, during this period, forest cover may still be overestimated by REVEALS because the local pollen production in a tundra-like landscape is very low (Hicks, 1977), so that long-distance transported pollen from the continent can have a big impact on the reconstruction. The REVEALS model makes the simplification of assuming that all pollen originates within the region where the site is located, an assumption that may not hold true in such environments. Furthermore, it is likely that the relative pollen productivity of the different taxa was also different in the much colder late glacial climate, as is indicated by differences seen today in PPEs from different regions (Broström et al., 2008). Thus, although REVEALS indicates *c*. 30% tree cover, the area of steppe-tundra was probably totally dominant during PAZ 1.

In the period *c*. 11,500–10,000 cal. BP, at the transition from the protocratic to the mesocratic stage, the climate got steadily warmer, with mean July temperature rising to above 10°C (Björkman, 2007). The forest cover expanded, with REVEALS showing an increase in tree cover from around 30% to over 80% of the landscape. As woodland became dominant in the region, the problem of long-distance transported pollen likely became smaller, and the REVEALS estimates of woodland cover therefore more reliable. REVEALS indicates that the cover of *Betula* quadruples from 11,600 to 11,400 cal. BP, while the cover of *Pinus* doubles a few hundred years later. *Corylus* starts expanding when trees cover four-fifths of the landscape.

During the mesocratic stage, the REVEALS estimated wooded area was rather constant as also suggested by pollen percentages. But with 10–15% of the landscape covered by grasses, herbs, and *Calluna*, open-land vegetation was much more frequent than earlier interpreted from uncorrected pollen values, where these taxa only make up 2–4% during this period. Our new interpretation based on the REVEALS estimates is that heathland and grassland occurred in areas with thin soils and exposed bedrock, which also characterize the bedrock plateaus surrounding Lake Färskesjön.

In PAZ 3, the tree composition alters significantly when the cover of *Betula* is reduced by half (to 20%), while *Corylus* and *Pinus* each cover about 25% of the landscape. *Alnus* and the broadleaved tree species *Ulmus, Quercus, Tilia*, and *Fraxinus* establish in the region, and *Ulmus* expands significantly from a few to 10% coverage. During the following centuries (PAZ 4), the cover of *Corylus* is halved to 10%, while *Quercus, Tilia*, and *Fraxinus* expand to 5%, 10% and a few percentage cover, respectively, resulting in a much more mixed broadleaved forest, but still with the open areas described above covering about 10% of the landscape. The proportion of open-land and early successional trees like *Betula* may also indicate a rather dynamic landscape with shifting openings in the forest with grass that were later overgrown with birch. There is a slow expansion of oak that doubles in cover to 10% during PAZ 5 and 6a, while the cover of *Pinus* is reduced to 15%.

Around 5500 BP, there is a significant change in the species composition of the woodland when the coverage of *Ulmus* is reduced by three quarters from 10% to 2.5% during the elm decline. The proportion of woodland, however, remains almost unchanged at 90%, as *Tilia, Quercus*, and, to a lesser extent, *Pinus* increase as *Ulmus* decreases.

A few hundred years after the elm decline, there is indication of grazing in the area by the presence of a small amount of *Plantago lanceolata*. Between 5000 and 3000 cal. BP (PAZ 6B), the area of open land is doubled to 20%, dominated by grass (15%). The abundance of *Artemisia, Plantago lanceolata*, and *Rumex acetosa* increases to a few percent, and *Calluna vulgaris* covers 5%. The expansion of open land happens at the cost of *Ulmus, Tilia, Quercus*, and *Pinus*, which all decline in cover. *Corylus* expands to some extent until 3500 cal. BP and thereafter also decreases, while *Betula* expands significantly from 15% to 24% cover, indicating a dynamic landscape were trees are cut down and the openings later overgrow in a secondary succession. Two new tree species, *Fagus* and *Carpinus*, establish in the landscape during PAZ 6B, possibly favored by the anthropogenic disturbance and less nutrients in the soil.

The telocratic stage is characterized by a total change of the woodland composition, namely, the retreat of *Ulmus, Tilia, Corylus*, and, to some extent, also *Quercus* on behalf of the expanding *Fagus, Carpinus*, and open-land vegetation (heathlands, pastures, meadows, and cropland). The open-land pollen indicators have values of 10–20%, while the REVEALS estimates of open-land cover reach 30–40% in core 1956, and up to 60% in the period 300–50 BP in core 2013, indicating that the landscape in southeastern Blekinge in the 17th to the 19th centuries AD was substantially more open than that found in the region today, with only two-thirds of the present tree cover. We regard these REVEALS values as a realistic estimate of the vegetation openness considering the geological and topographical character of the landscape of southeastern Blekinge and Småland within 50 km of Lake Färskesjön. The area surrounding the lake was during the 18th century (Figure 2) part of an extensive outland area with poor soils and sparsely wooded pastures and grazed heathlands (outlands) belonging to farmer villages, which were mainly situated at the coast. The fertile infield areas with cropland and hay meadows were fenced off from the grazed outlands. This structure of the farming landscape goes back to Prehistoric time, probably at least 1500 years (Berglund et al., 2014).

Human impact during late Holocene

Our interpretation of the human impact during the last 6000 years refers to the pollen diagrams in Figures 6 and 7. The following description is based on the diagrams of REVEALS estimates. We also consider the changes in palynological diversity or the 'diversity events' based on the complete pollen assemblages from the Färskesjön 1956 core (Berglund et al., 2008, Figure 6). Referring to this, we emphasize the value of combining REVEALS-based land-cover reconstructions with consideration also of rarer indicator species for open-land vegetation that are excluded in the REVEALS calculation, including, for example, *Potentilla, Jasione, Melampyrum*, and *Pteridium*. Although we do not quantify the cover of these species with REVEALS, their low pollen percentages (<0.2% of each in all samples) indicate that they only covered a very small fraction of the landscape. However, they are important indicators of human impact on the landscape (Gaillard, 2013). We compare phases of land-use change and 'diversity events' with the archaeological time scale of southern Sweden (Berglund, 1991; Myrdal and Morell, 2011).

As visible in the REVEALS diagram of core 1956 (Figure 7b), there is an indication of pastures around 5600 cal. BP through the first finds of *Plantago lanceolata*, also supported by other open-land indicators in the original diagram (Berglund, 1966b). This time corresponds to the Early Neolithic. A more general increase of pasture and meadow plants, as well as the first occurrence of cereals, does not take place until 4600 cal. BP. This change coincides with diversity event 1 culminating between 4700 and 4300 cal. BP, which is during the Middle Neolithic. From 3600 cal. BP, there is a more distinct increase of Gramineae, *Plantago lanceolata*, and *Rumex acetosella*, that is, an open landscape caused by expanding farming and grazing. The increase of *Betula* and the doubling of *Calluna* cover combined with a reduction of *Corylus* *c*. 3200–3000 cal. BP are interpreted as a change towards more open woodland and increased areas of heathlands. The expansion of heathland indicates an increase in grazing pressure and that poorer soils were used for this purpose. This phase may be related to diversity event 2 (3800–3300 cal. BP).

From 3000 cal. BP, the REVEALS estimates from core 2013 (Figure 7a) provide a more detailed picture of the open landscape development than the REVEALS diagram from core 1956. During PAZ 7, the landscape composition seems to be rather stable until *c*. 2300 cal. BP, with open land covering one quarter of the landscape. Grassland accounted for approximately 15% of the landscape, dominated by grasses but also including herbs like *Artemisia, Plantago lanceolata*, and *Rumex acetosa* at a few percentages each. At that time, a more pronounced expansion of pastures and cropland begins, which lasts until *c*. 1500 cal. BP. This expansion is characterized by a distinct increase of *Juniperus* and Cerealia together with high values of Gramineae, Cyperaceae, *Plantago lanceolata, Rumex acetosa*, and *Secale*. The results of the LOI analyses (Figure 8) show increased proportions of minerogenic matter in the sediment, which is interpreted as caused by soil erosion in the hydrological catchment of the lake (and possibly also eolian transport from sandy, cultivated soils nearby). During this phase, the complex diversity events 3 and 4 occurring during the Pre-Roman and Roman Iron Age were identified by Berglund et al. (2008).

During the following period 1500–1000 cal. BP (PAZ 8), which is during the Late Iron Age, tree cover increased as a consequence of reduced farming. The cover of *Quercus* doubled, and *Fagus* expanded to more than three times its former cover, probably invading former heathlands and wood pastures. The cover of *Corylus* on the other hand is halved to 5%. The decrease in the areas of pastures and cropland is reflected in lower REVEALS estimates of *Juniperus* and Cerealia. Berglund et al. (2008) noted a distinct drop in plant diversity around 1500–1300 cal. BP, between diversity events 4 and 5, followed by an increase. The LOI values show a decrease of minerogenic matter during the period 1400–800 cal. BP. In a larger European perspective, this decrease in agriculture in Blekinge coincides with the reforestation that characterized Europe during the 6th century AD (Lagerås, 2007). This has been explained as an effect of climate change and/or population decrease, or a combination of both.

The period 1000–350 cal. BP (PAZ 9) is a time of increased human impact with a gradual expansion of pastures and cropland as indicated by higher values of *Juniperus, Calluna*, and cereals.

The total cover of open land increases from 30% to 40% of the landscape mainly because of the doubling of heathland from 10% to 20%. Between 1000 and 600 cal. BP, the area of cropland is approximately doubled to 3%. There are minor changes in the forest composition, but *Fagus* doubles in cover to 20%, and during the period 1000–600 cal. BP, a reduction in broadleaved trees (*Quercus, Corylus*, and *Tilia*) occurs, which may be explained by expanding wood pastures. During the period 800–600 cal. BP, the LOI values indicate increased deposition of minerogenic material. The plant diversity values are high during 1200–900 cal. BP (diversity event 5). We correlate the time from 1000 to 450 cal. BP with the Medieval society expansion. The late Medieval population decline around 700–600 cal. BP is traced in some south Swedish pollen diagrams as a period of forest expansion (Lagerås, 2007). In our REVEALS diagram, there is no clear forest expansion, but there is a short lasting reduction in cropland cover to half of its former extent, followed by expansion of heathland (with *Calluna* cover rising from 9% to 17%) and especially *Juniperus* cover (gradually rising from <1% to 5%) after 700 cal. BP. This may have been caused by areas that were no longer cultivated being used for low intensity grazing.

A sudden change occurs at 350 cal. BP (AD 1600): tree cover decreases, particularly *Fagus* and *Quercus*, while *Juniperus*, cereals, and, to some extent, other pasture and meadow plants increase in abundance, so that the open-land area cover increases from 40% to 60% of the landscape. There is a change in the relationship between the pollen percentages and the open-land cover reconstructed by REVEALS, at the ratio REVEALS%/pollen% for open land (i.e. grassland, cropland, and heathland) falls from *c*. 3 to *c*. 2. This change is partly driven by the expansion of *Juniperus*, which has a higher pollen productivity than many of the other open-land species, and partly by the decline of *Fagus*, which is among the less highly productive tree species. But changes in other species also play a role for this relationship, underlining the importance of trying to correct for differences in pollen productivity when interpreting past landscape openness.

Cropland expands to cover *c*. 5% of the landscape by AD 1800. At the same time, there is a distinct increase of minerogenic matter with high values until AD 1950. Altogether, this reflects a more open farming landscape than earlier during these two centuries – a farm village landscape with infields (cropland, hay meadows) and outlands (heathlands, wood pastures) as it is documented in the land survey maps of that time (Figure 2). A change from AD 1850 includes a decrease of deciduous trees followed by a decrease of pastures, meadows, and heathlands, while cropland area is doubled to 10% from AD 1800–1900. This reflects a shift in land use from small-scaled farming towards modern agriculture, where pastures and meadows decrease in favor of concentrated croplands, and modern forestry where former heathlands and wood pastures are planted with *Pinus* and *Picea*. Since AD 1900, the cropland areas are reduced by one-third to 7%, and woodland has expanded further to cover 50% of the landscape, mainly caused by the increase of coniferous trees, with *Picea* and *Pinus* covering 6% and 15% respectively. The remaining part of the woodland, making up *c*. 30% of the landscape, is deciduous and consists of *Betula* (10%), *Corylus* (10%), and *Alnus* (5%) with smaller percentages of *Quercus, Fagus*, and *Carpinus*. The REVEALS%/pollen% ratio for the open land increases again because of the expansion of the relatively low pollen productivity tree *Picea* and the decline in *Juniperus* in the grasslands.

Landscape changes and nutrient loading on the Baltic Sea

In the lake sediment sequence, three phases, at *c*. 2200–1400, 800–600, and 300–0 cal. BP, are characterized by low values of LOI (see Figure 8), that is, relatively high content of minerogenic matter. As seen in Figure 8, these periods are also characterized by anthropogenic forest clearance, and cropland expansion is reflected in the REVEALS reconstruction. This indicates that increased land use lead to soil disturbance and increased erosion in the hydrological catchment of Lake Färskesjön. With the use of diatom-based transfer functions for reconstructing past phosphorous concentrations in lakes, it has been demonstrated in, for example, England (Birks et al., 1995) and Denmark (Bradshaw et al., 2005) that such catchment erosion, as a result of prehistoric and pre-industrial land use, can lead to increased nutrient levels in lakes. It has also been suggested that past land-use changes played a role in eutrophication, and in causing cyanobacteria blooms and periods of hypoxia in the Baltic Sea (Funkey et al., 2014; Zillén and Conley, 2010), although other authors (e.g. Bianchi et al., 2000; Eremina et al., 2012) have argued that hypoxia and cyanobacteria blooms are a natural feature of the Baltic Sea system, with variations controlled mainly by climate. A period of increased erosion, not only in the hydrological catchment of Lake Färskesjön but throughout the wider region reflected by the REVEALS land-cover reconstruction, could have resulted in a substantial transport of material, including nutrients, to the coastal waters around southeastern Blekinge. For example, reconstruction of cropland cover nearly doubles, and open land increases by a quarter between 1000 and 600 cal. BP. The Färskesjön record only shows an increase of minerogenic material in the later part of this period (see Figure 8), most likely because the expansion of crop- and grassland occurred first on the more fertile soils further west and near the coast, before reaching the watershed of Färskesjön. After 700 cal. BP, where cropland declines, there is a sharp drop in minerogenic content in the lake sediments, indicating decreased erosion during the late Medieval decline. From around 400 cal. BP, there is again increasing erosion, which seems to decline in response to the increase in forest cover after 150 cal. BP. Current palaeoecological studies of coastal, marine cores from the Karlskrona area (Filipsson et al., unpublished) may reveal whether and how these regional landscape changes affected the coastal marine environment.

Considering the uncertainties in the Färskesjön chronology, one of the phases of increased erosion observed at Lake Färskesjön terminates at approximately the same time as the hypoxic and cyanobacteria rich phases described from the central Baltic Sea by Funkey et al. (2014), that is, at 600–700 cal. BP. This is a period affected by population decline and land abandonment in many areas of Europe, including Sweden (Lagerås, 2007; Skog and Hauska, 2013), following the Black Death. However, more studies are needed to determine whether this reduction in impact did indeed contribute to the improved oxygen status in the Baltic, or whether this was rather caused by climatic changes associated with the end of the Medieval Climate Anomaly and onset of the 'Little Ice Age'. Although the effect of past land-use changes on the Baltic Sea is still under debate, there is no doubt that climate also plays a very important role in the processes behind cyanobacteria blooms and hypoxia (Bianchi et al., 2000; Eremina et al., 2012; Funkey et al., 2014).

A step towards disentangling the effects of human impact and climate is to study the variations in timing and degree of impact in different regions along the Baltic Sea coast. For example, comparison of the land-cover reconstruction from Lake Färskesjön with a similar study of Lake Storsjön in Småland (Åkesson, 2013) shows that the degree of anthropogenic landscape openness is much higher in Blekinge, as the REVEALS-based estimates of landscape openness around Lake Storsjön never reached values above 40%, against values up to 65% (±S.E. 4.5%) at Lake Färskesjön. The phases of increased impact also appear to be of shorter duration at Lake Storsjön. This difference may be reflected in differences in timing and extent of changes in nearby coastal areas (Ghosh et al., 2012; Nielsen et al., 2013).

Conclusion

1. The accuracy of chronology for Holocene pollen diagrams in Sweden has improved enormously since mid-20th century. Radiocarbon dating became available around 1960 but was then mainly applied on large peat samples. Absolute time scales were transferred from selected reference sites to non-dated stratigraphies by pollen-analytical correlations. This was facilitated by numerical methods applied since 1970s. Today, AMS radiocarbon dating makes it possible to date small samples (seeds, leaves, shells, etc.) obtained by sieving lake sediment or peat. Modern gravity corers are used to recover surface sediments with high water content. Time models for such young sediments are obtained by analyzing ^{210}Pb in sequences of top sediments. This makes it possible to link palaeoecology with the modern environment.
2. During the last 100 years, the pollen-analytical method has changed from being descriptive and concentrating on forest history. In the early 20th century, it was mostly used as a correlation tool in Holocene geology, but around the mid-20th century, plant ecologists became interested in the human impact on the environment and the early farming history. Identifications of pollen of plants from cropland, pastures, and meadows were then included in a complete pollen analysis, and the results often applied in multidisciplinary projects where palaeoecologists collaborated with archaeologists and historians.
3. Interpretation of human impact on landscapes and land use in the past has gradually reached a higher precision with the development of the indicator species and the comparative approaches (Behre, 1981; Birks and Birks, 1980; Gaillard, 2013). This development occurred in parallel with the application of numerical methods from the 1980s onwards (Birks and Gordon, 1985; Prentice, 1985). Further developments included empirical studies of the relationship between surface pollen assemblages and modern vegetation and finally the LRA of Sugita (2007a, 2007b) with its two models REVEALS and LOVE.
4. The REVEALS model was applied on the 'classical' Holocene pollen sequence from Lake Färskesjön (11,500–350 cal. BP) in southeastern Sweden and on a new sequence from the top sediments of the lake (3000 cal. BP to present). The REVEALS estimates were compared with the uncorrected pollen percentages. The REVEALS estimates indicate that the open-land vegetation is strongly underrepresented by pollen percentages by a factor of 2–5, which varies over time depending on the exact species composition of both the forest and the open vegetation types. Thus, the area of open land was significantly larger than previously appreciated, not only during the protocratic and telocratic stages of the Holocene but also during the mesocratic stage, which is traditionally interpreted as being densely forested, but in this area is estimated to have been 10–15% covered by grasses, herbs, and *Calluna*.
5. The vegetation dynamics of the open landscape is mainly caused by changes within the agrarian society – population pressure and land-use changes. The REVEALS model is useful for quantifying the development of cropland, open pastures as well as wood pastures, deforestation, reforestation, and so on. However, there is some loss of floristic details in comparison with a complete pollen dataset. Based on our case study Lake Färskesjön, it is possible to identify 'plant diversity events' from the pollen data which might not be noted in the REVEALS data, but nevertheless contain information on past human impact on the landscape.
6. In the regional area of Lake Färskesjön, farming was introduced in Early Neolithic *c*. 5000 cal. BP, but expansion of open farmland is not recorded until *c*. 3200–3000 cal. BP, that is, during the Early Bronze Age. A pronounced expansion occurred during the period 2300–1500 cal. BP, with deforestation and expanding of open areas from 30% to 40% of the landscape. This time corresponds to the Roman Iron Age. The following period 1500–1000 cal. BP is characterized by reforestation and reduced farming. The period 1000–500 cal. BP is a new phase of expanding farming related to the Medieval society expansion, possibly including the Medieval decline around 600–700 cal. BP, where the area of cropland is reduced by half. The most distinct expansion of open farmland occurred 350 cal. BP (AD 1600), with deforestation and expanding pastures and cropland lasting until AD 1850, culminating with a landscape openness of more than 60%. This was followed by a contraction of open land because of reforestation of heaths, pastures, and reduced areas of cropland as a consequence of the general land-use shift from traditional farming to modern agriculture.
7. Sedimentological studies of lake sediment cores, in combination with land-cover reconstructions, give additional information on erosion linked to farming, deforestation, and possible climate changes. Our study shows that several phases of increased forest clearance and areas of cropland are associated with increased erosion in the lake catchment, which likely leads to increased nutrient transport from land to the lake and ultimately to the sea. Future studies will show whether this had an impact on the nutrient and oxygen status of the coastal marine area of the study region.

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