Forest History as a Basis for Ecosystem Restoration—A Multidisciplinary Case Study in a South Swedish Temperate Landscape

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Abstract

Basic knowledge of the previous forest types or ecosystem present in an area ought to be an essential part of all landscape restoration. Here, we present a detailed study of forest and land use history over the past 2,000 years, from a large estate in southernmost Sweden, which is currently undergoing a restoration program. In particular, the aim was to identify areas with long continuity of important tree species and open woodland conditions. We employed a multidisciplinary approach using paleoecological analyses (regional and local pollen, plant macrofossil, tree ring) and historical sources (taxation documents, land surveys, forest inventories). The estate has been dominated by temperate broad-leaved trees over most of the studied period. When a forest type of *Tilia*, *Corylus*, and *Quercus* started to decline circa 1,000 years ago, it was largely replaced by *Fagus*. Even though extensive planting of *Picea* started in mid-nineteenth century, *Fagus* and *Quercus* have remained rather common on the estate up to present time. Both species show continuity on different parts of the estate from eighteenth century up to present time, but in some stands, for the entire 2,000 years. Our suggestions for restoration do not aim for previous "natural" conditions but to maintain the spatial vegetational pattern created by the historical land use. This study gives an example of the spatial and temporal variation of the vegetation that has historically occurred within one area and emphasizes that information from one methodological technique provides only limited information about an area's vegetation history.

Key words: analysis, *Fagus*, forest conservation, forest openness, historical sources, macrofossil, paleoecology, *Picea*, pollen analysis, *Quercus*, tree-ring analysis, tree species continuity.

Introduction

Restoration of broad-leaved forests is a trend in many countries in the temperate zone today, particularly in northern Europe (Stanturf & Madsen 2005). A common form of restoration is the replacement of monocultures of exotic coniferous trees with native broad-leaved trees. In most cases, the restoration aim is an alteration to a more "natural" forest condition (Bradshaw 1997). In a more far-reaching form, called "ecological restoration," the goal is the ecosystem present before the human influence became pronounced on the landscape.

Whichever approach used, basic knowledge of the previous forest types or ecosystem present in the area ought to be an essential part of all landscape restoration, if only as a reference point in the decision-making process of what goal is to be achieved (Davis 1989; Birks 1996; Foster 2002). Because of the marked human influence on temperate European ecosystems over the past few thousands of years, it is not enough to identify which forest type or vegetation composition occurred in the area just prior to the existing forest—an even longer time perspective is needed.

In this article, we present a detailed study of forest and land use history over the past 2,000 years, from a large estate in southernmost Sweden, which is currently undergoing a thorough restoration program. An important question during this process has been what today's dominating coniferous forest (>60% of total area, mainly Norway spruce [*Picea abies*]) should be replaced with and where on the estate the conversion should take place. Oak (*Quercus robur*) and Beech (*Fagus sylvatica*) are key species for biodiversity in Sweden today (Jonsell et al. 1998; Gärdenfors 2005), and several red-listed (endangered) lichen and beetle species associated with old individuals and dead wood of these tree species have been found on the estate (Malmqvist 1999, 2002). It has been shown that long tree species continuity (here defined as the same tree species present in a site for more than two tree generations) is a key factor for the occurrence and conservation of many of these rare species (Fritz & Larsson 1997; Honnay et al. 2004) because they are often dispersal

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limited (Ranius & Hedin 2001). The degree of openness is another important factor in conservation in northern Europe because many threatened forest species are dependent of sunny and warm conditions (Berg et al. 1994; Vera 2000), in particular wood-dependent beetle species (Jonsell et al. 1998; Ranius & Jansson 2000). From a conservational point of view, it could therefore be advantageous to identify the stands on the estate with long continuity of temperate broad-leaved trees and to determine how open they were in the past.

The aim of this study was to give an example of how knowledge of local and regional forest and vegetation history can give insights to be used during restoration and management of this particular estate, as well as restoration and management of areas in other types of landscapes (Foster 2002). In particular, we:

- Investigate which *tree species* and forest types have dominated on different parts of the estate over the past 2,000 years.
- Identify the areas of the estate that have *long continuity* of tree species and forest types important for conservation.
- Investigate how the degree *of openness* has varied on different parts of the estate over time, and in particular identify the areas that have a long continuity of open woodland conditions up to present time.
- Investigate the importance, and spatial patterns, of past *land use activities*.

We take a multidisciplinary approach and use paleoecological analyses (pollen, plant macrofossils, tree rings) in combination with historical sources (taxation documents, land surveys, forest inventories). A simultaneous use of these methods could give insights on spatial and temporal variations, for instance regarding openness, which is not possible to achieve using one method alone (Fig. 1). For the investigation of the long-term vegetation history within the estate, pollen and macrofossil analyses have been carried out at "small hollow sites" (sensu Jacobson & Bradshaw 1981) in three different locations on the estate. It has been shown in theory (Sugita 1998; Bunting et al. 2004) and in practice (Calcote 1998) that the variations in the pollen load between small sites could be considerable (as the variation in the vegetation that they reflect). Therefore, in order to extract as much information as possible of the estate's vegetation history, we choose to maximize the number of sites, rather than the number of levels at a particular core. We have compared the three small sites to a nearby "large bog site" to investigate how small hollow records, which reflect forest structure at the stand scale, differ from a record that presumably shows vegetation patterns at a larger spatial scale.

Methods

The Estate

The 2,000-ha Fulltofta estate is located in southernmost Sweden in the province of Scania (lat 55°52′N, long 13°37′E). It has been publicly owned since 1920. The management aim of the estate has recently shifted from being almost entirely focused on timber production to multiple use, where conservation, recreation, and economic values are regarded with equal importance (Ekstrand 1999). The eastern part of the estate rises to 145 m above sea level, lying on the slopes of the horst Linderödsåsen, which consists of orthogneiss, whereas the western part meets the shores of Lake Ringsjön at 50 m above sea level and is sedimentary clay (Germundsson & Schlyter 1999). The yearly precipitation in the area is 700 mm, and the mean January and July temperatures are −1.5 and 15.5°C,

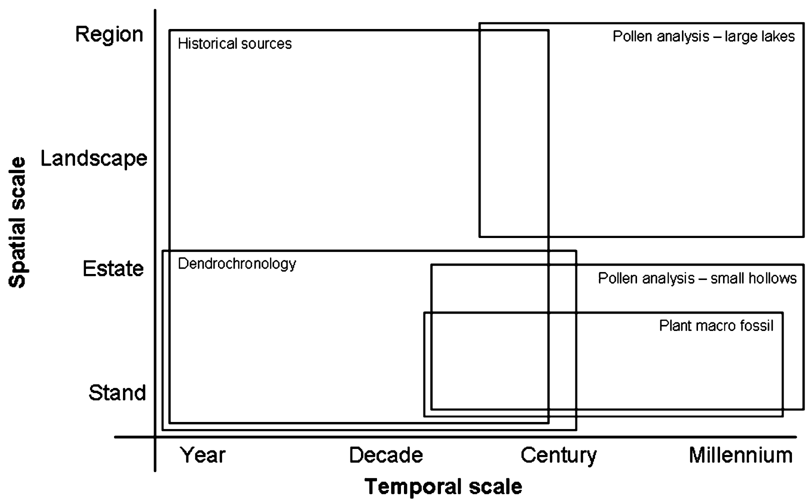

Figure 1. The spatial and temporal scales of the methods used in this study. Figure courtesy of A. White and G. L. Jacobson, University of Maine, U.S.A.

respectively (Germundsson & Schlyter 1999). The area lies within the nemoral (temperate) vegetation zone (Ahti et al. 1968).

Paleoecological Methods

The Häggenäs site (lat 55°53′37′′N, long 13°36′11′′E) is located in the former western infield (Fig. 2). It is a wetland that measures circa 10–20 m in width, stretches several hundreds of meters east-northeast, and is now overgrown by Birch (*Betula* spp.) and Alder (*Alnus glutinosa*). A 90-cm peat core was extracted in August 2002. The Kyllingahus site (lat 55°53′43′′N, long 13°39′39′′E) is located in the former central infields. It is a wetland circa 15 × 50 m in size. A 90-cm peat core was extracted circa 3 m in May 2003. The Vasahus site (lat 55°54′8′′N, long 13°38′55′′E) is located in the former outland and is a treeless, 25 × 40–m wetland surrounded by a fringe of trees, most of which are *Betula*. A 100-cm peat core was extracted from the center of the wetland in 1996. The analysis from Ageröds mosse (lat 55°56′N, long 13°25′E) was published by Nilsson (1964). Ageröds bog has a diameter of circa 1.3 km, located circa 12 km northwest of the Fulltofta estate.

The pollen samples were prepared for analysis using standard techniques (Berglund & Ralska-Jasiewiczowa 1986). A minimum of 400 pollen grains were counted from each level. Altogether, 36 levels from Häggenäs, 27 from Kyllingahus, and 19 from Vasahus covered the past 2,000 years. At Ageröds mosse, a minimum of 500 tree pollen grains were counted from the 36 levels that cover the time period in question. The results from all sites are presented as percent data, with pollen from all vascular plants as the total pollen sum, except for Ageröds mosse, where Heather (*Calluna*) was not included.

After subsampling for pollen, continuous plant macrofossil analyses were carried out on the cores from Häggenäs and Kyllingahus at 2-cm intervals according to methods described by Wasylikowa (1986). The 100-mL sediment slices were washed through two sieves of mesh sizes 500 and 280 μm. Identifications were made using plant keys and atlases (Bertsch 1941; Berggren 1969, 1981; Anderberg 1994) and a reference collection. The results are presented as concentration of macrofossils per 100 mL of sediment.

A dendroecological survey of *Quercus robur* and Juniper (*Juniperus communis*) from the Häggenäs site was carried out. Seven transects (50 × 4 m each in total 7 × 200 m = 0.14 ha) within 800 m of the paleoecological site were sampled (Fig. 2). Sampling also included dead stumps from earlier cuttings of *Quercus*, which were cross-dated using a master tree-ring chronology from the living *Quercus* trees. All tree rings were measured on a LINTAB measuring stage (precision 0.01 mm), and cross-dating was done both visually and with the aid of COFECHA correlation program (Grissino-Mayer et al. 1992). Because all stumps were more or less eroded in the outer part, the last ring represents an earlier date than the real cutting year. In two other sites, Jägarehyddan and Ramstorp (Fig. 2), tree ring cores were sampled and the ages of living trees estimated by counting the rings without being measured. The age of a living veteran *Quercus* in the western infields

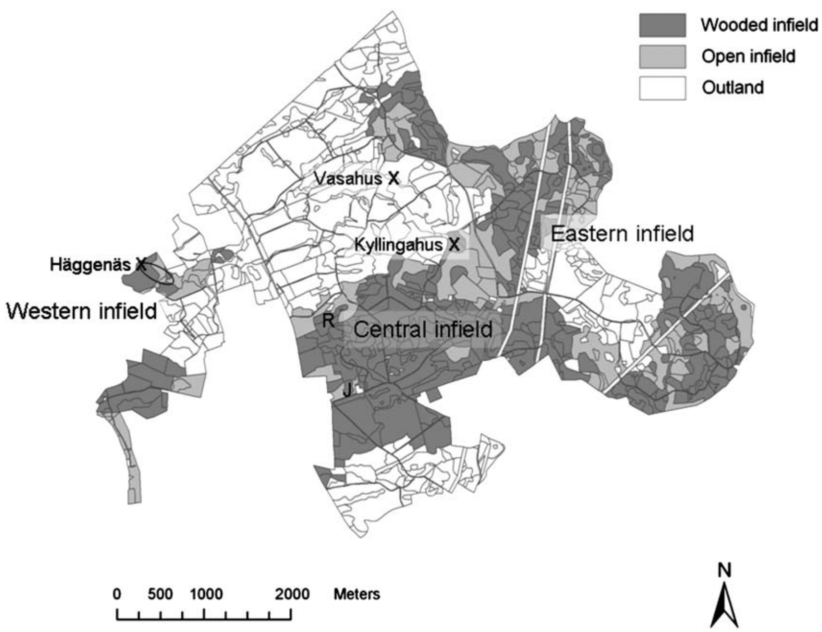

Figure 2. Map of forest stands in 2001 classified in historical land use categories according to the land survey from 1772. Stands on former infield and outland and the location of the cored sites and the tree-ring investigation (ellipse) are shown. R and J denote two stands discussed in the text, Ramstorp and Jägarehyddan, respectively. Black lines are modern roads, and wide white lines are electrical power lines.

was estimated by counting rings in a core and by extrapolating the age for the missing center.

Chronological Control

Dating was carried out using conventional ^{14}C analyses or accelerator mass spectrometry ^{14}C analyses (Table 1). All dates were converted to calibrated ages using OxCal 3.8 (Bronk Ramsey 1995). Two dating points used were the first significant amounts of Spruce (*Picea*) pollen at two of the sites that could be correlated to *Picea* plantation in the neighborhood. Another dating point was a noticeable layer of sand that we interpreted as erosion from a road construction (Table 1).

Historical Documents

Historical land use at stand scale was reconstructed using land survey maps of 1772 (scale 1:4,000, including detailed description), 1820 (1:30,000), 1860 (1:100,000), and 1915 (1:20,000) and forest management plans (including maps) from 1920, 1937, 1958, 1985, and 2001. A database was created including all forest stands as delimited in 2001. For each stand, the predominant land use and tree composition between 1772 and 2001 was determined using transparent overlays. From the presence of a tree species in a stand on two consecutive maps, we infer its continuous occurrence during the actual time span. The history of *Picea abies* plantation could be reconstructed in detail by accurate information of stand age in the management plans from 1920 to 1985 (peak of *Picea* stand area). Additional information on forest and woodland structure of the study area was provided from several descriptions ranging from 1703 to 1845.

Results and Discussion

Historical Land Use Categories

According to the land survey from 1772, the Fulltofta estate was separated into outland (Swedish *utmark*) and infield (*inäga*) (Fig. 2), a division that was widespread in southern Sweden until the beginning of the twentieth century. In general, the infields lay closest to the village and contained arable land and hay meadows, whereas the outlands were mostly forested and primarily used for grazing. However, in this part of southernmost Sweden, the grazing pressure on the outlands was often very intense and the most significant tree cover of economically important tree species was usually found on the infields that were protected from grazing (Emanuelsson et al. 2002). In Fulltofta, close to 70% of the infield area was covered with trees in varying densities and was denoted as "Forest land not mown and wooded meadows" (Table 2). Large parts of the outlands were treeless or covered with trees of little or no value, mainly *Betula* and *Alnus*.

Table 1. Datings used for the chronological models.

Site	*Laboratory Number*	*Depth (cm)*	*Technique and Material*	*^{14}C Date*	*Calibrated year (AD/BC)*
Ageröds mosse	St-976	34–38	Conventional sediment	430 ± 80	AD 1520
	St-977	85–90	Conventional sediment	1,090 ± 85	AD 945
	St-978	94–80	Conventional sediment	1,250 ± 85	AD 785
	St-979	118–121	Conventional sediment	1,495 ± 85	AD 540
	St-982	122–127	Conventional sediment	1,645 ± 95	AD 430
	St-983	169–175	Conventional sediment	1,935 ± 80	AD 95
	St-985	175–181	Conventional sediment	2,140 ± 85	95 BC
Vasahus	Beta-94333	20	Conventional sediment	149.7 ± 0.8 pM	AD 1956
		29.5	*Picea* planting		AD 1890
	Beta-94334	45	Conventional sediment	420 ± 60	AD 1470
	Beta-94335	65	Conventional sediment	1,500 ± 60	AD 590
	Beta-94336	85	Conventional sediment	3,560 ± 70	1920 BC
Kyllingahus		13.0–13.5	Erosion from road construction		AD 1919
		17.5	*Picea* planting		AD 1900
	Ua-21294*	21–22.5	Macrofossil	330 ± 35	AD 1565
	Ua-23374	33.25	AMS sediment	350 ± 40	AD 1600
	Ua-21295	37–41	Macrofossil	360 ± 30	AD 1500
	Ua-21296	62–63	AMS sediment	3,000 ± 35	1250 BC
	Ua-21297	88–89	AMS sediment	5,210 ± 45	4005 BC
Häggenäs	Ua-23373	14.5–15.5	AMS sediment	108.1 ± 0.5 pM	1958
	Ua-22275	23–24	AMS sediment	390 ± 40	AD 1484
	Ua-21336	34–35	Macrofossil	775 ± 45	AD 1252
	Ua-21334	60–62	Macrofossil	1,155 ± 45	AD 890
	Ua-21335	86–90	Macrofossil	1,645 ± 45	AD 390

AMS, accelerator mass spectrometry.
* Excluded from age-depth models.

Table 2. Areas (ha) of different forests and land use on different parts of the Fulltofta estate according to the land survey of 1772.

Vegetation Type	*Western Infield*	*Central Infield*	*Eastern Infield*	*Infield Total*	*Outland*
Fagus	0 (0)	38 (8)	147 (37)	185 (19)	18 (2)
Quercus/Fagus	0 (0)	174 (36)	51 (13)	225 (23)	0 (0)
Mixed *Quercus*	30 (31)	98 (20)	11 (3)	140 (14)	0 (0)
Alnus/Betula	20 (21)	78 (16)	18 (4)	116 (12)	138 (16)
Sum woodland	50 (52)	388 (81)	227 (57)	666 (68)	156 (18)
Open land	47 (48)	92 (19)	174 (43)	314 (32)	718 (82)
Sum	97	480	401	978	874

Values in parentheses are percentages of the total area on the different parts.

Tree Species History

According to the data from Ageröds mosse, *Quercus* was rather common in the region in the beginning of the record (Fig. 3). *Quercus* was also locally rather common (circa 10%) in Vasahus in the beginning of the period but with continuously decreasing values up to recent times. The surroundings of Kyllingahus seem to have been dominated by *Quercus* (circa 20%) until the eighteenth century, when it became less common for a couple of hundred years. Thereafter, the *Quercus* pollen percentages increased to circa 10% in recent time. *Quercus* macrofossils were found in the sediment from this site from AD 400 and onward, evidence that the species was locally present close to the coring point. The large numbers of macrofossils found at the top of the core probably reflect an overgrowing of the site by sapling trees when the agricultural activities became less intense in the twentieth century. At Häggenäs, both the pollen and the plant macrofossil data show that *Quercus* was common until about the eleventh century. The decrease after that is probably due to opening up of the site and the start of agricultural activities (Fig. 4). However, the macrofossil finding from the sixteenth century shows that *Quercus* was also locally present during the period when the pollen

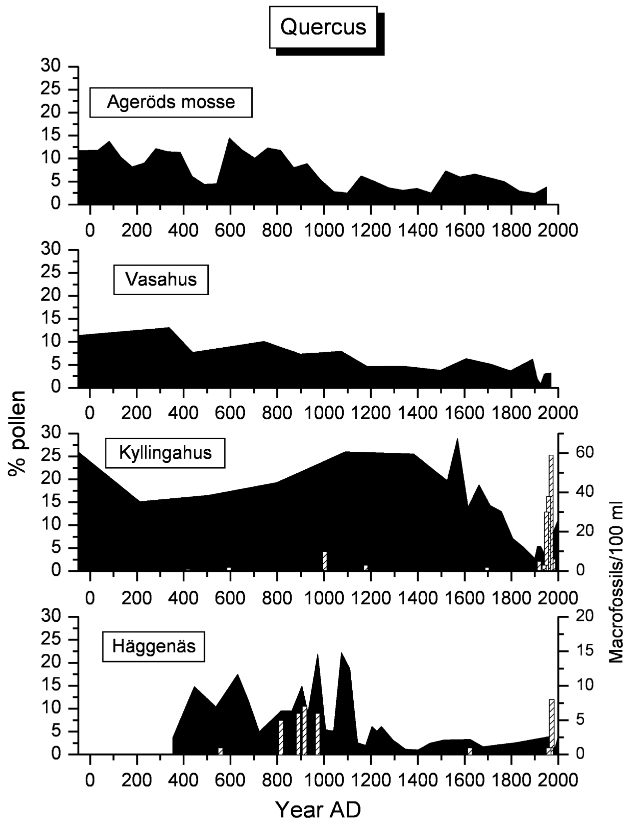

Figure 3. Pollen percentages for *Quercus* (black area) and the number of *Quercus* macrofossils (bars) from the different sites.

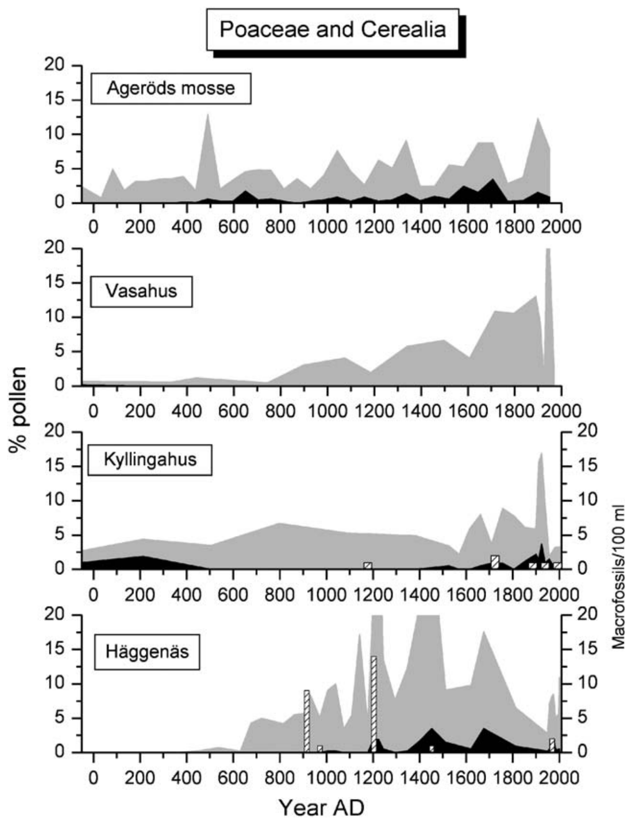

Figure 4. Pollen percentages for Poaceae (gray area) and Cerealia (black area). Note that the two types are added. Cerealia was not differentiated in Vasahus. Bars are number of Poaceae macrofossil.

percentages were low. In 1772, *Quercus* was a common species on the infield according to the land survey (Table 2).

Fagus first became established in the province circa 2,000 years ago (Berglund 1991). In Ageröds mosse, the pollen percentage of *Fagus* increased around AD 800 (Fig. 5). It was common from that time onward but with a slight decrease after the sixteenth century. The local development at Fulltofta was very different compared to the regional development, e.g., *Fagus* increased much later here and to a lesser extent. It disappeared from Häggenäs more than 200 years ago according to the pollen record, which is supported by the land survey from 1772 that no *Fagus* trees were found on the western sites (Table 2). It was continuously present around Vasahus and Kyllingahus until the present time according to the pollen data. The land survey from 1772 confirms that *Fagus* was a common species in the central and in particular the eastern infield, where *Fagus* forests occupied 38 and 147 ha, respectively (Table 2).

According to the pollen data from Ageröds mosse, Lime (*Tilia*) was present but relatively uncommon at a regional scale until AD 1000, when it disappeared almost completely (Fig. 6). The record from Häggenäs shows very high percentages (between 20 and 40%) until

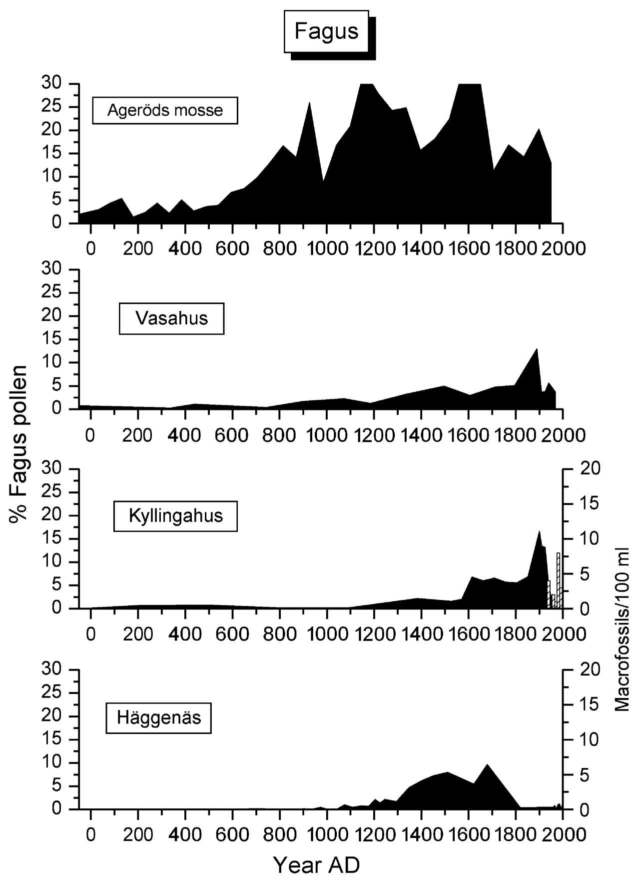

Figure 5. Pollen percentages for *Fagus* from the different sites.

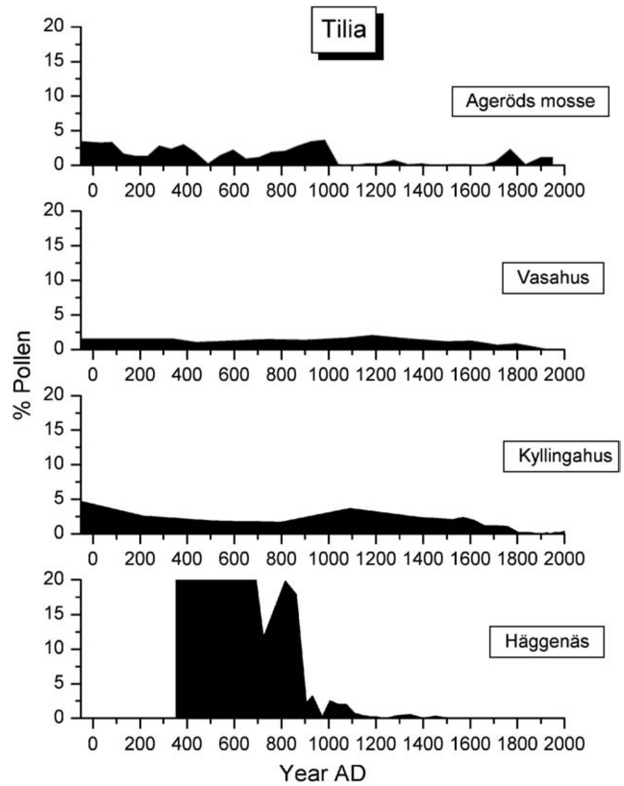

Figure 6. Pollen percentages for *Tilia* from the different sites.

circa AD 900. *Tilia* is insect pollinated and only produces a small amount of pollen (Andersen 1970), and the high percentages suggest that *Tilia* was very common at the time. The eastern sites (Kyllingahus and Vasahus) show a lower but more even occurrence of *Tilia* pollen from the beginning of record, until the species disappeared circa 200 years ago. The land survey from 1772 reports that *Tilia* was a rare species at Fulltofta. It was only recorded as 30 ha in the central part of the infield, in a mixed forest of *Tilia*, *Quercus*, *Corylus*, and *Alnus*. Scattered full-grown trees of *Tilia* are still found today in this area, in forest stands dominated by *Fagus* and Ash (*Fraxinus excelsior*).

The reason for the decline of *Tilia* and *Quercus* and the increase of *Fagus* in northern Europe since mid-Holocene is well debated. Climate has been regarded as an important factor (Iversen 1973; Huntley et al. 1989), but the role of humans has been emphasized by other authors (Kuster 1997; Björse & Bradshaw 1998; Lindbladh et al. 2000; Bradshaw & Lindbladh 2005). The data from Fulltofta support the latter opinion. The changes in Häggenäs took place during the Early Middle Ages, a warm period that presumably would not have favored *Fagus* in relation to *Tilia* and *Corylus* (Keigwi 1996). The human impact was furthermore probably intense in Häggenäs around the time of these changes, as can be seen from the large number of pollen from Poaceae (grasses) at the time (Fig. 4). In addition, the first grains of cereal pollen from this time emphasizes the importance of human factors behind the pattern, as do the fast rate of the changes.

Picea did not occur in the region until it was planted in the nineteenth century (Hesselman & Schotte 1906). The species shows very low values in the regional pollen diagram (Fig. 7). *Picea* pollen is virtually absent in Fulltofta until the upper part of all three cores, when it becomes very common in the diagrams from the eastern sites but not at the western site. The latter is in line with the well-documented historical data about the *Picea* plantations in Fulltofta. The very first plantation took place on the 70-ha "Maltesholm's Clearcut" (*Maltesholmshygget*) in the 1850s (Fig. 9). This pioneer effort was followed by two phases of plantations: the first from 1876 to 1893, when on average 10–20 ha/yr were planted, and a second phase from 1921 onward. In the 1980s, the area of *Picea* forests culminated to a total of 1,196 ha.

Hazel (*Corylus*) shows the same general decreasing trend as *Quercus* in the three Fulltofta sites but with the difference that *Corylus* has much lower values or is missing in the uppermost samples. This is in contrast to the regional site (Ageröds mosse) where high pollen percentages (10–15%) of *Corylus* persist up to present time. The land survey of 1772 mentions *Corylus* in a mixture with *Quercus*, *Fagus*, and *Tilia* on approximately 250 ha. Today, only a small fraction of these areas contain *Corylus*.

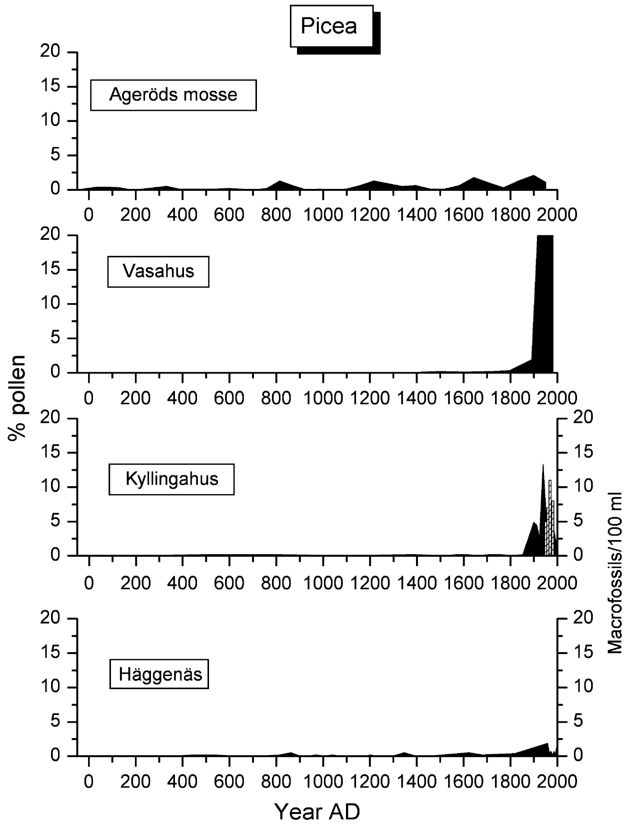

Figure 7. Pollen percentages for *Picea* (black area) and the number of *Picea* macrofossils (bars) from the different sites.

In all three Fulltofta sites, *Alnus* pollen percentages decreased gradually from 20–40% in the beginning of the record to just a few percentages in recent time. *Alnus* was a common tree on the outland areas in 1772.

The Fulltofta sites show very low *Pinus* pollen percentages, most of the time below 5%. *Pinus* trees produce large amounts of well-dispersed pollen (Broström et al. 2004), and such low values in "small hollow" sites probably represents pollen transported from distant sources.

At all three small sites from Fulltofta, *Betula* became increasingly common over the course of time, particularly during the nineteenth century. *Betula* was a very common species on the outland of the estate in 1772 according to the land survey. In total, 138 ha was covered by *Betula* in a mixture with *Alnus* on the outland at that point of time.

Tree Species Continuity

There is evidence for stand-level continuity of *Fagus* from 1772 up to the present time. Although the individual stands to a large extent are spatially unconnected, three blocks of *Fagus* can be identified (Fig. 9). The largest block is located on the infield in the central part of the estate. Today, these stands consist almost exclusively of *Fagus* trees, but in AD 1772, it was in a mixture with other broad-leaved species such as *Quercus* and *Tilia*. The two other blocks are located on the infield in the easternmost part of the estate. Both these areas were completely dominated by *Fagus* in 1772, but in the late nineteenth or the beginning of the twentieth century, many stands were planted with *Picea* (Figs. 8 & 9). The pollen and plant macrofossil analyses from Kyllingahus show that *Fagus* has been continuously present in the central infield, not only since the eighteenth century but also for several hundred years before that. In the two dendrochronology study sites in the central infield where *Fagus* has been continuously present since 1772 (Jägarhyddan and Ramstorp), *Fagus* trees are up to 180 years old. In Ramstorp, an exceptionally large, recently deceased *Fagus* tree was cored and estimated to be at least 300 years old.

There is also a continuity of *Quercus* since 1772 in many stands in the central part of the infield, although they are even more disaggregated than the *Fagus* stands (Fig. 9). One of the stands that have *Quercus* continuity according to the land survey is located adjacent to the wetland that was cored in Kyllingahus. The pollen and plant macrofossil data show that *Quercus* has been continuously present in the surroundings at that site during the past 2,000 years (Fig. 3). One *Quercus* stump close to the site was dated to have germinated around AD 1820. *Quercus* continuity is also recorded in the western part of the estate since 1772, also even if these stands are disaggregated. The pollen and plant macrofossil data at the Häggenäs site show that *Quercus* has been continuously present in the western infield throughout the time period, although it was somewhat less common the past 800 years than previously. The oldest known *Quercus* in the area is found in one of the

Figure 8. The plantation of *Picea* during different time periods.

stands of the western infield (not in the systematically sampled plots). A tree-ring investigation showed that this tree (*Gäddeken*) germinated in the middle of the fifteenth century, providing concrete evidence that the species has been present in the western infield for many centuries.

According to the paleoecological data, *Tilia* has not been continuously present on the estate up to present time. However, in the land survey from 1772, two stands in the central infield were described as partially harboring *Tilia* (Fig. 9). Because *Tilia* is rare but still present in these

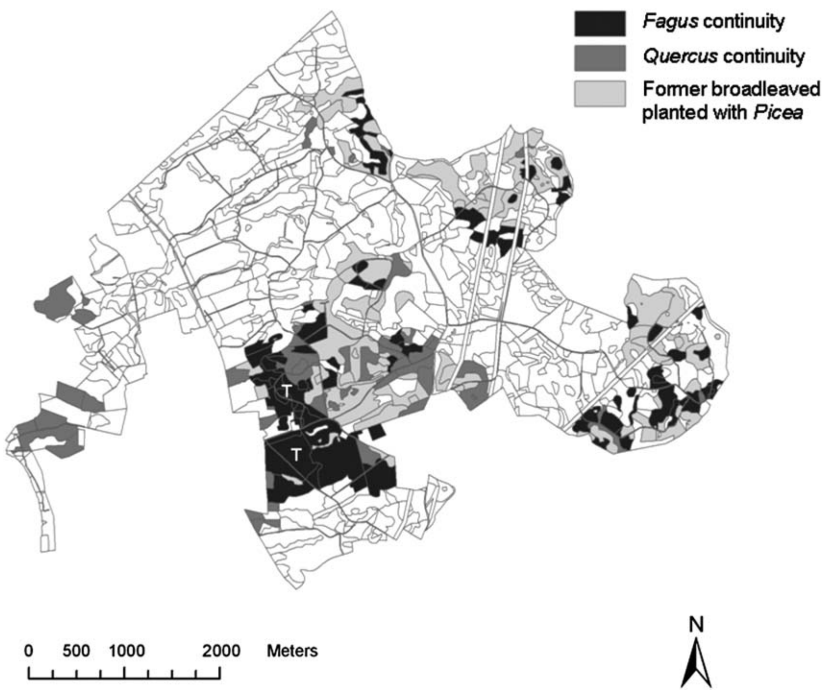

Figure 9. Stands with continuity of *Fagus*, *Quercus*, and *Tilia* since the land survey of 1772, and stands with planted *Picea* on former broad-leaved forest sites. The "T" denotes the two stands with *Tilia* continuity since 1772.

stands, today it is likely that it has been continuously present since 1772, if not longer.

Former Forest Openness

The degree of openness around a pollen site can to some degree be estimated by the percent pollen from the field layer (Broström et al. 1998), particularly by the that from Poaceae (Broström et al. 2004). The latter study shows that Poaceae in southern Sweden produces six to eight times less pollen per unit area as the common tree species in the region.

According to the data from Ageröds mosse, openness at the regional scale seems to be rather constant over the past 2,000 years (Fig. 4). At Häggenäs, the first sign of forest opening is dated to circa AD 600. High levels of pollen from Poaceae show that the surroundings were very open until the past centuries. The almost continuous representation of cereal pollen from circa AD 1200 onward shows that human activity was involved in keeping the area open. Several pollen grains from cereals were recorded from Kyllingahus during the first centuries of the first millennium, one of which was identified as Rye (*Secale cereale*) and one as Barley (*Hordeum*) (Fig. 4). An "ancient arable field" has been identified on the hill immediately east of the coring site (data from *Fornlämningsregistret*, The National Heritage Board—Archive of ancient remains). However, Kyllingahus probably did not have extensively open vegetation until circa the sixteenth century. The first signs of openness around Vasahus can be seen around AD 800 (Fig. 4). Poaceae pollen percentages also increased at this site around the seventeenth century.

The historical documents available provide information on forest and woodland structure during the eighteenth and nineteenth centuries, which to some extent can be used to infer the degree of openness. In AD 1772, the "open infield" (314 ha) contained arable fields and meadows according to the land survey (Fig. 2). There prevailed probably open conditions even if occurrence of a few trees cannot be totally excluded. It has been shown that a sparse tree cover on meadows and pastures was often omitted in historical documents from southern Sweden (Lanner & Gustavsson, unpublished data). The part denoted "wooded infield" (666 ha) (Fig. 2; Table 2) contained wooded meadows (60% of area) and high forest (40%) consisting of *Quercus* and *Fagus* and described as "mature," "full grown," or "high." About 10% of these high forests were explicitly described as dense in 1772, whereas no information on stand density is provided for the remaining areas. In AD 1845, the central part of the estate's infield was reported to have 150 ha of "large oak forest" (Swedish: *storverks ekskog*), whereas 250 ha contained "firewood, building timber, and shrub forests" (*bränne*, *hustimmer och buskskog*), implying rather open conditions, at least partially. The eastern infield area contained circa 60 ha high forest of Beech in 1845. However, even if the stands were denoted as "large" or as "high forest," they were probably more open than today's standard. Information from another estate in the region in 1839 shows that *Fagus* stands 100–160 years of age on average contained only about 50% of the timber volume compared to modern production forests of the same age and soil conditions (150–200 m^3/ha vs. 300–400 m^3/ha) (Brunet, unpublished data).

The tree-ring data from the western infield areas give unequivocal evidence for open conditions (Fig. 10). The *Quercus* individuals that regenerated from AD 1775 onward had clearly experienced open conditions during the early part of their life, in particular from the 1830s to the 1850s, due to very fast growth as could be seen from wide ring widths (data not shown). The presence of low-coarse branches on the old *Quercus* individuals of today is a clear sign of formerly more open conditions. Furthermore, *Quercus* regeneration in the area seems to have been a continuous process, which infers open conditions since the tree-ring record began, considering the well-known difficulties for the species to regenerate in shade (Vera 2000). The continuous regeneration of *Juniperus* from circa 1860 to late twentieth century in many of these stands is further evidence for open conditions in the past (Fig. 10).

The historical documents concerning the outlands allow a definite conclusion regarding openness. According to the land survey from 1772, all outland areas were "common land used for grazing" (*fälad*). Many of them were described as stony *fälad* or "stony *fälad* with *Betula* and *Juniperus*." Even with *Betula* trees, the outland areas were probably very open. There are numerous examples of the degradation of the outland of southern Sweden from the seventeenth century onward (Blennow & Hammarlund 1993; Emanuelsson et al. 2002), because of overgrazing.

Implications for Forest Restoration

Our study did not identify what could be the natural vegetation or the "baseline conditions" (sensu Davis 1989) of the estate. Human activities have been a significant factor

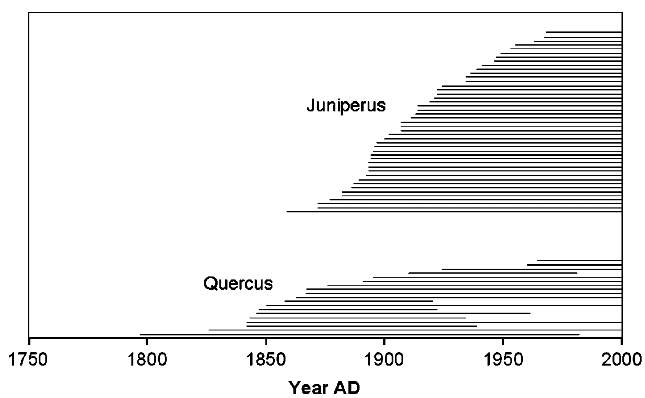

Figure 10. Germination and cutting age as revealed by the dendrochronological investigation from the seven transects close to the Häggenäs site. Each line represents a *Quercus* (lower group) or *Juniperus* (upper group) individual.

even at the beginning of the record, 2,000 years ago, which as can be seen in the evidence for agriculture around Kyllingahus (Fig. 4). Furthermore, even if the record did go further back in time and we could identify a period with a minimum of human impact, it is doubtful whether a restoration with that time period as a goal would be meaningful, considering the large changes in vegetation that have taken place during the millennia. The infield/outland system in Fulltofta has had a long history, perhaps at least since approximately AD 1100. From a conservational and recreational point of view, many of the valuable elements on the estate are connected to the former cultural landscape. Our suggestions therefore aim to maintain the spatial vegetational pattern that this land use created, even if the associated agricultural activities are gone.

In the *western infield*, the presence of many old *Quercus* individuals, valuable for conservation, and the fact that *Quercus* is the only important tree species with long continuity in many of the stands argue for a continuous promotion of this species. Maintenance of the mosaic of open and denser stands would probably benefit the high diversity of lichens and wood-dependent beetles that can be found in the area today (Malmqvist 1999, 2002). In the *central infield*, *Quercus* has been continuously present for thousands of years and *Fagus* for several hundred years. Furthermore, it was a stronghold for both *Quercus* and *Fagus* during the period of minimum forest cover from the sixteenth to the nineteenth century. We therefore suggest that many of the *Picea* stands in the area should be converted to *Quercus* and *Fagus* forest. Increased connectivity between the stands of rich deciduous tree species could be beneficial for rare species with low dispersal ability associated with these tree species (Ranius & Hedin 2001). In some places, we propose to restore the forest type that the paleoecological record tells us was very common in the past—a semiopen mixed forest with *Quercus*, *Tilia*, and *Corylus*. As we lack paleoecological information from *the eastern infield*, we do not know the long-term history of the area. However, as the dominance of *Fagus* that could be seen in 1772 today is no longer evident, we propose that many of the *Picea* plantations should be restored to rather dense *Fagus* forest, but mixed with some stands dominated by *Quercus*. The former *outland* in Fulltofta lacks continuity of broad-leaved trees. We propose that in the future, the main part of the *Picea* forest should be located to that area, in particular the eastern part of the outland. To secure the connectivity between the broad-leaved forests on the former infield areas, it could be necessary to convert some strategically located *Picea* stands to broad-leaved stands, in particular in the area separating the easternmost infield area from the other infield areas.

General Conclusions

Although this study is constrained to a single estate, some conclusions can be drawn that are valid for restoration actions in general.

The comparison between the sites in the study shows that the temporal and spatial variation within and between sites in the landscape has been considerable over the years, as also found in other studies (Foster 2002). A striking example of the local variation is the occurrence of *Tilia*. This species was much more common in Fulltofta 2,000 years ago than in the region (Fig. 6). The disappearance of *Tilia* occurred too long ago for it to be important from a conservational point of view, and rather few red-listed species are dependent of *Tilia* in comparison with *Quercus* and *Fagus* in Sweden today (Jonsell et al. 1998). But perhaps, the species could be interesting to promote because of recreational or historical reasons.

Fagus on the other hand shows the opposite trend in terms of abundance compared to *Tilia*. *Fagus* history in Fulltofta is rather short (approximately 400 years) and not very prominent compared to the regional data. This relatively short period of time has apparently been enough for *Fagus* to develop to an important tree species for many wood-dependent organisms. Other studies from southern Sweden show the same pattern, with *Fagus* having an important conservational role, despite having a relatively short and modest history (Lindbladh & Bradshaw 1998, Niklasson et al. 2002; Bradshaw & Lindbladh 2005).

Our study highlights the difficulties when decision-making in nature conservation (e.g., forest restoration or selection of areas to preserve) is based on a limited knowledge of the landscape history. In many cases, the only references available are a regional paleoecological record and/or historical maps. In practical restoration work, it is seldom possible to carry out an extensive vegetation investigation, but this study gives an example of the variation that can occur within one area and emphasizes that one regional pollen record or one historical map only gives limited information of an area's vegetation history. Our results argue for a network of studies in each important vegetation zone.

We used several different techniques, and the interpretation of the different records was facilitated by the possibility to calibrate on both spatial and temporal scales where the records overlapped. For instance, low pollen percent levels are often difficult to interpret and the presence of *Quercus* in Häggenäs from AD 1200 onward could have been overlooked if the plant macrofossil and historical data had not been available. Multiproxy reconstructions of vegetation history are often constrained by the lack of suitable paleoecological sites in places where historical maps and written records of land use history are available. This is illustrated in our study because one of the paleoecological sites was located on the outskirts of the estate and there were no sites in the eastern infields. Remaining undisturbed wetlands are rare in many areas, and investigations are therefore often biased toward more remote and inaccessible sites. With our experience, if the aim is to investigate multiple small hollows in areas with a history of long human impact, we recommend targeting suitable wetlands as the first step.

Implications for Practice

The study shows:

- How knowledge of local and regional forest and vegetation history can give insights to be used during restoration and management of an estate or an area.
- How a detailed reconstruction of forest and vegetation history is possible via a multidisciplinary approach.
- That changing patterns of vegetation composition and structure across time and space emphasizes that a single technique yields only limited information.
- The difficulties in identifying the natural vegetation of an area. We suggest that other criteria, for instance previous land use systems, could be used as a goal for a restoration project.

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