Reflections of pre- and early-agrarian human impact in the pollen diagrams of Estonia

A. Poska *, L. Saarse, S. Veski

Institute of Geology, Tallinn Technical University, Estonia pst. 7, 10143 Tallinn, Estonia

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Abstract

High-resolution pollen profiles based on 30 cores taken from Estonian lake and mire deposits were used to reconstruct the extent and type of land-use over most of the Holocene. Biostratigraphical studies combining pollen records, archaeological investigations, conventional and accelerator mass spectrometry (AMS) radiocarbon dates and numerical analysis were used to detect human impact on the landscape and vegetation. Indications of human activity were traced back to the Mesolithic (9000–4900 cal. BC) and are reflected in the pollen diagram by a wide range of anthropogenic indicators, which constitute nearly half of the total pollen sum, together with high charcoal content. Human impact during the Mesolithic is also indicated by the rarefaction analysis, which shows a doubling of palynological diversity. The Neolithic (4900–1800 cal. BC) is regarded as a transitional period between the pre-agrarian Mesolithic and the agrarian Bronze Age (1800–500 cal. BC). Changes in vegetation composition attributed to Late Mesolithic (6400–4900 cal. BC) land-use were found in several of the sites investigated. Pollen records display the development and intensive use of a pastoral landscape in the Middle Neolithic (4150–3200 cal. BC), expressed in pollen diagrams as a drop in the frequencies of broad-leaved trees and an increase in Picea abies, herb pollen and palynological diversity and in some cases increase in charcoal frequencies. Primitive tillage probably occurred during the Middle Neolithic, at least in the alvar (flat terrain with a thin soil cover on carbonaceous bedrock) and coastal areas of Estonia. The earliest Cerealia pollen finds are dated to ca. 4000 cal. BC and represented by Avena-type and Hordeum-type pollen. During the Bronze Age, crop cultivation played an important role in the farming economy. The beginning of crop cultivation in Estonia was almost simultaneous with southern Sweden, but more than 1000 years earlier than in Finland. The adoption of arable farming in Estonia occurred much later than in southern Sweden.

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Keywords: Pollen analysis; Pre-agrarian human impact; Introduction of agriculture; Estonia

1. Introduction

This paper provides an overview of the data available on the history of human colonization and land-use based on biostratigraphical evidence from Estonia (Fig. 1). The material discussed covers the entire Estonian territory including different landscape regions, but with special attention paid to the prehistoric development of the Estonian coastal zone. Several earlier investigations have collected and analyzed new biostratigraphical data including some synthesis of the available material (Moe et al., 1992; Poska and Saarse, 1996; Veski and Lang,
Saaremaa Island and coastal Estonia are well-studied regions, while the central part of the mainland is somewhat less explored (Fig. 2). Recent multidisciplinary investigations integrate biostratigraphical (pollen and diatom analysis), palaeogeographical and chronological (AMS and conventional radiocarbon dating) data with archaeological evidence (Veski and Lang, 1995, 1996; Kihno and Valk, 1999; Laul and Kihno, 1999; Saarse et al., 1999a). In combination with the numerical analysis (rarefaction analysis, numerical zonation and different ordination methods), these investigations have proved to be a reliable basis for assessing the role of pre-agrarian people in the landscape history and reconstructing the introduction and spread of farming in Estonia (Poska, 2001; Poska and Saarse, 2002a,b).

Interpretation of pollen diagrams offers the potential for reconstructing human impact on the environment throughout prehistoric time (Iversen, 1949; Behre, 1986; Birks et al., 1988, etc.). However, interpreting pollen diagrams in terms of tracing pre- and early-agrarian human impact in the boreal-nemoral forest zone is complicated by the fact that the development of woodlands during the first half of the Holocene was determined by climatic, edaphic or other ecological factors rather than by human influence (Behre, 1988; Hicks, 1992). Still, local woodland disturbances and increased nutrient concentration in soils appeared around settlements. Even the Stone Age people utilized the woodland surrounding their habitation sites by collecting wood for dwellings and fire. By opening up the forest and producing refuse, people created favourable conditions for the flourishing and spreading of light-demanding and nitrophi-

2. Material

About 400 Holocene pollen diagrams from different landscape regions are available from Estonia today. The following criteria were applied for the selection of sites suitable for inclusion in the present study:

(1) all sites with less than three radiocarbon dates were omitted to secure time control over the pollen sequence;
(2) all sites with less than 1000 pollen grains counted per sample were omitted to ensure the representativity of the pollen counts.

Application of the first criterion reduced the data set to 58 pollen diagrams. With the second criterion the data set was reduced to 30 sites (Fig. 2; Table 1), which were then analyzed in great detail to find the indications of human impact on the environment.

Two high resolution (in terms of sampling density, pollen analysis and C14 dating) sites from areas with different agrarian landscape development, both covering the entire Holocene, are used in this paper to illustrate the development of human impact in Estonia: (1) Lake Maardu, representing the area with early introduction and adoption of cereal cultivation and modest cattle rearing, and (2) Lake Ruila, representing the area with late introduction and adoption of cereal cultivation and pronounced cattle rearing.

3. Methods

3.1. Age determination

All radiocarbon dates were calibrated to calendar years BC/AD, if not stated otherwise. Calibration of the conventional and accelerator mass spectrometry
40


Table 1
List of biostratigraphically investigated sites examined in terms of human impact and supported by at least three radiocarbon dates

<table>
<thead>
<tr>
<th>Site</th>
<th>Coordinates</th>
<th>Total number of (^{14}C) dates</th>
<th>Oldest (^{14}C) date</th>
<th>Duration of studied sequence</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kõivasoo</td>
<td>58°54′15″N; 22°10′30″E</td>
<td>12</td>
<td>8495 ± 85</td>
<td>BO-SA</td>
<td>Königsson et al., 1998</td>
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<tr>
<td>Surusoo</td>
<td>58°31′30″N; 22°25′E</td>
<td>15</td>
<td>7740 ± 55</td>
<td>PB-SA</td>
<td>Veski, 1998; Rasmussen et al., 2000</td>
</tr>
<tr>
<td>Jõhvikasoo</td>
<td>58°28′30″N; 22°23′E</td>
<td>5</td>
<td>8245 ± 80</td>
<td>BO-SA</td>
<td>Hansson et al., 1996</td>
</tr>
<tr>
<td>Vedruka</td>
<td>58°19′20″N; 22°03′E</td>
<td>12</td>
<td>6860 ± 60</td>
<td>AT-SA</td>
<td>Poska and Saarse, 2002b</td>
</tr>
<tr>
<td>Pitkasoos</td>
<td>58°16′N; 22°13′E</td>
<td>7</td>
<td>9800 ± 80</td>
<td>PB-SB</td>
<td>Königsson and Poska, 1998; Königsson et al., 1998</td>
</tr>
<tr>
<td>Mustjärv</td>
<td>59°04′30″N; 24°06′E</td>
<td>7</td>
<td>9590 ± 120</td>
<td>PB-SA</td>
<td>Veski, 1998</td>
</tr>
<tr>
<td>Ruula</td>
<td>59°10′30″N; 24°26′E</td>
<td>14</td>
<td>10,390 ± 160</td>
<td>PB-SA</td>
<td>Poska and Saarse, 2002a</td>
</tr>
<tr>
<td>Kiilaspere</td>
<td>58°4′740″N; 24°26′10″E</td>
<td>4</td>
<td>1880 ± 60</td>
<td>SA</td>
<td>Veski, 1998</td>
</tr>
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<td>Velise</td>
<td>58°4′50″N; 24°2′72′0″E</td>
<td>8</td>
<td>9145 ± 70</td>
<td>PB-SA</td>
<td>Veski, 1998</td>
</tr>
<tr>
<td>Pulli</td>
<td>58°25′10″N; 24°40′E</td>
<td>6</td>
<td>9600 ± 120</td>
<td>PB</td>
<td>Poska and Veski, 1999</td>
</tr>
<tr>
<td>Tondi</td>
<td>59°26′40″N; 25°51′30″E</td>
<td>3</td>
<td>4010 ± 70</td>
<td>BO-SA</td>
<td>Kimmel et al., 1996</td>
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<tr>
<td>Maardu</td>
<td>59°26′30″N; 25°0′0′E</td>
<td>8</td>
<td>9490 ± 110</td>
<td>PB-SA</td>
<td>Veski, 1998</td>
</tr>
<tr>
<td>Kahala mire</td>
<td>59°29′20″N; 25°3′1′E</td>
<td>6</td>
<td>3660 ± 40</td>
<td>SB-SA</td>
<td>Poska and Saarse, 1999</td>
</tr>
<tr>
<td>Kahala</td>
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<td>13</td>
<td>9725 ± 80</td>
<td>YD-SA</td>
<td>Poska and Saarse, 1999</td>
</tr>
<tr>
<td>Viitna Piikjärv</td>
<td>59°26′40″N; 26°0′0′30″E</td>
<td>9</td>
<td>10,690 ± 100</td>
<td>PB-SA</td>
<td>Saarse et al., 1998</td>
</tr>
<tr>
<td>Kunda-Aruuso</td>
<td>59°28′N; 26°3′1′E</td>
<td>9</td>
<td>8695 ± 100</td>
<td>PB-SA</td>
<td>Poska and Königsson, 1996; Poska, 2001</td>
</tr>
<tr>
<td>Leekovo</td>
<td>59°23′N; 28°0′4′E</td>
<td>3</td>
<td>7760 ± 90</td>
<td>AT-SA</td>
<td>Lepland et al., 1996</td>
</tr>
<tr>
<td>Imatu</td>
<td>59°06′N; 27°2′8′E</td>
<td>3</td>
<td>9400 ± 120</td>
<td>PB-SA</td>
<td>Kimmel et al., 1999</td>
</tr>
<tr>
<td>Võhmaäärve</td>
<td>59°02′30″N; 27°1′8′E</td>
<td>14</td>
<td>7560 ± 70</td>
<td>AT-SA</td>
<td>Kimmel et al., 1999</td>
</tr>
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<td>Raagastvere</td>
<td>58°35′N; 26°3′9′E</td>
<td>11</td>
<td>9800 ± 120</td>
<td>PB-SA</td>
<td>Pirrus et al., 1987; Saarse et al., 1996</td>
</tr>
<tr>
<td>Parika</td>
<td>58°30′N; 25°4′6′E</td>
<td>8</td>
<td>9000 ± 75</td>
<td>PB-SA</td>
<td>Niinemets et al., 2002</td>
</tr>
<tr>
<td>Akali</td>
<td>58°24′40′N; 27°1′4′E</td>
<td>7</td>
<td>7200 ± 70</td>
<td>AT-SA</td>
<td>Moora et al., 1988; Poska, Saarse (unpublished)</td>
</tr>
<tr>
<td>Kalsas</td>
<td>58°11′30″N; 27°2′43′0″E</td>
<td>11</td>
<td>8160 ± 80</td>
<td>BO-SA</td>
<td>Kimmel et al., 1999</td>
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<tr>
<td>Tiolamaa</td>
<td>58°05′50″N; 27°2′3′E</td>
<td>13</td>
<td>5700 ± 60</td>
<td>AT-SA</td>
<td>Kimmel et al., 1999</td>
</tr>
<tr>
<td>Ala-Pika</td>
<td>58°03′30″N; 26°3′43′0″E</td>
<td>4</td>
<td>2460 ± 50</td>
<td>SB-SA</td>
<td>Õhno and Valk, 1999</td>
</tr>
<tr>
<td>Objogi</td>
<td>57°50′N; 27°3′5′E</td>
<td>10</td>
<td>10,050 ± 120</td>
<td>PB-SA</td>
<td>Mõ SERIAL, 1995</td>
</tr>
<tr>
<td>Karumiku</td>
<td>57°43′N; 26°5′8′E</td>
<td>10</td>
<td>6000 ± 80</td>
<td>AT-SA</td>
<td>Õhno and Valk, 1999</td>
</tr>
<tr>
<td>Tuulijärv</td>
<td>57°42′N; 27°3′34′0″E</td>
<td>9</td>
<td>8790 ± 80</td>
<td>DR3-SA</td>
<td>Ilves and Mõ SERIAL, 1987</td>
</tr>
<tr>
<td>Väskna</td>
<td>57°42′30″N; 27°0′4′E</td>
<td>16</td>
<td>9930 ± 70</td>
<td>DR3-SA</td>
<td>Ilves and Mõ SERIAL, 1987</td>
</tr>
<tr>
<td>Hino</td>
<td>57°3′40′N; 27°1′4′E</td>
<td>4</td>
<td>6485 ± 115</td>
<td>PB-SA</td>
<td>Laitl and Õhno, 1999</td>
</tr>
</tbody>
</table>

(AMS) dates was carried out using OxCal v. 3.5 (Van der Plicht, 1993; Bronk Ramsey, 1995; Stuiver et al., 1998) at the 1σ confidence level. Time-scales were constructed with the TILIA program (Grimm, 1991), using linear or polynomial interpolation between the calibrated dates. The choice of interpolation method was dependent on the uniformity of the sedimentation in the investigated basin. The Estonian archaeological periods, defined by cultural development, are given according to Kriiska (2001), Lang (1996) and Lang and Kriiska (2001) as: Early Mesolithic (9000–6400 cal. BC); Late Mesolithic (6400–4900 cal. BC); Early Neolithic (4900–4150 cal. BC); Middle Neolithic (4150–3200 cal. BC); Late Neolithic (3200–1800); Bronze Age (1800–500 cal. BC) and Iron Age (1800 cal. BC–1250 cal. AD).

3.2. Construction of human impact diagrams

A classical human impact diagram was constructed for each site on the basis of selected identifiable microfossils, which provide information regarding changing landscape utilization practices (Table 2; Fig. 3). Herb pollen taxa were grouped according to Behre (1981, 1988), Berglund and Ralska-Jasięwic- zowa (1986), Berglund (1991) and Hicks (1992),
while bearing in mind local conditions (Poska, 2001). Plants of disturbed biotopes (ruderals) were divided into two groups (major and minor) on the basis of pollen production (Königsson et al., 1998; Table 2) in order to more effectively display taxa with low pollen production. Along with the classical pollen diagrams, circular pie diagrams were constructed for each archaeological period to highlight the contribution of inferred land-use category to the sum of human impact indicators (Fig. 4).

3.3. Interpretation of human impact diagrams

When interpreting selected pollen diagrams in terms of tracing human impact, special attention was paid to the following:

(1) During pre-agrarian time: variations in the arboreal pollen (AP)/non-arboreal pollen (NAP) ratio, presence/abundance of apophytes and finds of microscopic charcoal dust. The estimation of changes in palynological richness is based on the results of rarefaction analysis E(T_{minimal pollen sum}) calculated using “psimpoll” (Bennett, 1998).

(2) During the early-agrarian time: presence/abundance of anthropochores, changes in tree pollen spectra and finds of microscopic charcoal particles. Scattered Cerealia pollen finds were interpreted as evidence for the introduction of crop farming and the start of continuous Cerealia pollen curve as the establishment of agriculture.

4. Results and discussion

Despite the high number (>400) of analytically investigated pollen sites only a few of these (30) meet the quality demands of human impact investigations. Furthermore, the spatial distribution of these high-resolution sites is rather uneven. Data are mainly concentrated in the coastal and southeastern parts of Estonia while inland areas are very sparsely represented (Fig. 2) making it difficult to reconstruct the impact of different landscape regions on human habitation patterns and early-agrarian activities using presently available biostratigraphical data.

4.1. Traces of pre-agrarian human impact

The first archaeological evidence of human presence in Estonia goes back to Mesolithic time (9000–4900 cal. BC). The oldest known settlement in Estonia, Pulli campsite (Fig. 2), dates to ca. 9000 cal. BC (Jaanits and Jaanits, 1978). Osteological and palaeobotanical evidence show that in the Early Mesolithic,
Fig. 3. Examples of human impact diagrams from areas with different agrarian landscape development: (1) early introduction and adoption of cereal cultivation and modest cattle rearing (Lake Maardu) and (2) late introduction and adoption of cereal cultivation and pronounced cattle rearing (Lake Ruila).
Fig. 4. Pie diagrams of land-use indicators from Lake Ruila and Lake Maardu.
human diet was based on hunting, gathering fruits, nuts and roots and fishing on inland water bodies. Marine resources were not utilized. In contrast, Late Mesolithic and Early Neolithic people utilized marine resources, especially marine mammals (Paaver, 1965; Lõugas et al., 1996; Poska, 2001). The observed change in dietary preferences coincides fairly well with the development of the brackish Litorina Sea in the Baltic basin (Kessel and Raukas, 1979). The higher water salinity induced a rise in the bioproductivity of the sea and favoured an increase in the seal population (Nuñez, 1996).

Two Estonian Mesolithic campsites have been intensively investigated by means of pollen analysis: Pulli in the southwest and Kunda Lammasmägi in the north (Poska and Kõngissson, 1996; Poska and Veski, 1999; Poska, 2001; Fig. 2). The wide range of human impact indicators include nearly half of the total pollen sum, high charcoal content and palynological richness in the samples collected directly from the cultural layer of Pulli settlement (Poska and Veski, 1999). This conclusion is supported by differences in the pollen evidence from the Pulli cultural layer and a contemporaneous undisturbed sediment sequence nearby. The investigation of a mire section at Kunda-Arusoo, approximately 1 km from the settlement at Kunda-Lammasmägi on a small island within a former shallow lake, shows a doubling of palynological diversity, the occurrence of different apophytic plant taxa (e.g. Apiaceae, Brassicaceae, Chamaenerion, Chenopodiaceae, Fabaceae, Helianthemum, Rosaceae undiff., Potentilla—type., different Ericales, etc.), charcoal peaks and unstable periods in tree pollen accumulation contemporaneous with the habitation phase (Poska, 2001). These results show that the impact of pre-agrarian hunter–gatherers on the environment is traceable with pollen analysis and is in good agreement with the investigations in Finnish Lapland, where hunter–gatherers changed the environment quite significantly over restricted areas even in intermittently visited campsites (Hicks, 1995).

Hunter–gatherer settlements in Estonia were commonly situated along the edges of bodies of water, utilizing the ecotones where plant communities were sensitive to disturbances and thus even a slight impact yielded observable consequences. During this study, the indications of pre-agrarian impact of human activities on the surroundings were recorded in most of the sites examined. Traces of human impact in Estonia commonly appear in the palynological record as a rapid (up to some hundreds of years) change in tree pollen frequencies (a rise in Betula and Corylus avellana, and a decline in Ulmus, Quercus robur and Tilia cordata) accompanied by a rise in apophytic herb pollen and higher palynological richness. In some cases, the above-mentioned changes are accompanied by an increase in the amount of charcoal particles. These indications are regionally asynchronous, appearing in different places at different times. However, the most common period of pronounced indications of forest disturbance falls into the time span between 6000 and 5000 BC. The intensity of indications is negatively correlated with the distance between the investigation and habitation sites. Investigations at Pulli and Kunda-Arusoo revealed that the high concentration of palynological indicators appears only at the settlement site and only during the actual occupation phase. In cases when the investigation site is situated at some distance from the campsite, only a low intensity signal recording a modest increase of herb pollen quantity can be detected. It must also be kept in mind that the signals described above and interpreted here as anthropogenic are mostly rather sporadic, weak and ephemeral; and the possibility of confusing the man-made vegetation disturbances with changes caused by natural factors (herbivores, storms, fires, changes of groundwater level, etc.) is great.

4.2. Introduction and adoption of cereal cultivation

In comparison with records from central Europe, the reflections of agrarian practices are rather weak in all the Estonian pollen diagrams examined. The amount of anthropochore pollen rarely exceeds 5% of the pollen sum even in modern samples. When looking for the signs of crop farming, only the start of cereal cultivation is identifiable with reasonable certainty (Figs. 3 and 4). Other possible field crops (hemp, different legumes, flax), vegetables and orchard trees, which until recent times played an important role in the household economy, often have a similar pollen morphology to that of the native wild species, or rather low pollen production, or were
harvested before flowering, and are therefore more-or-less impossible to trace by pollen analysis.

The introduction of cereal cultivation took place during the Neolithic in Estonia, at about 4000 cal. BC (Figs. 4 and 5). The earliest finds of cereal pollen derive from the Kõivasaar, Vedruka, Mustjärve and Velise sites in western coastal Estonia and from Akali in the River Emajõgi delta in eastern Estonia (Figs. 2 and 5). Middle Neolithic cultivation was probably limited to primitive tillage, at least in the alvar areas of coastal Estonia (Kriiska, 2000), as the earliest Cerealia pollen finds there are dated to ca. 4000 cal. BC, and are represented by Avena-type and Hordeum-type pollen (Königsson et al., 1998; Veski, 1998). In addition, Late Neolithic charred grains of Hordeum were found in a northern Estonian settlement site (Jaanits et al., 1982). Two directions of cereal introduction can be distinguished: the northwestern and the southeastern route. The habitation pattern, though, did not change after the appearance of the first signs of cereal cultivation, suggesting that the introduction of arable farming was a result of contacts and the spread of ideas in the border zone, rather than the immigra-
tion of people. During the Iron Age, cereals are recorded in all the sites examined all over the country, with a few exceptions in especially unfavourable locations for cultivation (Fig. 5; Leekovo and Toolamaa) in eastern Estonia. The Ulmus decline and the expansion of Picea abies were most likely initiated by the introduction of farming. The first finds of Cerealia pollen often coincide with a pronounced expansion of P. abies in the same region (Saarse et al., 1999b). Obviously, spruce was present in the region earlier, but it needed an external factor to expand. The elm decline, which has been connected with forest clearances (Birks et al., 1988; Greig, 1996), elm-disease (Peglar, 1993) and the introduction of agriculture (Moe and Rackham, 1991) is not very well developed in Estonia and appears mostly as a stepwise decrease of Ulmus frequencies contemporaneous with the decline in Tilia cordata and other thermophilous broad-leaved tree species. The Ulmus decline is not a synchronous event in Estonia, as the dates range from ca. 3800 to ca. 3200 cal. BC (Saarse and Veski, 2001). Moreover, it coincides fairly well with the first finds of Cerealia pollen in the region. The simultaneous

Fig. 5. Map of the first cereal pollen finds and the start of continuous cereal curve in Estonia.
decline of different thermophilous broad-leaved trees
and the different timing of event over a relatively
small area suggest that the Ulmus decline is likely to
have been caused, at least in Estonia, by human
activity connected with the introduction of arable
farming rather than by natural factors such as elm-

Fig. 6. Generalized map of the timing of the first cereal pollen finds in Europe (after Poska, 2001).
disease, which would affect only *Ulmus* stands, or climatic changes, which would have similar effects over a large area.

In most of southern and central Europe, cereal cultivation was introduced by 5000 cal. BC (Lang, 1994; Berglund et al., 1996; Haas, 1996; Fig. 6). By about 4000 cal. BC, farming practices had reached northwestern and northern Europe (Andersen et al., 1996; Berglund et al., 1996). The introduction of crop cultivation in Latvia and northern Lithuania was simultaneous with that recorded in Estonia around 4000 cal. BC (Lang, 1999; Vasks et al., 1999; Stančikaitė, 2000) and considerably earlier than in southern Finland (ca. 2500 cal. BC; Vuorela and Hicks, 1995).

The earliest traces of the adoption of cereal farming, defined as the start of a continuous *Cerelia* pollen curve, are dated to the Bronze Age at two locations (Maardu and Mustjärv) from coastal *alvar* areas and one from southeastern Estonia (Hino; Figs. 3 and 5). With more advanced farming techniques, crop farming gained importance, together with the regular treatment of domesticated animals and cultivated plants (Veski and Lang, 1995, 1996; Poska and Saarse, 1996; Poska et al., 1999). In contrast to earlier forest clearances, after which a regeneration of the forest normally occurred, Bronze Age clearances often resulted in a permanent change in the ecosystem. The first permanent fields appeared in the Bronze Age (Lang, 1996) and formation of the majority of Estonian *alvars* was initiated (Poska and Saarse, 1999). Numerous prehistoric fields and clearance cairns close to stone-cist graves and cup-marked stones are recorded, as a rule, on *alvar* areas (Lang, 1992; Lõugas, 1992). The adoption of cereal cultivation was quite homogeneous throughout Estonia and took place during the Iron Age (Fig. 5). Implementation of iron tools, ploughing and manuring enabled people to extend the size and number of fields and explore less favourable parts of Estonia. The first signs of *Secale cereale* are recorded from 500 BC onwards though it probably spread as a weed in other crops (Poska and Saarse, 1999, 2002a,b; Veski, 1998). The cultivation of *Secale* may have started around AD 500–600. Only at locations exceptionally unfavourable for cultivation, where the palynologically investigated sites are parts of mire complexes (Parika, Leekovo, Toolamaa and Kalsä; Figs. 2 and 5), and crop cultivation is rarely practiced even today, is the start of continuous *Cerealia* curve dated to later than 1050 AD.

### 4.3. Introduction and adoption of cattle breeding

The start of cattle breeding in Estonia is difficult to pinpoint by means of pollen analysis, as there are no pollen indicators that can be unambiguously connected with animal husbandry (Poska, 2001). Still, changes in the pollen record such as a drop in broad-leaved trees alongside an increase in *Picea abies*, herb pollen and palynological diversity has been interpreted as evidence for the existence of open and wooded pastures. The same indications are also quite typical for primitive arable farming, but the absence of *Cerealia* pollen makes such an interpretation less justifiable. The irreversible increase in general openness has also been treated as a reasonably good indicator of early cattle rearing. These changes are traceable all over the investigated area from Neolithic times onwards and are difficult to disregard despite the lack of confirming archaeological evidence. In good agreement with our results, Maldre (1999) shows that pastoral farming must have been known and more frequent than crop cultivation during the Late Neolithic. In areas where cereal cultivation was introduced before the Bronze Age (Fig. 3, L. Maardu), the start of the continuous increase in openness, as indicated by a constant rise of pollen derived from meadow plants, is more-or-less simultaneous with the first *Cerealia* pollen finds, showing that both crop farming and cattle breeding were practiced in parallel. In areas where the introduction of cereal farming took place later (Fig. 3, L. Ruila), the early increase in open-land indicators is more pronounced, and normally exceeds cereal cultivation indications.

### 5. Conclusions

1. High-resolution pollen records support the conclusion that the impact of the hunter–gatherers on the environment in Estonia was greater than has previously been suggested. Even so, vegetation disturbances were restricted in space and time, and did not leave long-lasting imprints on the environment or give rise to a widespread increase in landscape openness.
2. When interpreting pollen diagrams in terms of pre-agrarian human impact a good correlation was found between the hunter–gatherer habitation area and the rise of palynological richness, accompanied by finds of nitrophilous and apophytic (especially ruderal) herb pollen.

3. Cereal cultivation was introduced into Estonia, as into southern Sweden, at ca. 4000 cal. BC, more than 1000 years earlier than into Finland. The introduction started from the coastal zone and moved towards the inland areas.

4. The earliest signs of cereal cultivation appear on Estonian alvar areas during the Bronze Age. In most of Estonia, cereal farming was intensively used from the Iron Age onwards, though in areas exceptionally unfavourable for cultivation the adoption of cultivation is dated to Modern times.

5. The transitional period between the introduction and adoption of crop farming was rather long and varied, lasting from about 1000 up to 3000 years.

6. In areas favourable for agrarian practice, the introduction of cattle breeding took place at the same time as with the cereal farming. In areas where the introduction of cereal farming was delayed due to natural conditions unfavourable for tillage, cattle breeding was introduced before arable farming.

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