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ORIGINAL ARTICLE

Linking past cultural developments to palaeoenvironmental changes in Estonia

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Abstract Connections between environmental and cultural changes are analysed in Estonia during the past c. 4,500 years. Records of cereal-type pollen as (agri) cultural indices are compared with high-resolution palaeohydrological and annual mean temperature reconstructions from a selection of Estonian bogs and lakes (and Lake Igelsjön in Sweden). A broad-scale comparison shows increases in the percentage of cereal-type pollen during a decreasing trend in annual mean temperatures over the past c. 4,300 years, suggesting a certain independence of agrarian activities from environmental conditions at the regional level. The first cereal-type pollen in the region is found from a period with a warm and dry climate. A slow increase in pollen of cultivated land is seen around the beginning of the late Bronze Age, a slight increase at the end of the Roman Iron Age and a significant increase at the beginning of the Middle Ages. In a few cases increases in agricultural pollen percentages occur in the periods of warming. Stagnation and regression occurs in the periods of cooling, but regression at individual sites may also be related to warmer climate episodes. The cooling at c. 400–300 cal B.P., during the 'Little Ice Age' coincides with declines in cereal-type and herb pollen curves. These may not, however, be directly related to the climate change, because they coincide with war activities in the region.

Keywords Late Holocene · Baltic Sea region · Palaeoclimate · Early agriculture · Pollen analysis · Archaeology

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Introduction

Influences of environmental (climate) changes on human populations in the past are frequently registered as catastrophe-like events, for example droughts or a rise in water tables, that led to the abandonment of settlement sites, migration or even the decline of civilisations (Moora et al. 1988; Van Geel et al. 1996, 1998; Dearing et al. 2006). In some of these cases the role of climate change is generally accepted. But apart from migration and extinction as possible responses to environmental change, there can instead be adaptation and the evolution of appropriate cultural practices (cf. Boserup 1965; Coombes and Barber 2005). The interactions between human society and environmental change are, however, complex and difficult to study. Approaches that try to highlight the role of climate in cultural processes are frequently condemned for environmental determinism (Shennan 2003). There is "black box determinism", which tends to correlate climatic and cultural changes disregarding the processes involved, and "soft determinism", which emphasises the coexistence of natural and cultural factors and, where nature is seen as a limiting rather than supportive factor for human actions (Coombes and Barber 2005). The societal response depends on the predominating socioeconomic conditions and social organization, as well as the intensity and duration of climatic extremes (Diaz and Stahle 2007).

Although, associating climate variability with societal change is a complex and difficult task, comparisons between data may give new information and perspectives for both archaeology and palaeoecology. A positive correlation and synchronous events have been found to exist between human impact/land-use and climate change in Northwest Europe (Van Geel and Berglund 2000; Berglund 2003). Some authors see the agricultural developments in the British Isles and Southern Scandinavia around c. 6,000–5,700 years ago, during the Mesolithic–Neolithic transition, as a response to changes in climate and its interactions with soil resources, falling into phase with a dry continental climate (Macklin et al. 2000; Bonsall et al. 2002). Increases in charcoal frequencies in north–west Scotland at c. 6400, 5900 and 4260 cal B.P. correspond with phases of relatively dry climate inferred from the bog stratigraphy (Anderson 1998), while there is strong evidence for anthropogenic vegetation change in Scotland c. 5700 cal B.P., also expressed in cereal-type pollen and an abrupt change in human dietary patterns (Bonsall et al. 2002). Decreases or disappearances of cereal-type pollen in sediments, which appear to occur in the Oban area (56°24′N; 5°28′E) c. 4300–3450, c. 2850–2500 and c. 2100–1700 cal B.P. (c. 3900–3200, c. 2700–2400 and c. 2100–1800 ^{14}C B.P., respectively), closely coincide with periods of remarkably cooler and wetter conditions inferred from bog stratigraphies and elsewhere (Macklin et al. 2000). Climate deteriorations in this marginal area for cereal cultivation might not have caused the region to be periodically abandoned or depopulated, but rather have caused shifts in farming practices (Macklin et al. 2000).

Pollen-based reconstructions of palaeoclimate in Lake Raigastvere (Seppä and Poska 2004) and recent high-resolution palaeoecological studies of Männikjärve bog in central-eastern Estonia (Sillasoo et al. 2007) have provided new high-resolution data that can be used for analyses of climate changes in the late Holocene in the eastern Baltic Sea region, but also as contextual information for archaeological interpretations. These studies have discerned certain periods in both bog and lake archives: higher surface water tables c. 3170–2850 cal B.P. and c. 1770–1530 cal B.P. in Männikjärve (Sillasoo et al. 2007), and pollen assemblage zones dominated by *Picea* pollen at c. 3500–2900 cal B.P. and at c. 1800–1400 cal B.P. in Lake Raigastvere (3300–2800 and 1900–1500 years B.P., respectively; Saarse et al. 1996). These periods appear to occur more or less concurrently with changes in the material culture at c. 3050–2450 cal B.P. and c. 1900–1500 cal B.P., the Late Bronze Age and the Roman Iron Age in Estonian archaeology (Lang and Kriiska 2001; Kriiska and Tvauri 2002). Papers on vegetation changes and land-use dynamics often refer to climate deterioration as a cause for agricultural failure when interpreting the decline of the proportions of cereal-type pollen in pollen diagrams (Niinemets and Saarse 2007a, b). The current paper shows the related data side by side, discusses the coincidences that may lead to the introduction of societal or environmental determinism in palaeoecological and archaeological research, and analyses the human–environment interactions.

Study area

Estonia is located on the north-eastern coast of the Baltic Sea in the boreo-nemoral forest zone (Sjörs 1965), on the zonal boundary of the temperate and boreal climates (Fig. 1). The climate is transitional between the continental climate of Eastern Europe and the oceanic climate of Western Europe. The area is sensitive to shifts in major weather forming systems of Northern Europe. Annual mean temperatures vary from c. 6°C in the west to c. 4.5°C in the east. Summers are moderately warm, with July mean temperatures around 17°C in most parts of the country; winters are moderately cold, with January mean temperatures c. −6.5°C in the east and c. −2 to −5°C in the west. The winter climate is particularly dependent on the dominant atmospheric circulation mode. During the dominance of the zonal flow, winter temperatures are about −5 to 5°C, while an intensification of the Eurasian (Siberian) high-pressure often leads to southward extension of polar air

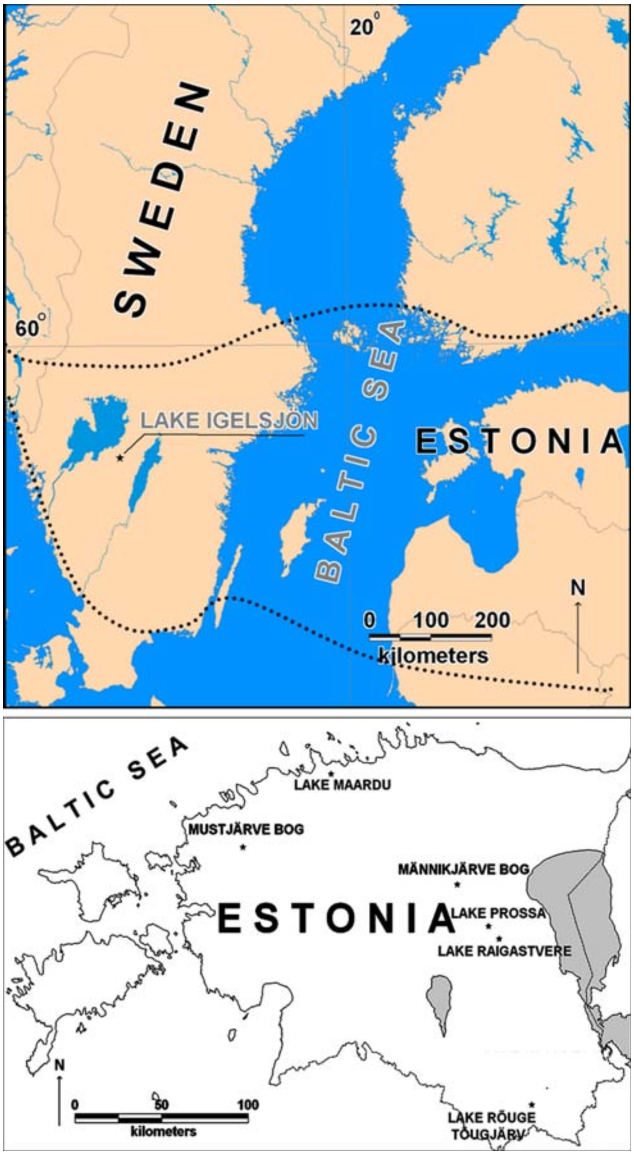


Fig. 1 Locations of the sites investigated and referred to in the contemporary boreo-nemoral vegetation zone (within the *dotted lines* in the top map; after Sjörs 1965)

with winter temperatures falling to −20 to −30°C (Johannessen 1970; Jaagus 2006).

Materials and methods

The dataset of palaeoclimate parameters and cereal cultivation reconstructions includes high-resolution peat multi-proxy data from Männikjärve bog in eastern central Estonia (58°52′N, 26°15′E; Sillasoo et al. 2007), pollen-based temperature reconstructions from central Estonian Lake Raigastvere (58°35′N, 26°39′E; Pirrus et al. 1987b; Saarse et al. 1996; Seppä and Poska 2004), cereal-type pollen finds from North Estonian Lake Maardu (59°26′30″N, 25°00′E; Veski 1996; Poska et al. 2004), Northwest Estonian Mustjärve bog (59°04′30″N, 24°06′E; Veski 1998), central Estonian lakes Raigastvere and Prossa (58°39′N, 26°33′E; Kihno, unpublished), and South Estonian Lake Rõuge Tõugjärv (57°44′20″N, 26°54′20″E; Veski et al. 2005; Poska et al. 2008) (Fig. 1).

Chronologies

The chronology of the Männikjärve core was derived from a high-resolution ^{14}C wiggle-match dated peat core (40 ^{14}C AMS dates; Yeloff et al. 2006; Sillasoo et al. 2007). The chronology of Lake Rõuge Tõugjärv with annually laminated sediments is based on varve counts (Veski et al. 2005). The chronologies of other palynological reference sites are based on at least six bulk ^{14}C dates (Poska et al. 2004), which were calibrated with the CALIB 4.2 program (Stuiver and Reimer 1993) using the INTCAL04 calibration dataset (Reimer et al. 2004). Age-depth modelling for each sequence (except Männikjärve) was performed by linear interpolation between the midpoints of the calibrated radiocarbon dates. A modern age was assumed for the uppermost sediment of the cores. The geological epoch of the late Holocene includes the following periods in Estonian archaeology: up to c. 3750 cal B.P. the Stone Age; 3750–2450 cal B.P. the Bronze Age; 2450–750 cal B.P. the Iron Age; and after c. 750 cal B.P. historical times (Lang and Kriiska 2001; Lang 2007). In this paper the following subdivisions are also being used: the early and late Bronze Age (3750–3050 and 3050–2450 cal B.P., respectively); the pre-Roman, Roman, middle and late Iron Age (2450–1900, 1900–1500, 1500–1150 and 1150–750 cal B.P., respectively), the Middle Ages (750–400 cal B.P.) and Modern Times (from 400 cal B.P. onwards).

Reconstructions

Changes in bog surface wetness in Männikjärve bog were inferred using detrended correspondence analysis (DCA) and zonation of macrofossil data, with particular reference to the occurrence of *Sphagnum balticum*, and a transfer function for water table depth using testate amoebae (Sillasoo et al. 2007). Pollen-based annual mean temperature (T_{ann}, °C) reconstructions were compiled using a weighted averaging–partial least squares (WA–PLS) two-component model, the Finland–Estonia pollen–climate calibration dataset and the fossil pollen record (Seppä and Poska 2004). Changes in the intensity of arable land-use were examined based on well dated and biostratigraphical material covering the time span from c. 4500 cal B.P. until the present (A.D. 1950).

Crop cultivation and animal husbandry were considered major agricultural activities, which in pollen profiles can be represented by a summary curve of cereal-type pollen (pollen of cultivated land, agricultural pollen) and herbs, respectively. The summary curve was used to overcome the differences in pollen determination level of the investigated sites. In some cases (Lake Rõuge Tõugjärv, Lake Maardu and Mustjärve bog) the cereal-type pollen was differentiated to species level, in other cases (Lake Raigastvere and Lake Prossa) only the general cerealia group was differentiated. Differences in pollination strategies of cereals, and problems in determining cereal-type pollen make some species overrepresented and well identified, and leave others underrepresented or in a taxonomic unit that includes both cultivars, weeds and wild species (Behre 2007). When possible, a *Secale cereale* curve is presented (Fig. 3c). Rye is a prolific pollen producer and can therefore, lead to overestimation of intensity of agrarian activities. Determination of cereal-type pollen was made using 1,000× magnification, phase contrast equipment and careful measurement of pollen grains.

The possibility that some cereal-type pollen grains can belong to wild grass species, for example to *Agropyrum* or *Glyceria*, cannot be totally discounted. Questions also arise when modern wild plants were used as crop plants in the past. The grains of *Glyceria fluitans*, for example, are known to have been used for food in some parts of Europe and in western Russia until the middle of the 19th century (Kuusk et al. 1979). Its pollen belongs to the *Hordeum*-type, but the plant is generally associated with natural wet habitats. However, cereal-type pollen does not have many natural sources in Estonia.

There are no pollen types that could be directly connected with cattle rearing in Estonia, and so the extent and intensity of such activity are difficult to assess. The summary curve of herbs is used for estimating general landscape openness. Poaceae and Cyperaceae pollen was excluded from the total herb sum, as the pollen of these taxa is often of extra-local origin (belts of reeds or sedges on lake shores) and can therefore, give misleading information on landscape openness. As these species are also dominant components of open meadow communities, exclusion of these species can on the other hand result in underestimation of the grassland area. Herb pollen may include species that grow on both cultivated fields and fallow pastures, for example *Rumex acetosella*, which is well represented in pollen diagrams. This is a cereal weed that prospers when soil conditions are poor for cereal growth (dry nutrient poor sandy soils), and is considered to be an indicator of lime-deficiency in soils (Eichwald et al. 1971). The plant was found to contaminate cereals up to 1% and cultivated grass 35% in the recent past (Ratt and Reitan 1969). The presence of *R. acetosella* in pollen profiles may cause similar changes in cereal-type and herb pollen curves.

Results

Palaeoclimate and palaeohydrological records

The annual mean temperature reconstruction from Lake Raigastvere was compared with water table depths inferred from testate amoebae and the number of macroscopic charcoal particles in Männikjärve bog (Fig. 2). The oxygen isotope record from Lake Igelsjön, central Sweden (Hammarlund et al. 2003) is provided to show a non-biological proxy from a region with similar climate. The data from these sites differ first of all by their sampling resolution. Variations of annual mean temperatures are shown relative to the present (A.D. 1950) temperature 4°C. Generally speaking, climate was warmer than present before c. 1900 cal B.P. Changes are clearly seen in Fig. 2, particularly the periods with temperatures cooler than present between c. 1900 and 1600 cal B.P., and between c. 700 and 250 cal B.P.

Periods of cooling and warming with temperature changes around 1°C and greater are marked in Fig. 2. Comparison of the periods of cooling and warming with water table reconstructions in Männikjärve bog shows that before c. 2650 cal B.P. the rise in temperatures coincides with decreasing bog surface wetness, while after c. 2650 cal B.P. it coincides with increases in water tables. This suggests (either) changes in precipitation patterns and/or the development of the bog, which is more sensitive to precipitation fluctuations in later than in earlier stages of its development (Sillasoo et al. 2007). However, it should be borne in mind that in the later stages of development, Männikjärve bog has suffered many times from fires and the wet shifts can mostly be seen as responses to these disturbances.

The most remarkable decrease in temperature, according to these data, occurred at c. 2000–1750 cal B.P., when in a period of c. 250 years annual mean temperature dropped c. 2.5°C and remained below present values for c. 300 years until c. 1600 cal B.P. Another similar, but more rapid cooling occurred c. 700 cal B.P., when temperature dropped nearly 2°C during 100 years and remained below present for c. 450 years (the Little Ice Age). A series of cooling events, though less significant, occurred between c. 3600 and 2750 cal B.P. A rapid temperature decrease occurred at the beginning of the series when during about 50 years annual mean temperature fell 1.5°C and then continued declining until c. 3300 cal B.P. The second cooling in this series took place at c. 3250–3000 cal B.P., by about 1°C according to this reconstruction, after a small warming. The third cooling in the series was by c. 1°C, lasting a little more than 100 years at c. 2900 cal B.P., also preceded by a warming. During the latter two cooling events the present temperature level was reached for the first time in this reconstruction.

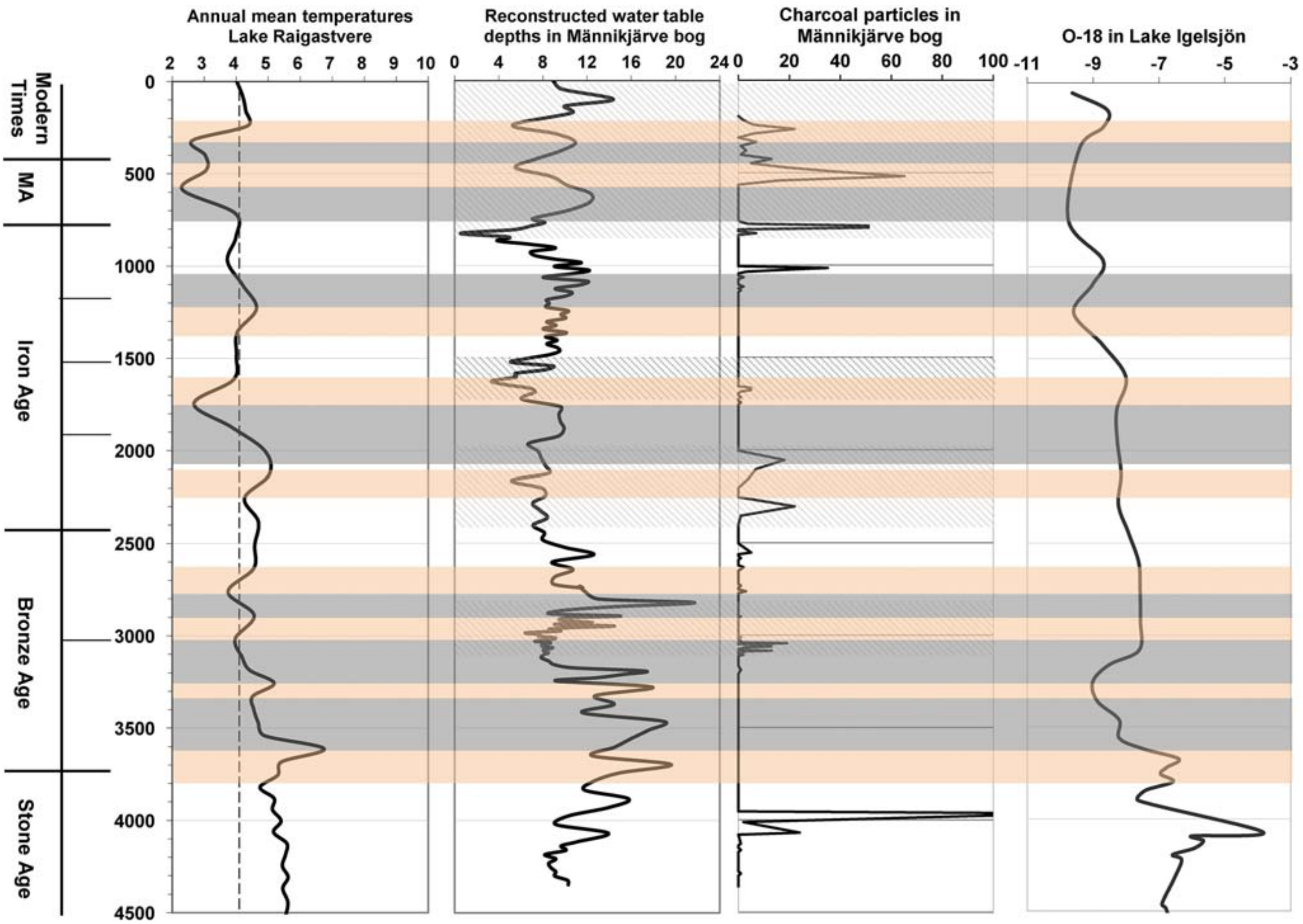


Fig. 2 Pollen-based climate reconstructions (T_{ann}, °C) from Lake Raigastvere (Seppä and Poska 2004); testate amoebae based water table reconstruction (−cm) and fire record (number of particles) from Männikjärve bog (Sillasoo et al. 2007); and oxygen isotope record (‰ V-PDB) from Lake Igelsjön (southern-central Sweden; Hammarlund et al. 2003). *Diagonal striping* indicates periods of higher surface wetness in Männikjärve bog, *dark shading* indicates cooling events, *light shading* indicates warming events in the annual mean temperature reconstruction. *Time scale* shows calendar years B.P. and Estonian archaeological periodisation (Lang and Kriiska 2001; Lang 2007)

Warming events in this reconstruction are not as significant in both their duration and amplitude as the cooling events. The most remarkable warming during the past 4500 years appears to have occurred between 3800 and 3600 cal B.P. with temperature rising nearly 2°C during 200 years. Warming events are recorded at c. 3300, 3100 and 2700 cal B.P. The latter marked the beginning of a longer warmer period. During this period another warming occurred at c. 2200 cal B.P., following a slight cooling, when during c. 150 years temperature increased by nearly 1°C. A remarkable warming of c. 1.5°C, after a remarkable cooling, is recorded between c. 1750 and 1600 cal B.P. Annual mean temperatures were still lower than at present, as in part were those of the other remarkable warming by nearly 2°C at c. 300–200 cal B.P. at the end of the Little Ice Age. This was also true of the less significant warming at c. 600–450 cal B.P., by c. 1°C in this dataset. A warming of comparable range, above the current temperature line, seems to have occurred c. 1350–1200 cal B.P.

Biostratigraphical evidence of crop cultivation

The start of cereal cultivation can only be determined with limited certainty (Poska et al. 2004). The curves of pollen of cultivated land have a positive trend from the beginning of a continuous pollen curve onwards, from between c. 4000 and 3000 cal B.P. (Fig. 3a, b). There are, however, remarkable differences between the regional summary curves and the curves of individual sites. In the regional curve changes are gradual, while the individual sites show significant fluctuations.

A slight increase in the concentration of pollen of cultivated land can be observed at c. 3800–3700 cal B.P. (Fig. 3a). The level attained is held until c. 3100 cal B.P.

when a new increase begins. The second increase lasts until c. 2600 cal B.P., after which there is a slight decline for about 200 years and a slight increase after c. 2400 cal B.P. lasting another c. 200 years. A new decrease is observed to begin c. 2000 cal B.P.; at c. 1900 cal B.P. a minimum is reached comparable to the level at c. 2900 cal B.P. The third remarkable increase is seen between c. 1700–900 cal B.P., with a stagnation period after that for about 200 years. A major increase in the concentration of pollen of cultivated land is traceable from c. 700 cal B.P. onwards with an interruption at c. 400–300 cal B.P., and a major decline during the last 200 years.

The curve of herb pollen generally follows the curve of pollen of cultivated land (Fig. 3a). However, its first increase after c. 3900 cal B.P. is faster and longer lasting, interrupted at c. 2800 cal B.P. The first decline is evidenced c. 2800–2600 cal B.P., followed by a new increase until c. 2400 cal B.P. The second remarkable decline is seen at c. 2200–2000 cal B.P., after which a slow increase takes place until c. 700 cal B.P., and a faster one after that date until c. 400 cal B.P., and between c. 300 and 200 cal B.P. A short interruption in the increase occurs c. 1400–1300 cal B.P., and declines at c. 400–300 cal B.P. and from c. 200 cal B.P. until present. The agricultural and herb pollen curves contradict each other particularly at c. 2800–2600 and 2600–2400 cal B.P., and less so at c. 2400–2200 cal B.P. showing opposite directions of change (Fig. 3a). In the first case the curve of herb pollen declines when the curve of pollen of cultivated land rises and vice versa in the second case.

Discussion

Human–environment interactions

The reconstructed trends in annual mean temperature fit well with general patterns of reconstructed climate change in Northern Europe during the late Holocene (Davis et al. 2003; Hammarlund et al. 2003; Seppä et al. 2005), indicating that pollen records from cultural landscapes can successfully be used as proxies for climatic reconstructions if landscapes with intensive agrarian activity are avoided. Some information about effective humidity and surface conditions may also be drawn from the presence of charcoal particles in bog sediments. In Männikjärve bog fires are suggested to have occurred, for example, at around 4000 cal B.P., 3100 cal B.P. and 1000 cal B.P. However, fires occurring during the last millennium have most likely been of anthropogenic origin, for example those at c. 790, 520, and 260 cal B.P.

The earliest clear evidence of cereal-type pollen in North western Estonia is dated to c. 5450 cal B.P. at Mustjärve (c. 4700 ^{14}C year; Veski 1998), in central Estonia to c. 5165 ± 115 cal B.P. at Kõrenduse (c. 4495 ± 35 ^{14}C year B.P.; Pirrus and Rõuk 1988) and in southern Estonia to c. 4580 cal B.P. at Rõuge (Poska et al. 2004). The earliest cereal-type pollen is *Avena* and *Hordeum*-type pollen. The cultivation of barley is supported by a late Neolithic (4650 cal B.P.) charred *Hordeum* sp. grain impressed in the pottery from the Iru settlement (2700 B.C.; Jaanits et al. 1982). In comparison, the earliest cereal find from Finland is also barley (*Hordeum vulgare* var. *nudum*), dated to c. 3640–3220 cal B.P. (3200 ± 170 ^{14}C B.P.; Vuorela and Lempiäinen 1988); local agricultural practices were confirmed by a single grain of *Hordeum*-type pollen. The earliest cereal find from Latvia is also barley (*Hordeum vulgare* s.l.), dated to the late Neolithic, c. 4000–3500 cal B.P. (2000–1600 B.C.; Rasiņš and Taurina 1983); during the pre-Roman Iron Age finds of barley and emmer (*Triticum dicoccum*) predominate. The earliest *Secale* pollen is found in Estonia c. 2450 cal B.P. (Poska et al. 2004; see also Niinemets and Saarse 2006).

Excavations from Asva (Saaremaa Island, Estonia) also have revealed, besides *Hordeum*/*Triticum*, the earliest finds of plausible weed cf. *Avena* sp. grain impressions, dated to before c. 2760–2540 cal B.P. (2585 ± 50 ^{14}C B.P.; Moora 1968; Jaanits et al. 1982). Other Estonian cereal finds are dated to much later periods (9–11th centuries; Sillasoo and Hiie 2007). The spread of *S. secale* and *T. aestivum* (incl. *T. compactum*) is in Latvian material indicated in the Roman Iron Age (1850–1650 cal B.P.). The earliest finds of oats are identified as *A. fatua*; the cultivation of *A. sativa* is suggested in the late Iron Age (10–12th century; Rasiņš and Taurina 1983). The earliest finds of weed type *S. cereale* in Finnish archaeobotanical material are dated to c. 2050 cal B.P., the earliest *T. dicoccum* to c. 2050–1550 cal B.P., *T. compactum* to c. 2090 cal B.P., *T. aestivum* to c. 1850–1450 cal B.P. and *A. sativa* to c. 1950–1550 cal B.P. (100 B.C., 100 B.C.–A.D. 400, 140 B.C., A.D. 100–500 and A.D. 1–400, respectively; Seppä-Heikka 1985; Häkkinen and Lempiäinen 1996). Next to the principal earliest cultivars barley and emmer, *Camelina sativa*, *Vicia faba*, *Pisum sativum* and *Panicum miliaceum* occur in archaeobotanical material from the southern parts of the region from about 2,000 years ago (Rasiņš and Taurina 1983).

The cereal-type pollen in most sequences is generally sporadic and at low abundance. It first occurs in the period of warm and dry climate in Northern Europe, as in the British Isles and Southern Scandinavia (Macklin et al. 2000; Bonsall et al. 2002). The approximate beginning of

Fig. 3 The summary (**a**) and individual curves (**b**) of cereal-type and herb (excluding Poaceae and Cyperaceae) pollen (%) of five investigated sites; *Secale cereale* pollen from sites were identified (**c**). *Black* cereal-type pollen, *grey* herb pollen excluding Poaceae and Cyperaceae. *Light shading* warming, *dark shading* cooling ▶

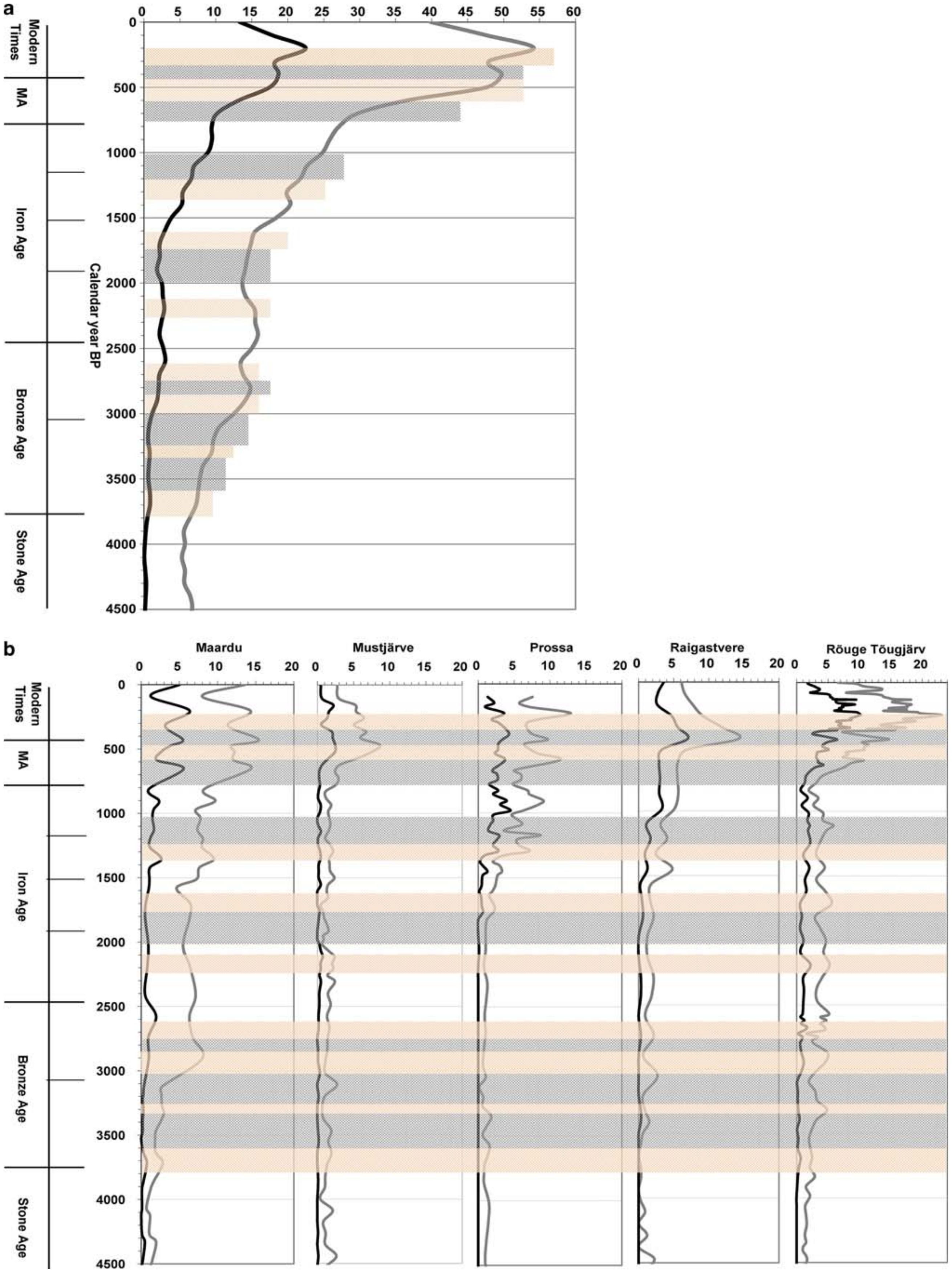
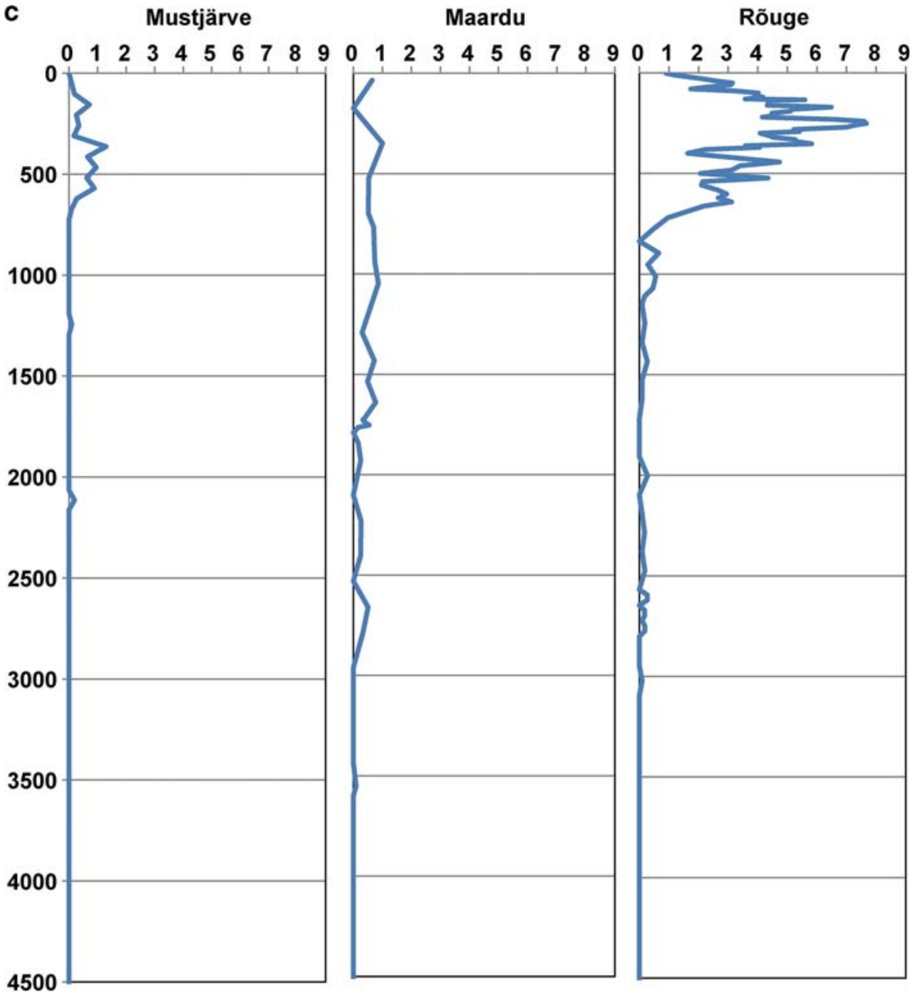

a
Modern Times
MA
Iron Age
Bronze Age
Stone Age
Calendar year BP
0 5 10 15 20 25 30 35 40 45 50 55 60
0 500 1000 1500 2000 2500 3000 3500 4000 4500
b
Maardu
Mustjärve
Prossa
Raigastvere
Rõuge Tõugjärv
0 5 10 15 20
0 500 1000 1500 2000 2500 3000 3500 4000 4500

Fig. 3 continued



continuous cereal-type pollen records in coastal Estonia at c. 4000 cal B.P. (Poska et al. 2004) takes place together with considerable changes in landscapes, inferred from lake level changes and bog stratigraphy (transition from fens to bogs; Saarse and Harrison 1992; Ilomets 1999), in the context of the beginning of decreasing annual mean temperatures. Similar developments in agriculture and environments are seen in Lithuania (Kondratienė 1998). In central and eastern Estonian areas with heavy clayey soils, the beginning of continuous cereal cultivation appears to take place later, around c. 2000 cal B.P. (Poska et al. 1999; Niinemets et al. 2002).

There is more evidence of cereal-type pollen in the Late Bronze Age all over Estonia: c. 2850 cal B.P. at Siniallika (2700 B.P.; Pirrus et al. 1987a), c. 2830 ± 84 cal B.P. at Raigastvere (c. 2700 ± 80 ^{14}C B.P.; Pirrus et al. 1987b) and c. 3100 cal B.P. at Prossa in central Estonia (Kihno, unpublished); c. 2500 cal B.P. at Kõverjärv (c. 2400 B.P.; Mäemets 1983), c. 2600 cal B.P. at Tuuljärv (c. 2500 B.P.; Ilves and Mäemets 1987), and c. 2604 ± 116 cal B.P. at Karuniidu in South Estonia (c. 2500 ± 60 ^{14}C B.P.; Mäemets 1983; Poska et al. 1999). An increased importance of cultivated land can also be observed in northern Estonian data from Lake Maardu (Veski 1996; Fig. 3b). The first physical evidence of fossil fields, similar to ones in Denmark and Åland, found in northern Estonia also dates to this period (Saha-Loo, c. 2750–2350 cal B.P.; Lang 1994; Kriiska and Tvauri 2002). Most of the evidence appears in the context of slight warming episodes, above the present level of annual mean temperature (Fig. 2). Archaeological evidence from the late Bronze Age of coastal Estonia refers in general to trade and contacts with southern Scandinavia and the southern Baltic regions. Old (scrap) bronze metalwork and clay vessels were imported, probably with cereals, in exchange for seal fat and other marine products (Kriiska and Tvauri 2002). The late Bronze Age is considered to be a period with a higher population density than previously and of the creation of new fields in the region (Fig. 4a).

The late Bronze Age stands out because of its richer archaeological material than from earlier periods. This period was preceded by a series of cooling events c.

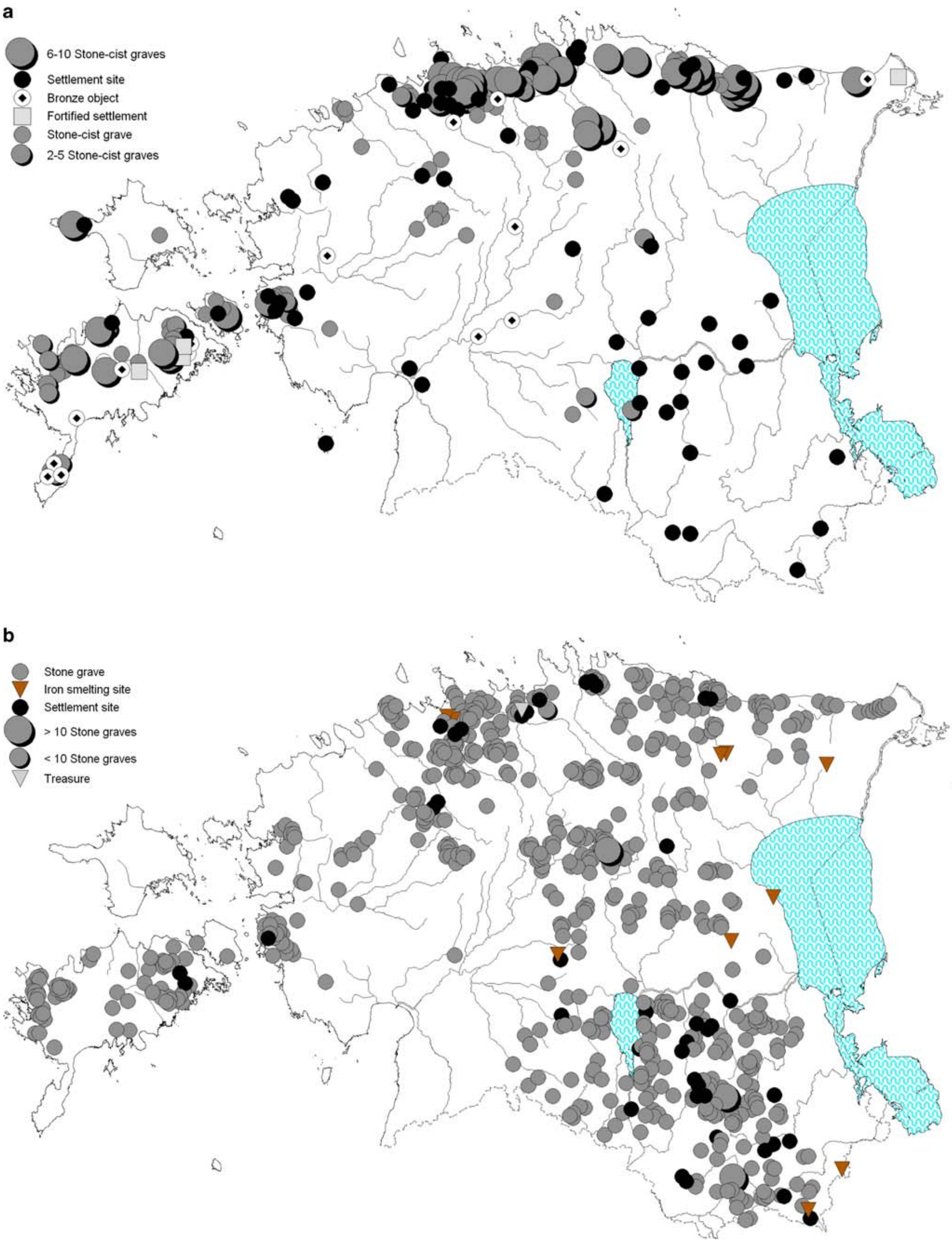


Fig. 4 Late Bronze (**a**) and Roman Iron Age sites (**b**) in Estonia (Kriiska et al. 2007)

3700–3000 cal B.P., revealed in Estonian records. A supposedly cooler interval between c. 3700 and 3100 cal B.P. can also be seen in the Swedish oxygen isotope record (Fig. 2; Hammarlund et al. 2003). Only one particular feature in Estonian archaeological material from this interval is known, which can be interpreted as a kind of indirect response to the climate change. This is the migration of settlement from the vicinity of the sea towards inland areas c. 3200 cal B.P. One of the reasons could be a search for better soil conditions for agrarian activities (Lang 1999), other possible reasons being the decline of seals for hunting and the need for better wood resources for winter survival. In the Netherlands and Denmark the provision of stables for sheltering animals in winter is observed for the first time, plausibly in relation to the cooler climate (and snow?), at the end of the early Bronze Age and the beginning of the late Bronze Age (according to Montelius, c. 3450–3200 cal B.P.; Behre 1998; Robinson 2003). Evidence from the Bronze Age shows the increase in importance of sheep and goats, possibly indicating an increased importance of wool products; this may be another societally determined response to cooler climate. A shift towards pig keeping, because pigs could adapt more easily to the cooler and moister climate conditions, is also seen as a possible response. All these changes might have in turn caused changes in land-use patterns and in vegetation (Harding 2000).

There is a noticeable shift in the patterns of plant exploitation practice c. 3150 cal B.P. (the beginning of the Urnfield period, 1200 B.C.), with regard to both intensity of cultivation, as well as the introduction of a number of new plants into cultivation. There were signs of more intensive use of legumes and oil-bearing plants, large finds of millet and evidence of possible rye cultivation in Britain (Chambers 1989; Harding 2000). Food historians note a pattern of introduction of new crops into consumption (and cultivation) during the periods of need (Montanari 1996). New crops could have emerged in cooler episodes through natural selection (e.g. “wheat of Allah”, Zohary and Hopf 1988). In addition, migration and the cultural exchange pattern should be considered: the late Bronze as well as the Roman Iron ages were the periods of intensified cultural/agricultural activities throughout Europe (Behre 1988, 1998; Harding 2000; Lang 2007).

The Roman Iron Age is another period of cooler and wetter climate in the eastern Baltic Sea region, with temperatures lower than present for the first time during the past 4500 years. In this period, a *Picea* pollen maximum occurs in palaeo-vegetation data (1800–1400 cal B.P.; Saarse et al. 1996). A remarkable cooling occurred at c. 2000–1750 cal B.P. (see above; Fig. 2). The impact of this event is seen in the chart showing regional cultivation (Fig. 3a) as a slight decline and stagnation in pollen concentrations of cultivated land, between c. 2000 and 1900 cal B.P., while the percentages of herb pollen increase slightly. Increase in agricultural pollen is seen only during the following warming. The Roman Iron Age is considered to be the period of introduction of local iron production (Peets 2003), and higher population density, particularly in the interior of Estonia (Fig. 4b). The biostratigraphical data show that the intensification of cereal cultivation, which began in the second part of the period, lasted for the rest of the Iron Age. Iron production that was based on local bog ores and smithies was a collective operation, the work force needed a higher concentration of housing and of food supplies, which had to be produced in the fields. Progressive agricultural practices with new tools and iron production certainly resulted in landscape changes, the duration of which was greater in agricultural lands than in lands of iron production only (Mighall et al. 2006; see also Laul and Kihno 1999; Peets 2003). At this time the material culture of south-eastern Estonia shows traces of East European influences, contrasting with the archaeological cultures in north western areas (Kriiska and Tvauri 2002).

Increases in the pollen of cultivated land were more abrupt than before at the end of the late Iron Age and the beginning of the Middle Ages in Estonia. This coincides with a rapid cooling comparable to the one in the Roman Iron Age (see above; Fig 2), which seems to have had no direct impact on agricultural activities. On the contrary, the period is characterised by cultural developments in the region, following the German and Danish colonisation, the creation of towns and the network of Hanseatic trade, the extensive development of fields and the introduction of new plants (vegetables) into cultivation (Sillasoo and Hiie 2007). Archaeobotanical and written sources agree that rye and barley were the predominant crop cereals in medieval Estonia. In tax lists they were demanded in equal quantities. Wheat was rarely grown even in manorial fields, and even in areas with a more favourable climate it almost never reaches 1% of total harvest, according to the tax lists (Ligi 1968). Oats are attested in both archaeobotanical and written sources, but their importance in cultivation is difficult to estimate. In tax lists they are demanded in much smaller quantities than barley and rye, but are requested in grain revenues on certain occasions in quantities three times those of rye and wheat put together, possibly for horse fodder (Sillasoo and Hiie 2007).

The level of agricultural development, reached by c. 3700 cal B.P. appears not to have been impacted by cooling events during the 700 years that followed. The percentages of pollen of cultivated land are constant and even increase slightly after c. 3100 cal B.P. The behaviour of the curve of herb pollen is different, increasing from c. 3900 cal B.P., independently of the curve for pollen of cultivated land, indicating no shifts in farming practices that might be expected as responses to climate change (Fig. 3). Also other cooling events in prehistoric times seem not to have triggered bigger changes in farming practices in the study area; changes around 2000 cal B.P. are of little significance. Cooler climate coincides with declines in both cultivated land and herb pollen curves at c. 400–300 cal B.P., during the Little Ice Age. However, this decline is plausibly not related directly to climate change, but rather to war activities (Russian–Livonian war), which caused the destruction, deportation and military recruitment of the population. Written sources refer to numerous abandoned fields and households, particularly in eastern Estonia, and the decrease in population as the result of battles, diseases and poor harvests (Kahk and Tarvel 1992; Mäesalu et al. 1997). The latter could have been caused by the colder climate, but also by poor management of the fields.

Increases in the regional curve of pollen of cultivated land coincide with significant (around 1°C and more) warming events at c. 3800, 2700, 1700, 1300, and 300 cal B.P. The herb pollen curve declines independently of the cereal–pollen curve at c. 2200 cal B.P. The contradictions between the curves of the different pollen groups are seen at c. 2800–2600 and 2600–2400 cal B.P. These show changes in opposite directions, which may be interpreted as small shifts in land-use patterns. Although there is a decreasing trend in annual mean temperatures over the past c. 4300 years, the proportion of cereal-type pollen increases through time, suggesting a certain independence of agrarian activities from environmental conditions at the regional level. Agricultural indices at individual sites in different landscapes may respond to environmental changes differently, but they show similar changes under the pressure of similar societal factors.

The northern site of Maardu shows that warming events have had in many cases a positive impact on cultivated lands at the end of the Neolithic, in the Bronze Age, Iron Age and historical times, but there also are situations, where the opposite is seen, or where the concentration of pollen of cultivated land increases during cooling events. Changes also take place without significant climate change.

In the central-eastern site of Raigstvere the decline of herb pollen, but also of pollen of cultivated land, is frequently seen during warming events before c. 1500 cal B.P.; after that the pattern changes. Significant agricultural activities at Prossa begin c. 1800 cal B.P. The pattern for these two sites is similar. Here also, agricultural changes occur in the periods without significant climatic changes. In the south eastern site at Lake Rõuge Tõugjärv warming events have a more positive than negative correlation with agricultural indices; herb pollen shows decreasing trends during cooling events before historical times. However, these patterns are not consistent. The north-western site of Mustjärve bog is similar to other sites during the historical periods; in prehistorical times the scarce data vary between sites.

Conclusion

The relationship between climate and cultural changes is complex. Climate change may have had different impacts on the economy of societies in different territories and landscapes. These differences may have led to cultural and economical diffusion by means of emigration, colonisation and wars, with both positive and negative consequences. Cultural/agricultural changes may have taken place during periods of need (qualitative change) or through communication and colonisation (quantitative and qualitative change). In a small sparsely populated country, immigration (and political change) might cause considerable cultural changes that overshadow climate change, such as in the Middle Ages; or attacks from outside may have destroyed the economic balance necessary for standing against the climate change, such as during the Little Ice Age. However, in many cases considerable warming events had a positive impact on past agricultural activities in the region, while in prehistoric times in particular, cooling events are related to regional stagnation if not decline. This paper also confirms that periods of regression in cereal cultivation can be found both in warmer and in cooler episodes, or independently of any climate change at all.

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