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ORIGINAL ARTICLE

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New evidence of possible crop introduction to north-eastern Europe during the Stone Age

Cerealia pollen finds in connection with the Akali Neolithic settlement, East Estonia

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Abstract Long term (from the Mesolithic to the Bronze Age) habitation of the Akali settlement on a clearly defined bog-island in East Estonia is used as an example of transitional development from a prosperous foragers' habitation centre to a hinterland of established farming cultures, taking place through availability, substitution and consolidation phases of crop farming in the boreal forest zone. The pre-Neolithic finds of *Triticum* and *Cannabis* t. pollen at c. 5600 B.C. are interpreted as possible indications of the acquaintance of foragers with farming products, through contacts with central European agrarian tribes during the availability phase. The substitution phase is marked by more or less scattered pollen finds of various cereals and hemp and, at Akali, is connected with Neolithic period 4900–1800 B.C. An increasing importance of crop farming in the economy is characteristic of the consolidation phase, but because natural conditions are unfavourable for arable land-use, a regression of human presence is recorded during the second part of the Neolithic. The settlement was abandoned during the Bronze Age at the time when crop farming become the basis of the economy in Estonia. The re-colonisation of the area, traced to ca. A.D. 1200, took place for political reasons rather than through increasing suitability of the landscape.

Keywords Estonia · Cerealia pollen · Stone Age · Bronze Age · Crop introduction · Boreal-nemoral forest zone

Introduction

The nature and timing of the introduction of agriculture during the Mesolithic-Neolithic transition is one of the most challenging questions in European prehistory. There are many different theories on the question of why the change in subsistence took place. In principle, these can all be divided into three groups: (1) climate change or population pressure leading to increasing competition for available food resources; (2) exceptionally good conditions for food gathering allowing experiments with new and unstable resources; or (3) changes in society, which led to social stratification and competition among the leaders causing the need for possessions of high status and value (Gebauer and Price 1992). In the first case a probable rapid displacement of non-agrarian Mesolithic culture by agrarian Neolithic occurred. In the second and third cases the transition probably took place as a complex and protracted phase of cultural substitution, with the gradual introduction of new techniques (ceramics, domesticated animals, cereal growing etc.; Innes et al. 2003). However, as the spread of farming is spatially and temporarily extremely complex, it seems possible that all these theories could apply at different times and in different places or in combination. Tracing the timing of initial crop introduction, in the form of an exchange of goods or small-scale gardening, is extremely difficult, especially in the above-mentioned cases 2 and 3, where the infiltration of ideas rather than the migration of people might be expected. In these cases, the time lag between the introduction and the final establishment of agrarian practices could extend over a considerable time period, possibly several millennia (Poska 2001). Direct evidence, in the form of archaeological or plant macrofossil finds, of the early small-scale appearance of crop cultivation or trade of farming products is very hard to obtain. Without such direct evidence, cereal pollen grains may be a key palaeoecological signature (Edwards 1988, 1989).

In this paper we present pollen, charcoal, loss-on-ignition and radiocarbon data from Akali, a Late Stone Age settlement site inhabited over a period of 3000 years, near the mouth of the Emajõgi River, East Estonia (Moora et al. 1988). Special attention is paid to early Cerealia pollen finds and the comparison of first appearances of Cerealia pollen with available data from the neighbouring regions.

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Outline of the principles of Cerealia pollen identification

Today cereal pollen identification is generally based on three main characters (Beug 1961; Andersen 1979; Levkovskaya 1987; Fægri and Iversen 1989; Dickson 1988; Table 1):

1. *The size of the pollen grain*: According to Andersen (1979) and Beug (1961) the mean size of pollen grains from cultivated species is larger than 37 µm and only a few wild grasses surpass this limit (e.g. *Hordeum murinum*, *Agropyron repens*, *Elymus arenarius*, *Avena fatua*). According to Levkovskaya (1987) the mean size of pollen grains from cultivated species mounted in glycerol is larger than 45 µm.
2. *The surface structure of the pollen grain*: Two major surface types are distinguished by Beug (1961): *scabrate* – seen under the light-microscope as isolated dark dots and *verrucate* – seen as irregular dark spots. On the basis of the above mentioned sculpturing types the major cultivated cereal taxa are divisible either into two groups (Andersen 1979; Levkovskaya 1987) – the *Avena-Triticum* and the *Hordeum* groups (the latter including *Secale cereale*); or into three groups (Beug 1961) – the *Avena*, *Triticum* and *Hordeum* groups (the latter again including *Secale cereale*) (Table 1).
3. *The constitution of the pore and the annulus* (diameter and sharpness of the outer boundary): The cultivated cereals generally have a thick annulus with a sharply delimited outer boundary. According to Andersen (1979) the mean annulus diameter for the *Hordeum* group is 8–10 µm and for the *Avena-Triticum* group >10 µm. According to Beug (1961) the mean diameter of the annulus is somewhat smaller; 7–8 µm in the *Hordeum* group and >8 µm in the *Triticum* and *Avena* groups (Table 1).

Site description

Akali (58°24′40″ N and 27°14′35″ E) is situated on a small island in an extensive (25000 ha) wetland region Emajõe Suursoo near the mouth of the River Emajõgi (Fig. 1). Spring floods regularly submerge up to 7000 ha of this landscape, including the lower parts of the Akali region. The wetland formation in the lowest parts of the Emajõgi estuarine area started soon after deglaciation, when the area emerged from the waters of the local ice lake at the beginning of the Holocene. Mire formation continues to this day due to the greater land uplift in north Estonia compared with the south, tilting the Peipsi basin southwards and submerging this area. The rate of bog formation at Akali has been relatively stable throughout its history, ca. 50 cm per 1000 years (Moora et al. 1988). Today *Carex*-fen forms the major vegetation unit of the landscape and wooded patches are only preserved along river valleys (*Salix* spp., *Alnus glutinosa*, *Betula humilis* and *B. pubescens*) and on bog islands (with the addition of *Picea abies* and *Pinus sylvestris*). The investigation site is covered by sparse *Betula* stands with a rich Polypodiaceae undergrowth. The well-dated high quality Saviku pollen profile, 1.5 km north of Akali, has been used to describe the regional vegetation history (Sarv and Ilves 1975) and to establish the water level changes in Lake Peipsi (Hang et al. 1995; Hang and Miidel 1999).

The Akali settlement was placed at the crossing of important waterways connecting the Baltic Sea coast with northwestern Russia, and inland Latvia with the North Estonian coast (Fig. 1). The site was discovered in 1937 and has since been repeatedly excavated (Jaanits 1959; Moora et al. 1988; Jaanits and Moora 1999; Jaanits et al. 1999). Three pollen profiles were analysed in connection with archaeological excavations in the 1950s (Jaanits 1959, p. 23), and two (No 6 and 8) in the 1980s, which were also radiocarbon dated (Moora et al. 1988; Fig. 1; Table 3). However, these pollen diagrams were constructed primarily for stratigraphical purposes and, due to their low pollen counts, cannot be used for human impact studies. Based on the continuously changing typology of ceramics and the continuity of the cultural layer, persistence of habitation throughout the Neolithic period and up to the Bronze Age is interpreted by archaeologists (Jaanits 1959, p. 293). Regardless of the scant Mesolithic artefacts, charcoal dating 6255±100 B.P., TA-103 (Punning et al. 1968; Fig. 1; Table 3) from a hearth places the establishment of habitation at Akali at the end of Mesolithic period.

Table 1 Average pollen size and annulus diameter for selected cultivated and wild Poaceae taxa according to Beug (1961), Andersen (1979) and Levkovskaya (1987)

	Mean pollen size µm /annulus diameter µm/surface structure		
	Beug 1961[a]	Andersen 1979[b]	Levkovskaya 1987[a]
Avena sativa L.	52.0/8.7/verrucate with “Punktklumpen”	40.9/10.7/verrucate	62.1/10.7
Hordeum vulgare L.	45.8/7.5/scabrate	37.3/8.2/scabrate	
H. distichon.	46.3/7.5/scabrate		50.4/8.3
Triticum aestivum L.	56.4/12.0/verrucate with “Punktgruppen”	45.0/11.8/verrucate	59.6/9.8/verrucate
Secale cereale L.	53.3/7.4/scabrate	40.1/9.0/scabrate	53.1/10.3
Panicum miliaceum L.	37.4/6.9/verrucate with “Punktklumpen”		40.6/5.4
Agropyron repens L.	43.9/6.4	37.7/8.8/scabrate	55.2/5,9/scabrate
Phleum pratense L.	38.0/6.1	32.3/5.7	41.4/7.0
Phragmites communis L.		22.9/5.9	41.2/6.6

[a] Measured pollen grains mounted in glycerol

[b] Sizes are standardised to *Corylus* =24.5 µm, measured pollen grains mounted in silicon oil

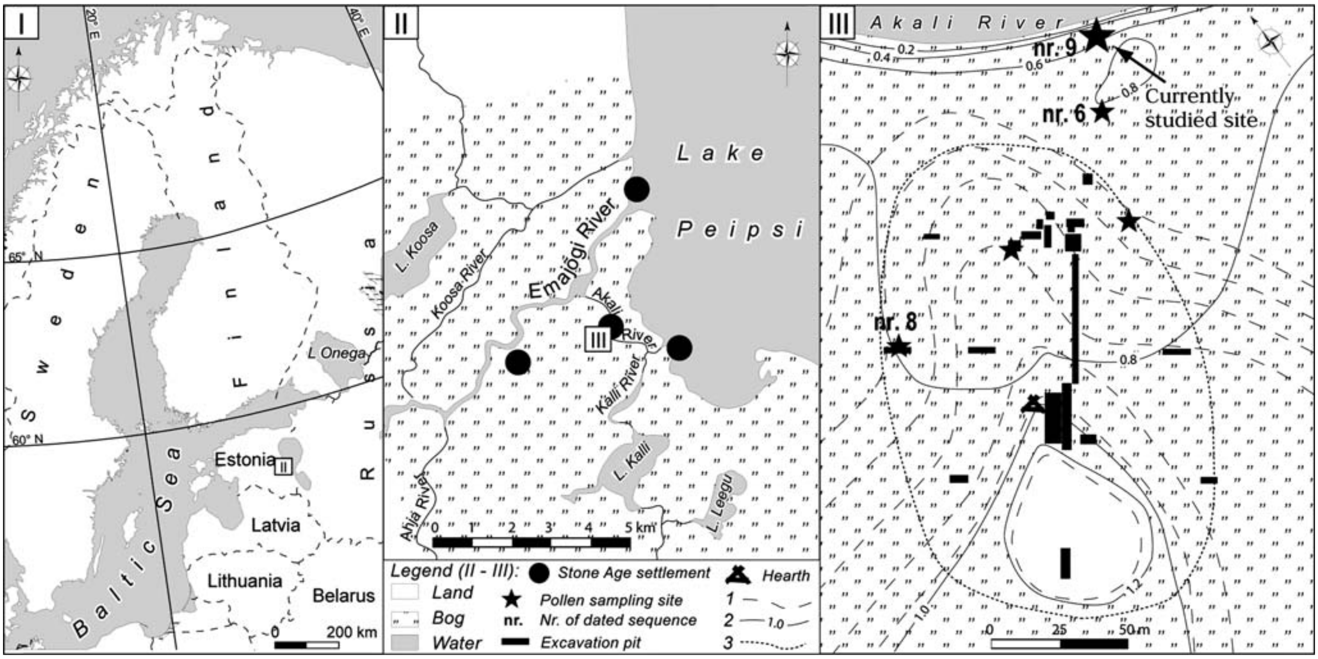

Fig. 1 Location of the study area. **I** - location of Estonia; **II** – modern map of the area around the sampling site; **III** – detailed modern map of archaeologically and palynologically studied sites on Akali island (after Jaanits 1959); 1 – contours of soil surfaces at the time of foundation of the settlement, 2 – contours of the modern topography, 3 – settlement borderline

Material and methods

A 480-cm long sediment sequence (core 9; Fig. 1-III) for pollen and loss-on-ignition analyses, together with AMS radiocarbon dating was recovered with a Belarus peat sampler in June 1995 from the Akali (Kalli) River bank, ca. 50 m north of the nearest excavation pit (Fig. 1). The lithostratigraphy of the profile is presented in Table 2 and Fig. 2.

AMS dates for bulk material and terrestrial macrofossils (Fig. 2, Table 3) were produced at the Ångström Laboratory, Uppsala University (Ua). The macrofossils dated consisted of small amounts of terrestrial herbaceous material (mainly *Carex* spp. leaves and seeds) which were extracted by soaking 1 cm thick peat samples in NaOH, sieving through 250 μm mesh and picking out recognisable plant remains. The charcoal from the hearth was dated at the ^{14}C Laboratory of Tartu University (TA) and bulk peat samples from cores 6 and 8 – at the Institute of Geology, Tallinn (Tln), using conventional methods.

The AMS date (1890±60, Ua-11751) from a depth of 250 cm is exceptionally young in comparison with the other dates and with the pollen stratigraphy of the area and was excluded from the age-depth curve construction (Fig. 2). All the radiocarbon dates were calibrated to calendar years B.C./A.D. using INTCAL 98 at 1σ confidence level (Stuiver et al. 1998). The archaeological timescale follows that of Lang and Kriiska (2001). The age-depth curve was constructed by polynomial (5th order) interpolation between the available AMS dates. The top of the sediment column was considered to be recent.

Samples for loss-on-ignition (LOI) were taken at intervals of 10 cm and for pollen analysis at intervals of 5 to 10 cm. The LOI analyses were made at the Institute of Geology, Tallinn University of Technology, burning material at 550 °C and 900 °C (Heiri et al. 2001).

Pollen preparation followed a standard acetolysis method described by Erdtman (1936) and Fægri and Iversen (1989), involving cold HCl and hot KOH treatment followed by

Table 2 Lithostratigraphy of the Akali profile

Depth (cm)	Sediment description
0–20	Water with *Phragmites* stems (Detritus herbosus)
20–70	Carex peat with *Phragmites* rests (Turfa herbacea), LOI increases with depth from 57% to 84%
70–260	*Carex* peat (Turfa herbacea), LOI varies between 85–93%
260–400	*Carex-Phragmites* peat (Turfa herbacea), LOI above 90%
400–450	*Phragmites-Carex* peat (Turfa herbacea), LOI between 91–94%
450–465	Woody *Phragmites* peat and sand (Turfa lignosa+Turfa herbacea+Grana), LOI 85–87%
465–468	Organic silt (Limus humosus+Argilla granosa), LOI around 30%
468–480	Silt with dispersed organic matter and macroremains (Argilla granosa+Substantia humosa+Detritus herbosus), LOI 2–4%

Table 3 AMS ^{14}C and conventional ^{14}C dates from the peat section and the hearth at Akali

Depth (cm)	No. of core	^{14}C age, B.P.	Calibrated age B.C./A.D.[a]	Lab. code	Material
80–82	9	1385±45	A.D. 645±25	Ua-23902	*Carex* peat
172–174	9	2285±45	315±70 B.C.	Ua-23903	*Carex* peat
245	9	4355±100	3065±165 B.C.	Ua-15595	Plant macrofossils
250	9	1890±60	A.D. 130±70	Ua-11751	Plant macrofossils
352	9	5755±55	4605±70 B.C.	Ua-23904	Plant macrofossils
360	9	6360±105	5310±125 B.C.	Ua-15596	Plant macrofossils
402–404	9	6380±55	5380±60 B.C.	Ua-23905	*Phragmites-Carex* peat
425	9	7200±70	6080±75 B.C.	Ua-12083	Plant macrofossils
Hearth		6255±100	5190±100 B.C.	TA-103	Charcoal
190–200	6	3480±60	1800±75 B.C.	Tln-281	*Carex* peat
340–350	6	6390±70	5380±65 B.C.	Tln-282	*Carex-Phragmites* peat
165–175	8	3340±60	1620±70 B.C.	Tln-347	*Carex* peat
175–185	8	3610±70	1980±105 B.C.	Tln-348	*Carex* peat

[a]Calibrated age according to CalPal (www.calpal-online-de)

5 min acetolysis and mounting in glycerol jelly. The sample was stained with fuchsin prior to counting. After chemical treatment samples were counted without delay. Pollen analysis was carried out under a Wild Leitz microscope using 250× magnification for routine counting. All critical determinations were made using phase-contrast equipment and 1000× magnification.

During identification the pollen reference collection of the Department of Earth Sciences, Uppsala University and pollen keys by Fægri and Iversen (1989) and Moore et al. (1991) were used. The pollen taxonomical names are given according to Fægri and Iversen (1989). The Cerealia identification was based on criteria presented above ("Outline of the principles of Cerealia pollen identification" section). All Poaceae pollen grains larger than 45 μm were considered as possible Cerealia pollen.

The Cerealia pollen determined had the following characteristics (presented as: pollen type – size of the pollen grain, pore diameter, annulus thickness, surface structure, shape):

1. *Avena* t. – 45–53μm, 2–3 μm, 2–4 μm, verrucate with irregular groups of points, round;
2. *Hordeum* t. – 50–60 μm, 3–4 μm, 2–4 μm, scabrate, round;
3. *Triticum* t. – 48–60 μm, 2–4 μm, 2–3 μm, verrucate with some groups of points, round to oval;

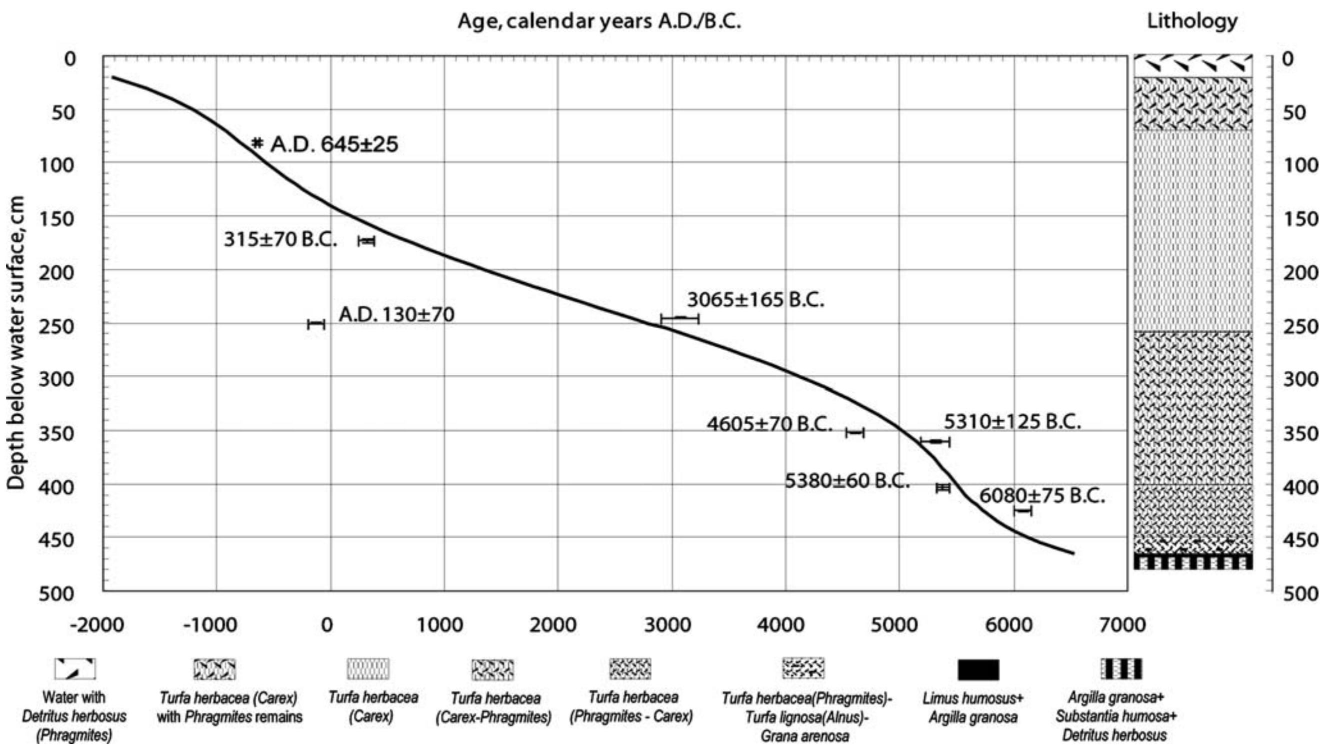

Fig. 2 Age-depth curve, based on ^{14}C AMS dates (Table 3) from Akali. Lithology according to Table 2

4. *Secale cereale* – 55–70 µm, ≥3 µm, ≥3 µm, scabrate, oval.

A tree pollen sum of ca. 1000 grains was achieved for each level. Due to extremely low pollen concentration in the minerogenic sediments the lowermost 20 cm of the core (460–480 cm) were not analysed. The basis for the percentage calculations was the sum of terrestrial pollen. Poaceae pollen (partly probably derived from local *Phragmites communis* reeds) is represented throughout the sequence at moderate and stable values and was therefore not excluded from the basic pollen sum. The percentages of the other identified microfossils were calculated from the basic pollen sum. The pollen diagrams were designed with the Tilia, Tilia.GRAPH and TGView programs (Grimm 1991). The herbs are grouped according to Behre (1981, 1988), Berglund and Ralska-Jasiewiczowa (1986), Berglund (1991) and Hicks (1992), taking into consideration local conditions (Poska 2001).

The zonation of pollen data is based on the constrained cluster analysis by sum-of-squares (CONISS) method using the PSIMPOLL 4.10 program (earlier version published by Bennett 1994). The significance of the statistically determined zones was estimated by comparison with the broken-stick model described by Bennett (1996). Palynological richness was estimated by rarefaction analysis (Birks and Line 1992) using the PSIMPOLL 4.10 program (Bennett 1994, 1998). All identified terrestrial pollen taxa were included and the basic pollen sum for calculations was set to $E(T_{500})$.

Landscape development in the Akali area

The age-depth curve (Fig. 2) indicates an accumulation rate of ca. 19 years/cm through most of the organic part of the sequence but in the lowermost part of the profile the calculated accumulation rate increases to ca. 10 years/cm. The calculations of the yearly peat accumulation rate based on peat bulk density give a similar result (Ilomets 1984).

The formation of *Phragmites* and *Carex* peat (465–70 cm) started at about 6500 B.C. The LOI analysis reveals the homogenous nature of this unit. The composition of the sediment is very stable and the organic fraction forms the major part of the deposit, particularly between 450–200 cm where the LOI exceeds 90%. In the upper part of the peat layer (between 200–70 cm; 1400 B.C. – A.D. 1100) the sediment composition is somewhat more irregular due to a moderate rise in the input of carbonaceous and terrigenous matter. Nevertheless, the organic content does not fall below 80%. A notable decrease in organic content is only seen in the topmost part of the peat section (70–0 cm; A.D. 1100 – present) where the organic fraction decreases from 84% to 55% due to a considerable increase in the calcareous, and especially the terrigenous fraction.

The main features of the vegetation history at Emajõe Suursoo have been discussed earlier (Jaanits 1959; Sarv and Ilves 1975; Moora et al. 1988; Saarse et al. 1996; Jaanits and Moora 1999; Kimmel et al. 1999).

Pollen analysis of the Akali core has revealed an unbroken record from the mid-Holocene (6500 B.C.) up to the present. Four local pollen assemblage zones (PAZ) were distinguished by means of statistical analysis (Table 4; Fig. 3).

According to Hang et al. (2001) the deglaciation and drainage of proglacial lakes at the beginning of the Holocene left the area covered by glacial clay and glaciolacustrine sand deposits, with the water level in Lake Peipsi near the mouth of the river Emajõgi lower than at present. According to Kimmel et al. (1999) afforestation started immediately, with the establishment of *Pinus sylvestris* and *Betula* spp. as pioneer trees. Only the lowermost parts of the area were occupied by wetland species, leaving ample space for woodland development. *Pinus* and *Betula* were soon followed by *Ulmus* spp., *Corylus avellana* and *Alnus* spp. (Kimmel et al. 1999).

At Akali, the start of organic sedimentation and the formation of sedge-swamp at ca. 6500 B.C. (AK – 1) mark the rise in ground water. *Pinus sylvestris* formed woods

Table 4 Temporal extent of PAZ and main events in vegetation and land-use development

PAZ (depth, cm) cal yr B.C./A.D. *Archaeological Period*	Dominant vegetation type Indications of human impact
AK–1 (460–340) 6600–4900 B.C. *Late Mesolithic*	*Pinus sylvestris* woods on higher ground. *Betula* and *Alnus* in lower area. Start of sedge-swamp formation Few ruderal-land and forest grazing indicators. Scattered *Triticum* t. and *Cannabis* t. pollen finds
AK–2 (340–250) 4900–3200 B.C. *Early* and *Middle Neolithic*	Coniferous woods with moderate numbers of broad-leaved trees. Sedges dominate on lower ground *Hordeum, Triticum, Avena* and *Cannabis* t. pollen finds. High palynological richness and increase in ruderal-land and meadow indicators
AK–3 (250–150) 3200–1100 B.C. *Late Neolithic* and *Early Bronze Age*	*Picea abies*-dominated coniferous woods. Ferns spread at the expense of sedges Few *Avena* t. pollen grains in first part of zone. Stagnation in human impact indicators at its greatest during second part of zone
AK–4 (150–20) 1100 B.C.–A.D. 1995 *Late Bronze Age*, *Iron Ages* and *Historical Times*	Coniferous woods on higher ground, deciduous (*Betula* and *Alnus* dominated) on lower ground. The new spread of sedges terminates domination of ferns Scattered *Secale cereale*, *Centaurea cyanus* and *Cannabis* t. pollen finds in upper part of zone. Continuous increase in ruderal-land, meadow and general open land indicators

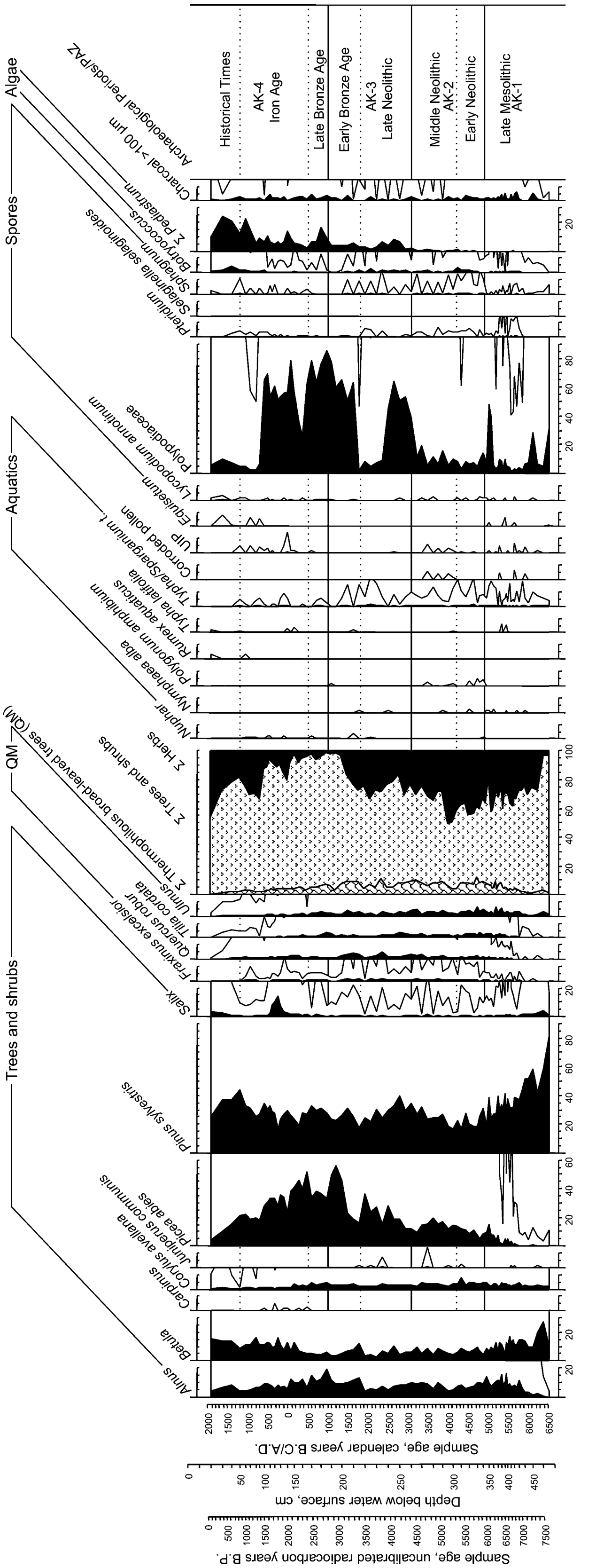

Fig. 3 Pollen diagram of selected pollen, spore, algae and charcoal percentages. The white silhouettes are a x10 exaggeration. Pollen zones and archaeological periods correspond to Table 4

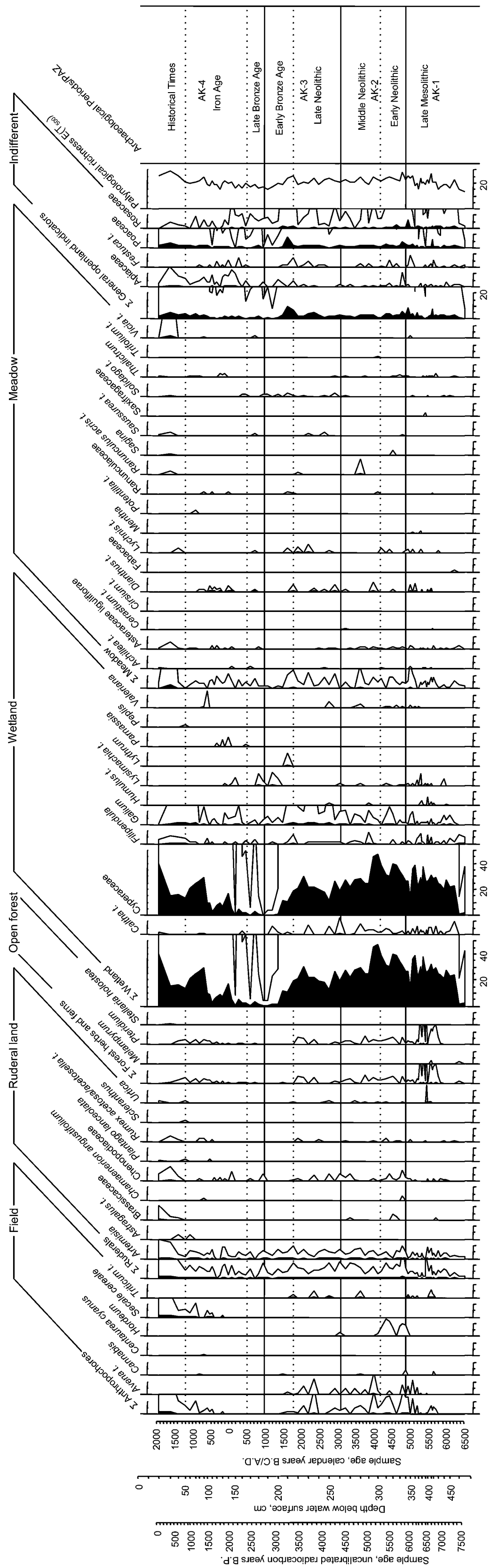

Fig. 4 Pollen diagram of herb pollen percentages. The white silhouettes are a ×20 exaggeration. Pollen zones and archaeological periods correspond to Table 4

on higher ground; *Betula* and *Alnus* thrived in lower-lying areas. With the immigration of *Picea abies* at ca. 5800 B.C., *Pinus* had a successful competitor for habitat. The first traces of human presence, seen as a modest rise in ruderal-land, meadow and forest-grazing indicators, occur during Late Mesolithic period (AK – 1; Fig. 4). The first scattered *Triticum* t. and *Cannabis* t. pollen finds appear as early as 5600 B.C. accompanied by *Urtica*, *Solidago* t., *Juniperus* and *Melampyrum* pollen and *Pteridium* spores. The palynological richness doubles at the same level. These signs clearly point to human presence close to the sampling site, and appear ca. 600 years earlier than suggested by the archaeologists.

During the mid Holocene (AK – 2; 3) *Picea* dominated the coniferous woods and a moderate admixture of thermophilous broad-leaved trees (*Ulmus*, *Tilia*, *Quercus* and *Fraxinus*) developed on higher ground. The establishment and spread of the thermophilous broad-leaved tree species was hindered by lack of suitable habitats, the soils being unsuitably wet. Sedges dominated on lower ground up until ca. 3000 B.C. where, over the following 2000 years, ferns spread at their expense. This period coincides roughly with the Sub-Boreal chronozone, generally known as a time of relatively dry climate leading to less marked spring floods and generally somewhat lower ground-water levels (Saarse and Harrison 1992). The increasing *Pediastrum* curve could rather be a signal of the increasing eutrophication induced by human activities than an indication of a rise in water level.

At the beginning of the Neolithic period (4900 B.C.; AK – 2) continuous *Hordeum* t. pollen finds, accompanied by scattered *Cannabis* t., Brassicaceae, *Rumex acetosa/acetosella* t., *Urtica*, *Trifolium* t. and *Juniperus* pollen, and high palynological richness, testify to the presence of man on Akali island and are in good accordance with the archaeological record. During the Middle Neolithic the cereal pollen finds become sporadic. However, finds of *Avena* t., *Hordeum* t., *Triticum* t. and *Cannabis* t. pollen still occur. The considerable *Picea abies* decline detected around 3500 B.C. was probably caused by active land-use in the area.

After 3100 B.C., during the Late Neolithic (AK – 3), all traces of human impact, including the finds of cultivated plants, cease, with the exception of few *Avena* t. and *Triticum* t. pollen grains observable up to 1500 B.C. A decrease in all human impact indicators and also in palynological richness is recorded. This stagnation period lasts for the following 2000 years and is at its deepest at the end of the Bronze Age.

During the Late Holocene (AK – 4) *Pinus* gains in importance at the expense of *Picea*. The *Picea* stands occupied the best soils in the area, and were probably severely affected by farmers' attempts to use the highest parts of the area for cattle grazing and hay making. The continuing rise in ground water level and more prominent spring floods (usually up to 1 m, and, in wet years, up to 1.5 m; Jaani 2001) occasioned by the more humid climate during the Sub-Atlantic period generated favourable conditions for the spread of sedges and brought to an end the domination of ferns at Akali. The rather unstable water regime could also have promoted the importance of *Betula* and *Salix* at the expense of *Alnus*. During the Iron Age, around A.D. 500 arable land indicators re-appear in the form of sporadic occurrences of *Cannabis* t. and *Secale cereale* pollen accompanied by *Centaurea cyanus*. The rise in ruderal-land indicators, including *Chamaenerion angustifolium* and *Rumex acetosa/acetosella* t., meadow and general open-land indicators is recorded at about the same time. During Historical Times, of the cultivated crops, only *Secale cereale* pollen appears permanently in small quantities. However, the ruderal-land, meadow and general open-land indicators, and palynological richness show maximum values.

Evolution of land-use and introduction of cultivated crops to the Baltic region

According to Zvelebil and Rowley-Conway (1984), in the transition from foraging to farming in north and north-east Europe three major phases can be distinguished:

1. the availability phase, when farming is known to foraging groups through exchange of information and materials with farming tribes;
2. the substitution phase, with farmers moving to foragers' territory or foragers adopting farming as a supplementary form of subsistence;
3. the consolidation phase, as the final stage of the transition to farming is reached through the maturing of social and economic structures of the old frontier to the hinterland conditions.

Lang (1999a), summarising the known evidence from eastern Baltic region and Finland, added a fourth category: the supplementary proto-agrarian phase, and described it as the intensification of the use of native plants by foragers. Such a usage of native plants is detectable from macrofossil analysis of cultural layers but is, unfortunately, very hard to spot by means of pollen analysis. Only the introduction of anthropochores (cereals, hemp, fruit trees, vegetables, weeds etc.) allows agrarian practices to be traced with confidence.

The distribution of Stone Age material cultures in northern Europe gives good grounds for assuming that both the acquaintance and substitution phases could appear through contacts of boreal forest zone foragers with farming tribes of the central European plains, long before the time today acknowledged as that of the introduction of cultivation to the Baltic region. However, during the acquaintance (Lang 1999a) or availability phase (in the sense of Zvelebil and Rowley-Conway 1984) the amount of pollen produced by those few specimens of crops which had accidentally fallen to the ground or even been raised by man for religious or status purposes (Lang 1999a, b) must have been exceptionally small and sporadic. The possibilities of pinpointing signs of these first acquaintances with cultivated crops by means of pollen analysis are insignificant. However, investigations which concentrate on Stone Age habitation centres may give signals of the acquaintance phase when sufficiently high spatial and temporal resolution pollen sequences, with a high standard (in terms of pollen identification level and amount of pollen counted), are interpreted. Such areas in north-eastern Europe are, for example, the Gopło in Poland, the Sventoji area in Lithuania, the Lubans area in Latvia, the mouth of the river Emajõgi in Estonia and the Lake Onega area in Russian Karelia.

The first *Triticum* t. pollen grains found in the Akali sequence date back to ca. 5600 B.C., the end of Late Mesolithic period, and are so far the oldest recorded Cerealia t. pollen finds in Estonia. These dates correspond to the age of Cerealia t. pollen finds from southern and central Europe (e.g. de Beaulieu and Goeury 1987; Rösch 1990; Küster 1988; Greig 1996; Haas 1996), which, in general, do not extend north of 50° N latitude. In north-eastern Europe contemporaneous Cerealia t. pollen finds are recorded at two sites: at Sporovskoye in Belarus (Zernickaya and Šimakowa 2000) and at Eini lake and the mouth of the Malmuta River at Lubans Plain in Latvia (Seglinš et al. 1999). The last mentioned Latvian sites are not independently dated by radiocarbon and the findings are biostratigraphically assigned to the first part of the Atlantic period. The earliest ^{14}C dated Cerealia t. pollen finds in the Baltic region are known from Zosu bog on the Lubans Plain in Latvia (Ilves and Medne 1979) and *Avena* t. at Duba, on the South-Eastern Plain in Lithuania (Stančikaitė 2000) and are younger, corresponding to the start of the Neolithic period. The earliest traces of cereal cultivation recorded in the Baltic coastal zone of Poland date back to ca. 5500 B.P. (4350 B.C.) (Ralska-Jasiewiczowa and Latałowa 1996).

In dealing with exceptionally early finds of Cerealia pollen the possible misidentification of pollen derived from wild grasses or the long-distance transport of these pollen grains must be kept in mind as an alternative explanation for these finds. Many reservations have been expressed by a number of authors (Beug 1961; Andersen 1979; O'Connell 1987; Levkovskaya 1987; Fægri and Iversen 1989; Dickson 1988; Moore et al. 1991), regarding the certainty of Cerealia identification. In most of these cases the main concern is that pollen derived from several wild grass genera are common(*Agropyron*, *Bromus*, *Elymus*, *Glyceria* etc.) have similar characteristics to cultivated cereals. As some of the above-mentioned wild grass are common in Estonia and connected with settlements (e.g. *Agropyron repens*) or wet areas (*Glyceria fluitans* and *G. plicata*) the possibility of misidentification is considerable. The possibility of finding long-distance transported Cerealia pollen at Akali would be negligible, taking into consideration the low pollen production and large pollen size of cereals, in combination with the high pollen production of the local species and the distance to the possible source area. Furthermore, the simultaneous appearance of *Cannabis* t. pollen and an increase in ruderal-land and meadow indicators, in combination with high palynological richness values, points clearly to human disturbance. Consequently the possible existence of wheat and hemp plants or products at the Akali settlement cannot be excluded.

During the Neolithic period human economy changed considerably, moving from a substitution basis with foraging to crop farming and cattle breading. This led to a considerable change in habitation pattern and could, therefore, be connected with the substitution and consolidation phase of agriculture in the sense of Zvelebil and Rowley-Conway (1984) in the eastern Baltic. The earliest known indisputable evidence of cultivation are remains of *Cannabis sativa* dated to the Middle Neolithic, ca. 4000 B.C. from the Sventoji area, Lithuania (Rimantiene 1999). The indirect archaeological evidence in the form of tools connected with tillage, e.g. ards (ploughs) and hoe-shaped artefacts are recorded in the Sventoji area even earlier, in connection with the Early Neolithic Narva culture settlements (Rimantiene 1999). However, the first cereal remains (*Setaria italica* and *Triticum dicoccum*) are found in the same area at ca. 3000 B.C. (Rimantiene 1999). The first cereal macrofossil remains from Latvia and Estonia are *Hordeum* remains found in the Kreiči settlement (Zagorskis 1963) and the Iru settlement (Vassar 1939) dated to ca. 2700 B.C. From Finland the first cereal finds, also in the form of *Hordeum* remains, are recorded at Turku, Niuskala (ca. 2110–1890 and 1600–1450 B.C.) ca. 500 years later than in Estonia (Vuorela and Lempiäinen 1988). Because of the long lasting (from the Mesolithic to the Bronze Age) and permanent habitation on a clearly defined island the Akali settlement can be used as a classic example of the transitional development of a prosperous foragers' habitation centre through a substitutional crop farming phase with the diminishing importance of the settlement to a hinterland of established farmers.

The start of the Neolithic at 4900 B.C. is well marked in the pollen record from Akali with the start of the continuous curve of *Hordeum* type pollen, scattered finds of *Cannabis* t. and an increase in ruderal-land indicators and palynological richness (Fig. 4). It is striking that the earliest cereal macro-remains, also considerably younger, found in Latvia, Estonia and Finland are barley. Recent investigations of the annually laminated lake Rõuge Tõugjärv, SE Estonia revealed the first *Triticum* t. pollen finds at 5000 B.C. (Veski pers. comm.). Cerealia t. pollen (probably *Hordeum* t.) accompanied by pollen of weeds and ruderals was found in sediments from the Gipka site, Kurzeme, Latvia which was occupied ca. 4300 B.C. (Vasks et al. 1999). Palynological records of an early agrarian-cattle breeding economy on the Russian plain, corresponding to the Late Atlantic, have been reported from the forest steppe zone and Middle Russian Upland by Khotinsky (1993). Finds at Pegrema village, Lake Onega, Russian Karelia (Vuorela et al. 2001) are ca. 1800 years younger. In the light of the above mentioned data it is rather difficult to confirm the existence of cereal cultivation in the Akali area, but the possibility that the crop farming could have been known to the inhabitants of the settlement through the exchange of information and goods with farming tribes from regions further south cannot be totally neglected.

During the Middle Neolithic period (4200–3100 B.C.) traces of crop cultivation at Akali are represented by scattered finds of *Avena*, *Hordeum*, *Triticum* and *Cannabis* t. pollen (Fig. 4). The increase in meadow and ruderal-land communities provides evidence of the increased human pressure on the landscape. It is notable that scattered hemp pollen finds are always connected with early Cerealia t. pollen finds at Akali. The contemporaneous finds of *Cannabis sativa* remains in the Sventoji area, Lithuania (Rimantiene 1999) confirm the possibility of hemp cultivation at Akali. According to Rimantiene (1999), the first cultivated plants adopted by Stone Age foragers were rather the useful ones (e.g. hemp) than the edible ones (e.g. cereals). Königsson et al. (1997) found Cerealia pollen in Radbelik fen (near Novgorod) sediments dated to ca. 4500 B.P., and stated: "there was very active cultivation of the soils in the Ilmen area already 4500 years ago (3200 B.C.)". The appearance of pollen derived from various cultivated crops suggests possible tillage in the area. However, the weakness and diversity of the signals and the scantiness of land naturally available for agriculture points rather to horticultural crop cultivation than to large-scale tillage.

The regression of cultivation and of general human impact indicators starts during the Late Neolithic period (3100–1800 B.C.), which is in good correlation with the archaeological results. All human impact indicators decrease and traces of cultivation disappear with exception of some *Avena* t. and *Triticum* t. pollen grains occurring up to 1800 B.C. (Fig. 4). The Late Neolithic Corded Ware culture in Estonia (one of the Battle Axe cultures) was already clearly agrarian and brought about a drastic change in economic and settlement strategies (Kriiska 2000). The present natural conditions of the Akali settlement, advantageous for hunting and fishing, were rather unsuitable for tillage and the settlement lost its importance as a habitation centre. The hinterland phase of Akali lasted ca. 2000 years, throughout the Bronze Age and the earliest part of the Iron Age. This regression period is recorded by the disappearance of cultivation indicators and a decrease in ruderal-land and meadow indicators in the pollen data (Fig. 4).

Traces of the re-exploitation of Akali appear during the later part of the Iron Age, around A.D. 500, as scattered *Secale cereale*, *Centaurea cyanus* and *Cannabis* t. pollen occurs accompanied by some increase in ruderal-land and meadow indicators. The scantiness of cultivation indicators in comparison with indicators of meadows and grazing shows that at first the area was re-occupied as additional land for grazing or hay-making. The appearance of *Plantago lanceolata* pollen, the start of the continuous *Secale cereale* curve and the reappearance of *Urtica* pollen around A.D. 1200 point to the re-colonisation of Akali. Akali island was occupied up to the 20th century and the topmost part of the island was used for crop farming and horticulture.

Conclusions

1. The pollen data, being otherwise in exceptionally good agreement with the known archaeological evidence for the settlement history at Akali bog-island, places the establishment of settlement to ca. 600 years earlier than supposed by the archaeologists.
2. The Emajõe Suursoo mire surrounding the Akali settlement site experienced considerable environmental changes during the Holocene. Paludification started in the vicinity of Akali at about 6500 B.C., was more intensive at the beginning (peat accumulation rate ca. 10 years/cm) and ceased later (peat accumulation rate ca. 19 years/cm).
3. *Triticum* t. pollen accompanied by *Cannabis* t. pollen is recorded at ca. 5600 B.C., ca. 600 years earlier than other Cerealia pollen finds known from Estonia, and can be interpreted as possible traces of the acquaintance of foragers with farming products, through contacts with South European agrarian tribes during the availability phase.
4. Various Cerealia species and hemp pollen finds at Akali can be connected to the substitution phase of crop farming during the Neolithic period, 4900–1800 B.C.
5. The regression of human presence at Akali is recorded during the second part of the Neolithic period and abandonment of the settlement took place during the Bronze Age. Natural conditions favourable for fishing, hunting and gathering were often unsuitable for arable farming and caused a reduction in importance or abandonment of former prosperous Stone Age settlements during the transfer to extensive crop farming.

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