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Shoreline Displacement and Vegetation History on Island Naissaar, Baltic Sea

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ABSTRACT

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A comprehensive study of peat and lacustrine sediments from Bletkärri Mire (Naissaar Island, Estonia) was performed using pollen, diatom and ^{14}C analyses. Naissaar Island is situated in the Gulf of Finland (about 10 km north from Tallinn) on the North-Estonian coastal plain. The objectives of this study were to determine the time of the isolation of the lagoon from the Baltic Sea, establish the developmental history of the island and to reconstruct the vegetational dynamics under natural conditions as well as under human impact during the last millennium. Due to the land uplift, prior shore lines can be observed up to a height of about 26 m a.s.l Organogenic deposits started to form in a small lagoon isolated from the Baltic Sea about 5,000 BP. Calculations show that emergence of the island started 7,500–7,700 BP during early Litorina Sea stage and areas lower than 15 m a.s.l. formed during the Limnea Sea stage. This is in good accordance with data from Hiiumaa Island and NW Estonia.

ADDITIONAL INDEX WORDS: *Shoreline displacement, pollen and diatom analysis, Baltic Sea.*

INTRODUCTION

The compilation of regional developmental schemes for the eastern part of the Baltic Sea has been made by ERONEN (1974, 1976), KESSEL and RAUKAS (1979), and others. Regional correlations of the development of the sea have been made by GLÜCKERT and RISTANIEMI (1982), KESSEL and RAUKAS (1984) and others. However, the age boundaries of some stages in the development of the Baltic Sea, determined in different regions in recent years, differ significantly from one another (RAUKAS and HYVÄRINEN, 1992). Disagreements are partly caused by diverse treatment of the stages in various areas by different authors and inadequate paleogeographical and ecological data. Above all, information on the climate and the paleosalinity in the Baltic basin is poor.

Valuable information about the development of vegetation can be obtained by studying the sediments in a relatively closed landscape unit, for example, a small island. More than a thousand small islands are situated on the northern and western coasts of Estonia. They had formed at different times because of land uplift and are in various stages of development. A wide spectrum of shoreline forms including beach ridges, sandy plains, escarpments, plains of abrasion, and sequences of lake and bog deposits offer good possibilities for the study of the history of the Baltic Sea as well as the regularities of development of climatic conditions and their influence on the vegetation.

Some of the small islands in the Estonian coastal waters were used as military bases by the former Soviet Union. They were strictly closed for scientific research, and this valuable source of paleogeographic information could not be studied until recently. Data presented here are the first that explain landscape development on Naissaaar Island.

Naissaar Island has been inhabited for a millennium. There are also a large number of historical documents since the 11th century, including land use and vegetation maps. Paleoecological methods provide ways to assess relationships between human activities and ecosystem response in rather small and closed landscape units. A comprehensive study of peat sequence from Bletkärri mire using pollen, diatoms and ^{14}C data was performed.

STUDY AREA

Naissaar Island (area 18, 6 km^2) is situated in the Gulf of Finland about 10 km north of Tallinn on the North-Estonian coastal plain in the region of Cambrian outcrops (Figure 1). A complex of Vendian and Cambrian terrigenous sediments covered with Quaternary deposits lies on the basement. The Quaternary sediments (thickness 60 m) are represented by glacial, fluvioglacial, marine and eolian deposits.

The Post-glacial development of Naissaar began in Pre-Litorina time, when the highest part of the island emerged from the sea. The following development was determined by the rates of land uplift and eustatic fluctuations of the sea level (ERONEN, 1974). As a result of these processes the different types of shorelines (beach ridges, sandy plains with dunes, escarpments and plains of abrasion) were formed. There are also some paludified areas and small mires concentrated mainly in the eastern part of the island. The highest elevation on the island is 27 m. The 20 m isobase is represented

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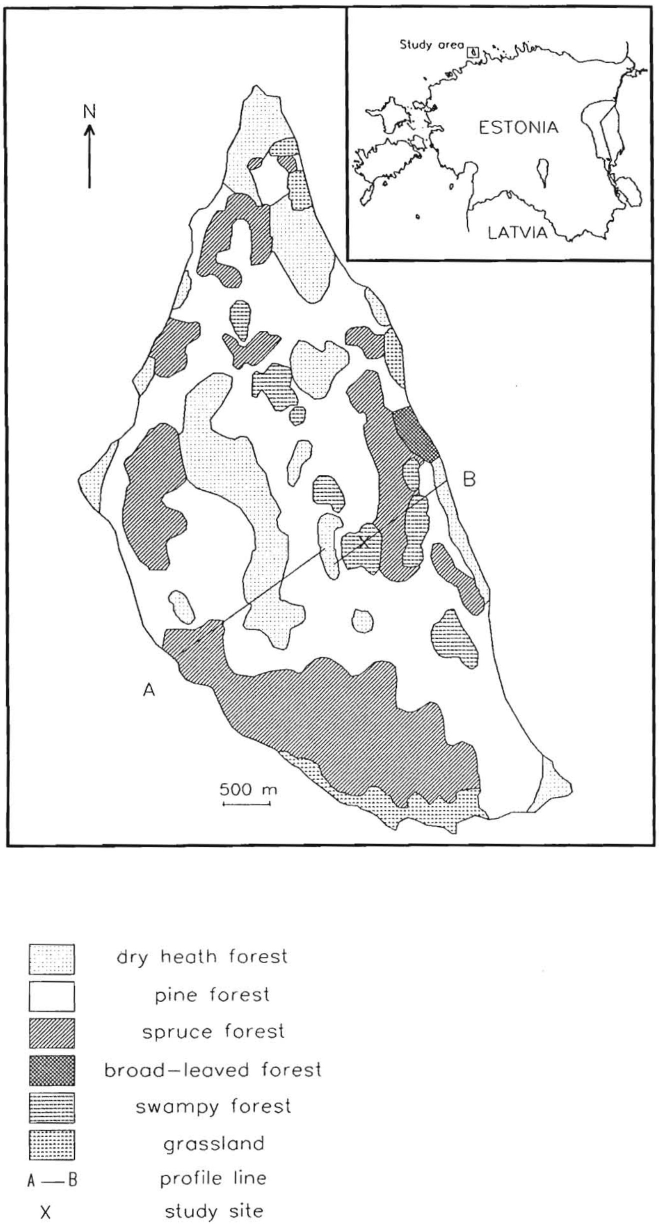

Figure 1. Location of the study area on the northern coast of Estonia.

as an abrasional terrace all around the central area of the island.

Naissaar Island is today almost entirely covered by forest (Figure 1). Pine forests with *Vaccinium vitis-idae* and *V. myrtillus* predominate. Dry heath forest with *Calluna vulgaris* and lichens spread on the coastal dunes and in the higher central part of the island. In the eastern and southern parts there occurs spruce forest with *Oxalis acetosella*. Spruce grows rarely in pure stands, more frequently it is mixed with pine and birch. Around the mires there are belts of swampy pine forests. Here and there some plots of birch-alder swamp forest can be found. Nemoral broad-leaved forest occurs in a single locality (called Danish Kings Garden) in the southwestern part of the island (Figure 1) on an area of about 5 ha. The ecosystems of the island are in rather good conditions and they deserve environmental protection. On March 31 1995 a Naissaar Nature Park was established.

Bletkärri Mire lies about 18 m a.s.l. at the foot of the highest beach ridge (Figure 2) and is built up mainly of gravel and medium-size sand. The area of the mire is about 10 ha and its surface is 20 m above sea level. The mire was formed after the isolation of a small lagoon in the course of the land uplift.

STRATIGRAPHY

Organogenic sediments lie on the marine sands with pebbles. The complex of sediments have a total thickness of 218 cm and consist of gyttja, forest peat, *Eriophorum* peat and low decomposed *Sphagnum* peat in its uppermost 70-cm part.

METHODS AND RESULTS

Pollen Analysis

Sampling was carried out with a Russian peat sampler 8 cm in diameter. The core was wrapped in polyethylene film and kept cold before subsampling for pollen and diatom analyses in the laboratory. 1- cm thick samples for pollen analysis were taken every 10 cm. Standard methods were employed to prepare the samples for pollen analysis (Moore *et al.*, 1991). The samples were mounted in glycerin and at least 500 arboreal pollen grains were counted in every sample. The pollen diagram (Figure 3) was drawn using the TILIA and TILIA GRAPH programs written by E.C.Grimm. Four local pollen assemblage zones (PAZ) were distinguished.

PAZ Na 1 (5,500–4,300 BP) 210–175 cm contains pollen of *Alnus* (up to 40%), *Betula* and *Salix*. Pollen of *Artemisia*, (Chenopodiaceae, Rosaceae, Cruciferae) are represented by high values. Pollen spectra of this kind are typical of the modern vegetation in open coastal areas and many islands of Estonia (Kokovkin and Ratas, 1992). The depression where the Bletkärri Mire developed was surrounded by coastal meadows and seashore communities with birch and alder. At the end of PAZ Na 1 remarkable changes in the pollen composition appeared. The *Alnus* content decreased rapidly and *Salix* diminished. The content of *Betula* pollen increases and reaches its maximum values in the beginning of the next zone.

PAZ Na 2 (4,300–3,000 BP) 175–125 cm. The sharp decrease in the content of herbaceous pollen speaks in favour of an increase in forestation due to shoreline displacement. During this time the share of broad-leaved trees (*Ulmus*, *Tilia*, *Quercus* and *Corylus*) reaches its maximum distribution around the site studied. The vegetation was typically coastal with shrubs, dwarf-shrubs and deciduous trees growing near the sea-shore simultaneously.

PAZ Na 3 (3,000–1,600 BP) 125–75 cm. This zone is characterized by the appearance of *Picea* and an increase of *Pinus* pollen. The share of broad-leaved trees decreases continuously. Coniferous forests became dominant, with Ericaceae species (*Calluna* and *Vaccinium*) common in the ground flora.

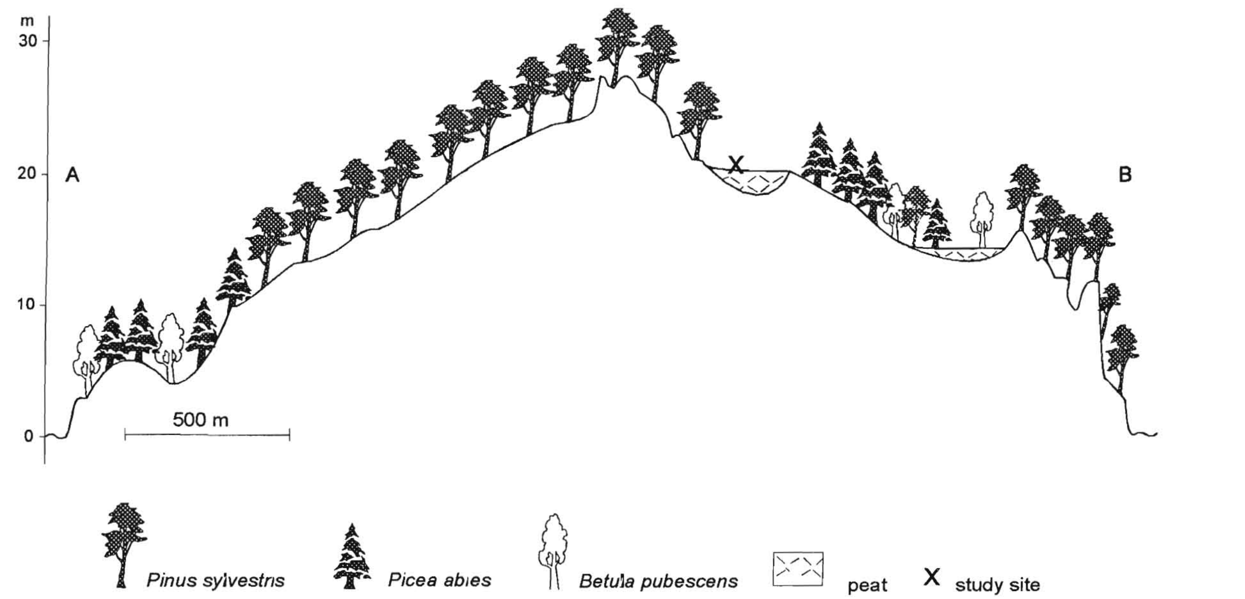

Figure 2. Profile of the Naissaar Island.

PAZ Na 4 (1,600–0 BP) 75–0 cm. Coniferous species predominate and there is an increase in the Gramineae, Cyperaceae and *Artemisia* pollen due to spatial expansion of the mire and the formation of open areas around it. Pollen of Cerealia-type, indicating land cultivation, are recorded about 1,600 BP. Weak indications in the pollen diagram suggests the existence of coastal meadows and cultivation of cereals since that time.

Diatom Analyses

The material for diatom analyses from the lowermost subsamples were prepared according to HÅKANSSON and REGNELL (1993). The subsamples were mounted in Naphrax. About 300–400 diatom valves were counted per sample. The results are presented in Figure 4.

Zone I. The paleoenvironmental reconstructions using fossil diatoms demonstrate a clear change in the flora composition at a depth of 213 cm (Figure 4). In the lowermost part of zone I the dominant taxon is *Cocconeis scutellum* Ehr. represented by over 35% of the total number of diatoms. This is an indicator of brackish-marine conditions. Other diatom taxa (*Cocconeis*, *Epithemia* and *Synedra*), represented in this zone are typical indicators of mesohalobous or euhalobous environments.

Zone II. In this zone, the diatoms typical of marine and brackish-marine water disappear quickly and the taxa *Pinnularia*, *Tabellaria* and *Eunotia* become predominant. They indicate a rapid transition from brackish marine conditions to a freshwater environment. The presence of the genus *Eunotia* suggests a stage with restricted open water and advanced paludification. *Tabellaria flocculosa* (Roth) Kütz. (up to 39%) and the oligosaprobic *Pinnularia viridis* (Nitzsch) Ehr. (up to 37%) are species characteristic of an oligotrophic freshwater environment with slightly acidic conditions (pH < 7) indicating formation of a mire.

Table 1. *Stratigraphy of the Blettkärri mire peat sequence.*

0–70 cm	*Sphagnum* peat
70–180 cm	*Eriophorum* peat
180–200 cm	forest peat
200–219 cm	gyttja

^{14}C Dating

Samples for ^{14}C dating were taken from forest peat at a depth of 188–193 cm and from *Bryales* peat at a depth of 117–122 cm (Fig. 3). The samples were dated using a conventional technique (PUNNING and RAJAMÄE, 1993). The results show that the rate of the accumulation of organic matter was rather constant at approximately 0.4 mm yr^{-1}.

DISCUSSION

The radiocarbon and diatom data show that the isolation of a small and shallow lagoon from the Baltic Sea took place 5,200–5,300 BP on a threshold of 18 m a.s.l. This is in good correlation with data from southern Finland. Near Espoo, the isolation of lake Lippajärvi with a threshold of about 20 m a.s.l. is estimated to have occurred about 5,000 BP (HYVÄRINEN, 1984). According to HYVÄRINEN *et al.* (1988) this event might be correlated with a regressive phase of the Litorina Sea (phase LIII). The coastal forms developed during this phase at heights up to 19 m (HYVÄRINEN *et al.*, 1988) are located on Hiiumaa Island (northwestern Estonia) and in northeastern Estonia.

The lagoon isolation horizon is a good indicator to establish a shore displacement curve because it helps to avoid the un-

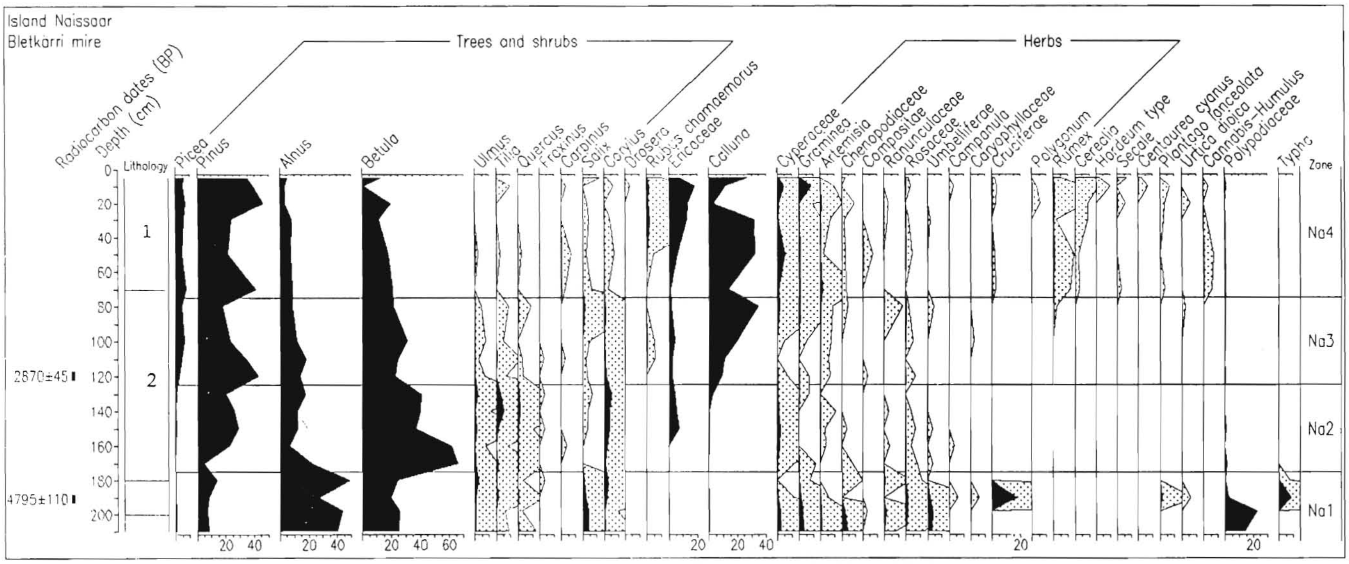

Figure 3. Percentage pollen diagram from Bletkärri Mire. 1—low decomposed *Sphagnum* peat, 2—*Eriophorum* peat, 3—forest peat, 4—gyttja.

certainties between the shoreline morphology and the ancient sea level caused by wave activities or abrasion of earlier accumulated sediments (PUNNING, 1993). Judging by the sharp transition from a brackish-marine to fresh-water diatom flora, the threshold level in Bletkärri Mire reflects exactly the isolation level.

Knowing the altitude of the threshold and the rate of the present vertical movement for the area studied, it is possible

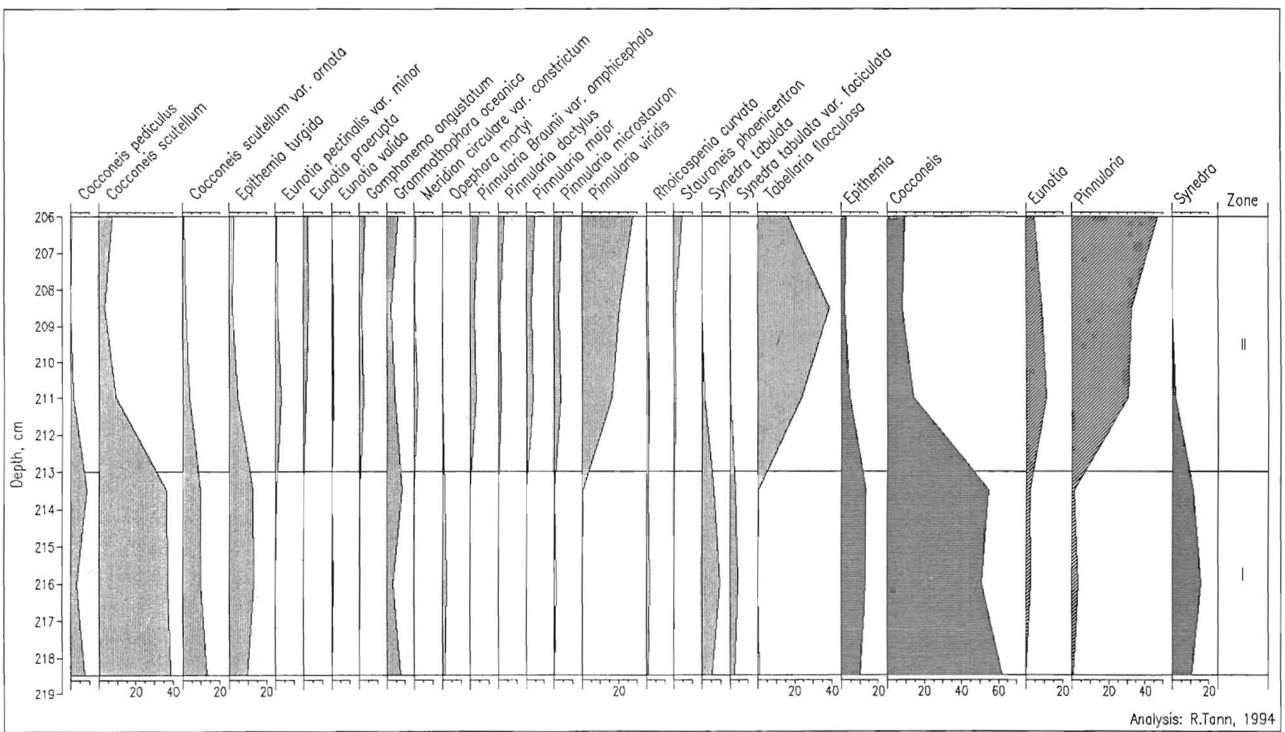

Figure 4. Diatom diagram from Bletkärri Mire.

to reconstruct the shoreline levels by using the following formula (PUNNING, 1987):

$$H_t = t \times T_0 + h_t - E, \quad \text{where}$$

H_t = the height of shorelines with respect to the present sea level;

T_0 = the rate of vertical movement at the present time;

t = time, years BP;

h_t = residual isostatic compensation;

E = the height of sea level with respect to the present one.

Calculations show that the emergence of Naissaar Island started 7,500–7,700 BP and the abrasional level at an altitude of 20 m was formed about 6,000 BP. This is in good accordance with data obtained by KESSEL (1961) and RATAS (1976) for Hiiumaa Island and northwestern Estonia showing that the coastal formations at heights about 20–26 m correspond to the phase LI and at 19 m to phase LIII. Assuming that the post—Litorina shore displacement curves for Hiiumaa and Naissaar Islands are also in accordance, the Limnea Sea shoreline limit has to be at an altitude of about 12 m (RAUKAS and HYVÄRINEN, 1992) formed about 4,000 BP.

The current topography of Naissaar Island suggests that the rate of the spatial increase of the emerged land was different in eastern and western parts of the island. In the southeastern and southern part of the island the extent of the land area has been more or less constant since the beginning of the emergence. The northern and northeastern parts of the island were reworked more intensively by abrasional processes during the Limnea Sea stage and therefore the increase of land area was less there.

The temporal and spatial regularities of the extension of the land area affected the development of the vegetation on the island. In addition to global climatic processes, the soil, pioneer vegetation and other local processes, such as the widening of the terrestrial area, exerted an essential influence upon the development of the ecosystems. Consequent changes are reflected on the pollen diagram from Bletkärri Mire (Figure 3).

The similarity of the pollen content during the PAZ Na 1 with the modern vegetation succession in the coastal areas in northern and western Estonia demonstrates that the climatic conditions do not play the primary role in the establishment of the pioneer vegetation in open coastal areas. The divergence of the open coast from the studied area, the development of soils and wetness might have been the reasons for the development of a mixed forest around the mire. In addition to climatic factors, the spatial extent of the mire and the transition of the paludified land into eutrophic *Eriophorum* mire were the reasons why deciduous trees were supplanted by coniferous trees. Today broad-leaved trees grow in the coastal areas while on sandy soils mainly *Calluna*-type dry heath forest and swampy pine forest with patches of birch on more humid soils occur.

Several authors (VUORELA, 1986; SEGERSTRÖM, 1990) have pointed out that when interpreting pollen data it must be kept in mind that grasses and many herbs normally regarded as indicators of agriculture are also common on shores or in naturally disturbed environments. Also the appearance of *Hordeum* pollen requires careful consideration as it is well known that some wild grass pollen may key out as *Hordeum*-type (WALLIN and SEGERSTRÖM, 1994).

The first signs of human impact appear on Naissaar Island in the peat layers that formed during the first centuries AD (PAZ Na 4). The appearance of Cerealia-type pollen (*Secale cereale*) and increased herbaceous pollen (Figure 3) indicate that land cultivation and cattle breeding were conducted on the coastal plains and meadows about 1 km from the studied site. The frequency of anthropogenic indicators in the pollen diagram may be explained also by changes in the openness of the landscape caused by frequent forest fires or clearance. There is ample evidence of both fires and logging in historical records.

CONCLUSION

(1) A comprehensive study of a sediment sequence from Bletkärri Mire on Naissaar I. (Baltic Sea) shows that the isolation of the studied basin with a threshold level at 18 m took place about 5,200 BP. This is in good accordance with data obtained for areas with a similar rate of land uplift.

(2) The rates of the spatial increase of the emerged land in the northeastern and southwestern parts of Naissaar Island were different. In the southwestern and southern parts of the island the extent of the land area has been stable since the beginning of the emergence. The northern and northeastern areas of the island were formed mainly during the Litorina Sea stage. The limit of the Limnea Sea is situated at the 15 m isobase.

(3) The development of the vegetation around the Blettkärri Mire was to a great extent determined by the postglacial evolution of the landscape, especially by the retreating of the shore line and the spatial growth of the mire.

(4) Human impact is reflected by the appearance of the Cerealia-type pollen and pollen of disturbance indicators about 1,600 BP.

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