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Early Holocene coastal settlements and palaeoenvironment on the shore of the Baltic Sea at Pärnu, southwestern Estonia

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Abstract

Studies were conducted on 16 sections of buried organic matter (pre-Ancylus Lake and pre-Litorina Sea) and associated Stone Age cultural layers in the Pärnu area, southwestern Estonia. Buried organic beds are each part of a sedimentary sequence, which is repeated, forming two overlying sets of an orderly succession of five layers. The organic sedimentation of the lower set (set 1) occurred about 10,800–10,200 years BP, and that of the upper set (set 2) about 9450–7800 years BP. Associated with set 1 is the Early-Mesolithic settlement of Pulli, and with set 2 are the Stone Age cultural layers at Sindi-Lodja. The Early- and Middle-Mesolithic sites in Estonia are concentrated on shores of rivers and lakes to utilise of a variability of resources. The hunters and fishermen followed the ancient Pärnu River downstream to the receding shoreline of the Yoldia Sea. After about 10,700 years BP, they were forced to retreat inland in front of the transgressive Ancylus Lake shore which first inundated the Paikuse area about 10,400 years BP, and Pulli and higher sites about 10,200 years BP. The total amplitude of the transgression preceded 11 m and reached up to 14 m a.s.l. in the area. The Litorina Sea transgression reached 7 m a.s.l. after 8000–7800 years BP. The Mesolithic, Neolithic and modern sites on top of each other in the Pärnu area may suggest that, although years apart, they were inhabited by the same group of people who stayed in the area and moved back and forth together with the shifting shoreline of the Baltic Sea.

1. Introduction

The ever-changing Baltic Sea influences our life. It is out of the question that it did not do the same in the past. One of the prime interests of Quaternary geologists around the Baltic is to detect the environmental changes in the shifting coast of the Baltic Sea Basin, while archaeologists make efforts to investigate how people adapted to the fluctuating sea-level, how Stone Age people managed and manipulated the animal and plant resources of the water bodies, and to what extent was their impact on the local environment. Thus, it is vital to have information on the location of the changing coastline at different times in the past. To find answers to these questions, we need effective collaboration between archaeologists and the scientists dealing with palaeoenvironmental studies. This interdisciplinary study is directed to solve some of the problems.

Several investigated vertical sections exposed along the Pärnu River in southwestern Estonia provide high-resolution records for bio-and chronostratigraphical, geological, archaeological and palaeogeographical reconstructions of the interaction of man and environment during the early phases of the Baltic Sea in the area. Southwestern Estonia is characterised by slow post-glacial isostatic uplift and the landscape is relatively flat. Therefore, even small increases in sea level can easily lead to the flooding of substantial areas. The complex deglaciation history of the Baltic Sea area, with dammed lakes and early phases of post-glacial seas has, at times,

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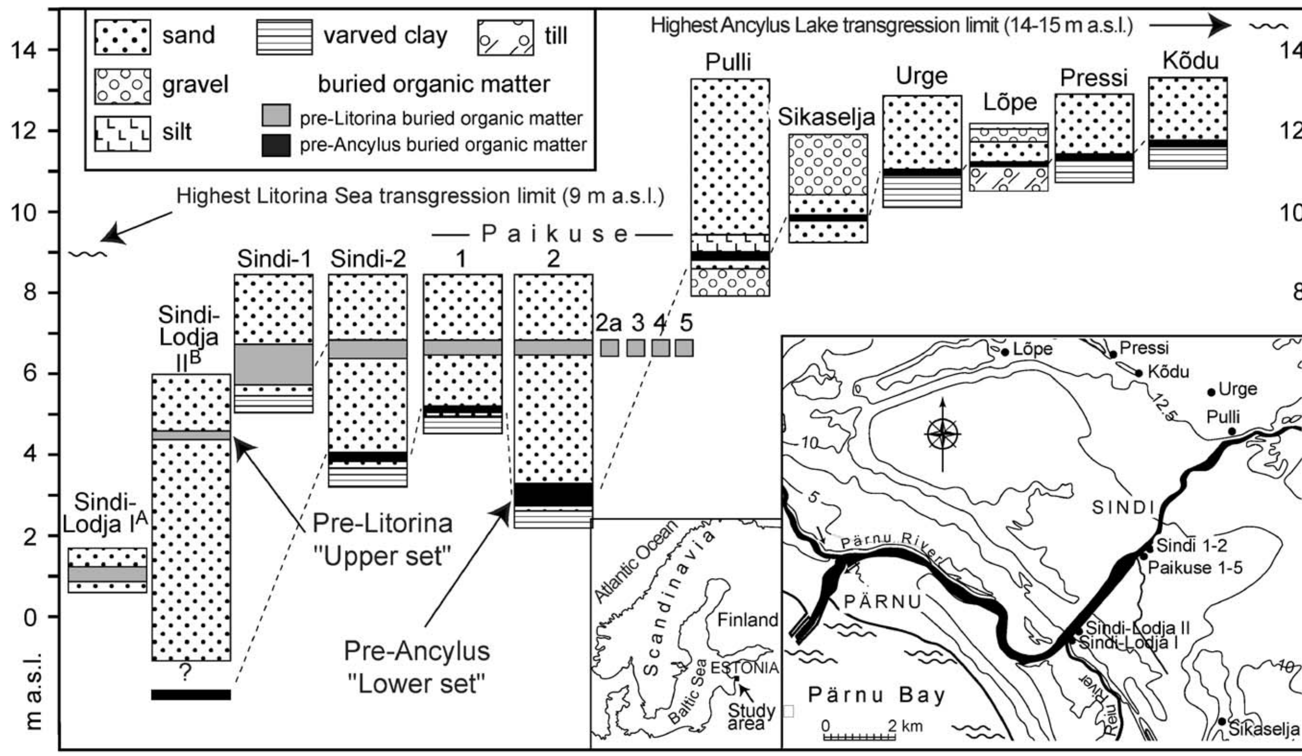

Fig. 1. Location of the study sites in the Pärnu area and a simplified geological cross-section. Buried organic matters represent either the pre-Ancylus Lake or pre-Litorina Sea lowstand and terrestrial accumulation (peat/cultural layers). Pulli and Sindi-Lodja are Stone Age settlement sites.

left southwestern Estonia submerged below the level of Baltic Sea basin, while at other times, it emerged as terrestrial land. Therefore, transgressive deposition of water-laid sediments of the Ancylus Lake or the Litorina Sea have led to repeated burial of peat and/or gyttja deposits and associated archaeological settlement layers (Fig. 1). Some sections expose even two or more such buried beds.

The human history of southwestern Estonia is characterised by numerous Stone Age settlements (Kriiska, 2001a). The Pulli site contains the earliest trace of human activity in Estonia as it was occupied by Stone Age hunters and fishermen about 11,200–10,200 years ago (Jaanits and Jaanits, 1975, 1978; Selirand and Tõnisson, 1984; Lõugas, 1997; Poska and Veski, 1999).

2. Methods

Vertical sections exposed along the Pärnu River and nearby were studied by a complex set of geological and archaeological methods: litho-and archaeostratigraphy, altitude levelling, archaeological excavations, typology, radiocarbon dating, loss-on-ignition, pollen, diatom and archaeo-osteological analyses. Preparation of samples for microfossil analysis (diatoms and pollen) followed standard methods (Battarbee, 1986; Berglund and Ralska-Jasiewiczowa, 1986). Radiocarbon dating follows conventional liquid scintillation on bulk or wood material, and AMS dating on terrestrial material. All the ages used in this study refer to calendar years, calibrated from radiocarbon ages using the OxCal 3.5 program and the 1σ range.

3. Investigated sites

3.1. Lithostratigraphy

The lower reaches of the Pärnu River are known for extensive layers of buried organic matter. We have studied 16 sections (Fig. 1; Table 1) within a 40 km^2 area. In principal, the lithostratigraphy of those sections follows a standard description and position of strata is given as altitudes from the modern sea-level (m a.s.l.). Buried organic beds occur at several intervals, namely, an upper organic bed, up to 100 cm thick, and a lower organic bed, up to 60 cm.The two buried peat beds are seemingly each part of a sedimentary sequence which is repeated, forming two overlying sets of an orderly succession of five layers. From the bottom upwards, each set starts with (1) a thin layer of sand, followed by (2) a peat bed (or cultural layer of an archaeological settlement site), in turn followed by (3) laminated silt and sand with thin organic layers, grading upwards to

Table 1
Investigated sections of buried organic layers

Site	Coordinates	Altitude of the buried organic matter (base)				Analyses[a]
		Lower set (L2)		Upper set (U2)		
		m a.s.l.	Thickness	m a.s.l.	Thickness	
Sindi-Lodja I[a]	58°22′N; 24°35′40″E			1.0	0.3	P, ^{14}C, A, O
Sindi-Lodja II[b]	58°22′10N; 24°35′50″E	−1(?)	?	4.4	0.35	^{14}C, A, O, D
Sindi-1	58°22′40″E; 24°36′40″E			6.0	1.0	P, ^{14}C
Sindi-2	58°23′05″N; 24°37′30″E	4.0	0.2	6.2	0.25	P
Paikuse 1	58°22′50″N; 24°37′E	5.13	0.11	6.68	0.14	P, ^{14}C, D
2	58°22′52″N; 24°37′05″E			6.6	0.3	^{14}C
2a	58°22′52″N; 24°37′05″E			6.55	0.35	^{14}C, D
3	58°22′54″N; 24°37′05″E			6.87	0.2	D
4	58°22′56″N; 24°37′05″E			6.87	0.22	D
5	58°23′N; 24°37′10″E			6.99	0.4	D
Pulli	58°25′10″N; 24°40′20″E	9.0	0.2			P, ^{14}C, A, O, D
Sikaselja	58°21′N; 24°40″E	10.0	0.1			
Urge	58°25′40″N; 24°39′30″E	11.0	0.15			^{14}C
Lõpe	58°26′30″N; 24°35′30″E	11.1	0.18			^{14}C, P
Pressi	58°27′N; 24°36′30″E	11.5	0.1			^{14}C, P
Kõdu	58°27′30″N; 24°37′50″E	13.5	0.18			^{14}C, P

[a] P—pollen; ^{14}C—radiocarbon analyses; A—archaeology; O— osteology; D—diatoms. [b] ^{14}C analyses.

(4) organic-poor sand on which (5) dune deposits or a soil profile is developed (Fig. 2).

The lower set rests unconformably over sand and gravel above varved clay and ends upwards with a podzolised sand. The lower buried organic beds range from 3 m a.s.l. at Paikuse-2 to about 13 m a.s.l. at Kõdu. There are indications of a ''lower'' peat at Sindi-Lodja.

The upper set rests unconformably above the lower one and terminates upwards with the modern soil cover. There is a pronounced 1-cm sand layer in the upper pre-Litorina Sea peat at all Paikuse sections. The upper buried organic beds range from 0.5 m a.s.l. at Sindi-Lodja I to about 7 m at Paikuse.

Layers 1–5 vary in thickness between the two sets, and between the 16 sections. The buried organic layers represent the pre-Ancylus Lake and the pre-Litorina Sea organic beds or sets. The sites also differ from each other by the number of sets they contain: some have only the pre-Ancylus Lake layers, some only the pre-Litorina Sea ones, and some have both. Most of the sites are natural, i.e. no archaeological artefacts have been found. Pulli and Sindi-Lodja I–II are Mesolithic settlement layers contemporaneous to the natural layers.

3.2. Chronology

The organic sedimentation of set 1 (the pre-Ancylus Lake organic layers L2) occurred about 10,800–10,200 years BP, if AMS dates on terrestrial material and conventional ones on wood and charcoal are considered (Table 2). The range is 11,200–10,200 years BP if all dates are taken into account. The organic layer at Paikuse about 5 m a.s.l. is somewhat older (10,750–10,400 years BP) than the one in Pulli about 9 m a.s.l.

The organic sedimentation of set 2 (the pre-Litorina Sea organic layers U2) occurred time transgressively about 9450–7800 years BP. Again, the lower organic layers are considerably older (9450–8400 years BP) than those on greater altitudes (8500–7800 years BP). We prefer the AMS dates on terrestrial material and conventional dates on wood and charcoal.

3.3. Archaeology

The Pulli Early Mesolithic settlement site contains the earliest trace of human activity in Estonia. Stone Age hunters and fishermen occupied the site about 11,200–10,200 years BP (conventional dates on organic matter from the cultural layer, Table 2). Recent AMS dates on charcoal, terrestrial seeds and elk bone have placed the settlement site to about 10,800–10,200 years BP (Poska and Veski, 1999). The somewhat older conventional dates might date the organic layer, when AMS dates on archaeological material date the settlement itself. In that context, it is important to note that both AMS and conventional dates on charcoal from the fireplaces at Pulli coincide well and date back to 10,800–10,300 years BP. According to the characteristics of the settlement layer, archaeological and osteological find material from Pulli the site was seasonally occupied over several years for hunting elk and beaver, and fishing pikeperch and bream (Lõugas, 1997). The archaeological find material is quite sparse (2–3 artefacts/m^2) and contains mainly flint scrapers, burins and arrowheads, but also bone and antler objects. Two-third of the flint is high-quality dark

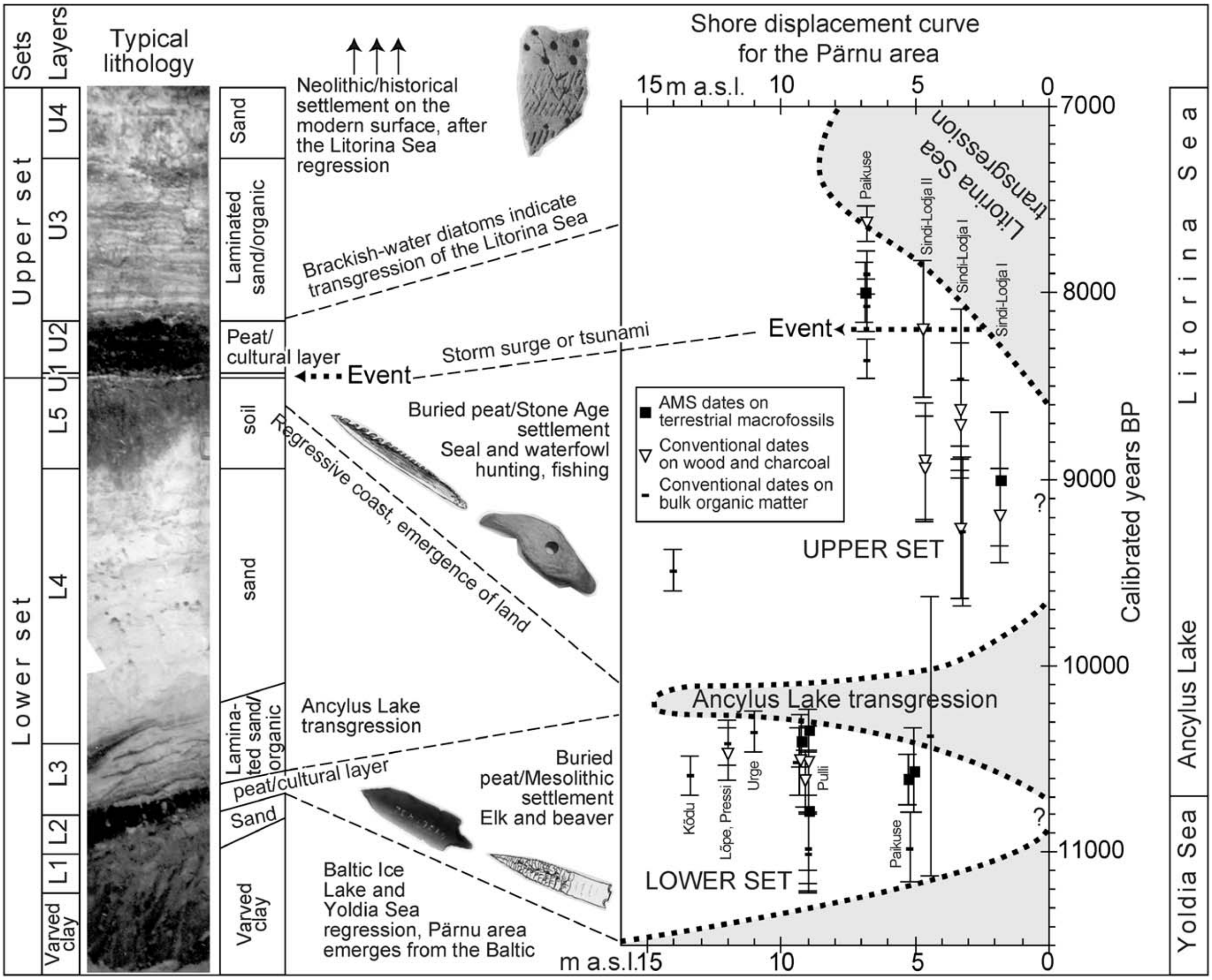

Fig. 2. Shore displacement curve for the Pärnu area, with indications to lithostratigraphy, chronology, and archaeological and geological events.

flint from Southern Lithuania and North Belarus (Jaanits et al., 1982).

Sindi-Lodja I and II settlements, south–west from Pulli at the convergence of Reiu and Pärnu rivers, were discovered in 2000 (Kriiska, 2001a). The Sindi-Lodja II Middle-Mesolithic cultural layer at 4.5 m a.s.l. and about 6 m below the contemporary land surface dates to 9100–8000 years BP (Table 2). The Sindi-Lodja I settlement contains two Mesolithic cultural layers at about 1.5 and 3 m, which date at 9200–8800 years BP, and a Neolithic/Historic layer at ground level. Associated with these cultural layers (buried organic matter) are numerous Middle-Mesolithic artefacts (mainly small flint artefacts and scrapers). The majority of flint (grey) seems to be of local provenance, a smaller part of the flint (dark) is imported. The origin of the latter is thought to be the same as from Pulli. The thick and rich in finds Mesolithic cultural layers at Sindi-Lodja suggests year-round habitation.

Numerous Stone Age artefacts have also been found by dredging the bottom of Pärnu River between Pulli, the river-mouth of Reiu, and up to Pärnu, indicating the erosion of cultural layers by the rivers. These finds are mainly bone and antler objects (Indreko, 1948).

3.4. Fauna history

The bone material from Pulli Early Mesolithic site was dominated by beaver (50% from mammal bones) and elk (44% from mammal bones) followed by brown bear and wild boar. Some bone fragments came from roe deer, red deer, marten, otter, wolf and domestic dog (Table 3). Somewhat surprisingly wild boar, roe and red deer occur in the Preboreal material. The ecology of these species is more dependent on broad-leaved forests, but probably the water meadows of riverbanks and the environment near estuaries offered good habitat for these species. They occupy the so-called marginal

Table 2
Radiocarbon chronology of the investigated sites

Set/Site	^{14}C age, uncalibrated years BP	Lab. code[a]	Altitude, m a.s.l.	Dated material	Calibrated age, years BP, 1σ	reference
Lower set (L)						
Paikuse	9575±90	TA-2547	5.2–5.1	Peat	11,160–10,790	Veski (1998)
	9350±75	Ua-11691	5.23	Wood	10,740–10,520	Veski (1998)
	9340±130	Ua-12446	5.05	Seeds	10,750–10,410	Veski (1998)
Pulli	9095±90	Ua-13352	9.00	Elk bone	10,460–10,230	Poska and Veski (1999)
	9385±105	Ua-13351	8.95	Charcoal	10,800–10,450	Poska and Veski (1999)
	9145±115	Ua-13353	9.27	Seeds	10,480–10,260	Poska and Veski (1999)
	9575±115	TA-176	9	Cult. layer	11,170–10,790	Kessel and Punning (1969b)
	9300±75	TA-175	9.3	Peat	10,640–10,440	Kessel and Punning (1969b)
	9350±60	TA-949	9	Charcoal	10,730–10,530	Jananits and Jaanits (1978)
	9600±120	TA-245	9	Cult. layer	11,210–10,800	Punning et al. (1971)
	9285±120	TA-284	9.3	Charcoal	10,640–10,290	Ilves et al. (1974)
	9620±120	Hel-2206A	9	Soil, INS	11,220–10,800	Halia and Raukas (1992)
	9290±120	Hel-2206B	9	Soil, SOL	10,650–10,320	Halia and Raukas (1992)
Urge	9125±85	Tln-1691	11	Peat	10,460–10,260	Raukas et al. (1995b)
Lõpe	9215±70	Tln-1631	11.2	Peat	10,480–10,290	Raukas et al. (1995a)
	9260±70	Tln-1632	11.2	Wood	10,610–10,330	Raukas et al. (1995a)
Pressi	9135±70	Tln-1991	11.5	Peat	10,450–10,260	Raukas et al. (1999)
Kõdu	8480±90	Tln-66	13	Peat	9600–9470	Kessel and Punning (1974)
	9340±45	Tln-1993	13	Peat	10,690–10,540	Raukas et al. (1999)
Upper set						
Sindi-Lodja I, II	7300±150	Ta-2785	4.7	Wood	8380–8010	
	7630±120	Ta-2783	3.33	Peat	8640–8270	
	7780±120	Ta-2737	3.3	Wood	8810–8450	
	7870±80	Ta-2774	3.3	Wood	8830–8590	
	7980±100	Ta-2736	4.65	Wood	9060–8750	
	8035±80	Ta-2788	4.65	Wood	9080–8800	
	8070±70	Ua-17013	1.8	Charcoal	9180–8820	
	8190±80	Ta-2789	3.3	Wood	9320–9070	
	8210±80	Ta-2786	3.3–3.2	Wood	9450–9080	
	8250±150	Ta-2787	3.25–3.2	Peat	9480–9080	
	9170±200	Ta-2784	4.45	Cult. layer	10,750–10,000	
Sindi	6710±110	TA-55	7	Wood	7720–7530	Kessel and Punning (1969a)
	7215±90	TA-133	7	Peat	8210–7990	Punning et al. (1977)
Paikuse	7535±80	Tln-2603	7.0	Peat	8460–8250	
	7120±120	Ua-12447	6.85	Seeds	8080–7840	Veski (1998)
	7030±120	TA-2548	6.6–6.7	Peat	8010–7780	Veski (1998)

[a] TA (Ta)—^{14}C Laboratory, Tartu University, Estonia; Tln—^{14}C Laboratory, Institute of Geology at Tallinn Technical University, Estonia; Hel—Radiocarbon Dating Laboratory, Helsinki University, Finland; Ua—Ångström Laboratory, Uppsala University, Sweden.

zone (an area between forest and water) as usually Stone Age people did. All mentioned herbivores need shrubs and young stand, which is available at lake and riverbanks, and wetland edges. The feeding ecology of wild boar is dependent on hazel groves and the thick humus layer, which contains worms and molluscs, around them. The pthe opulation of pikeperch (95% of fish bones at Pulli) in the eastern Baltic Sea basin was probably already at that time isolated from the rest of group, which live in inland lakes (i.e. Lake Võrtsjärv and Lake Peipsi), and formed their own characters. There were many bird bones in the osteological material. Only one species was identified so far (diver), but probably most of them came from waterfowl.

Bones from Sindi-Lodja I and II sites were badly preserved and the amount was small. Therefore, the conclusions are preliminary and the relative importance of one or another species can change after recovering more samples. It seems that together with hunting of terrestrial mammals like elk and wild boar, the settlers of Sindi-Lodja were oriented to seal hunting and pikeperch fishing (Table 4). The ringed seal's ecology is related to littoral zone of water bodies. It can even go up to rivers to feed, especially rivers, where the whitefish (powan) spawns. People did not have to go far from the coast to catch ringed seal and pikeperch. Populations of pikeperch and powan are still in Pärnu bay and river, and the ringed seal is not a rare visitor there either.

Table 3
Animal bones from the Pulli site

Species	MNI	NF
Beaver (*Castor fiber*)	30	500
Elk (*Alces alces*)	25	447
Roe deer (*Capreolus capreolus*)	2	2
Red deer[a] (*Cervus elaphus*)	1	2
Wild boar (*Sus scrofa*)	7	17
Brown bear (*Ursus arctos*)	8	34
Wolf (*Canis lupus*)	3	3
Dog (*Canis lupus* f. *familiaris*)	2	3
Marten (*Martes martes*)	1	1
Otter (*Lutra lutra*)	2	2
Red-throated diver[a] (*Gavia stellata*)	1	1
Pikeperch[b] (*Stizostedion lucioperca*)		94
Bream[b] (*Abramis brama*)		5

MNI—minimum number of individuals; NF—number of fragments.
[a] Identified by Kalju Paaver, Lembi Lõugas.
[b] Identified by Janis Sloka Lõugas, 1997.

Table 4
Animal bones from Sindi-Lodja (SL) I and II Stone Age settlement layers (identified by L. Lõugas)

Species	NF from SL I	NF from SL II
Elk (*Alces alces*)	3	
Wild boar (*Sus scrofa*)	6	2
Wolf or Dog (*Canis* sp.)	1	
Beaver (*Castor fiber*)	1	
Ringed seal (*Phoca hispida*)	6	3
Pikeperch (*Stizostedion lucioperca*)	20	6
Whitefish (*Coregonus* sp.)	1	
Pike (*Esox lucius*)	3	
Aves indet.	1	4

NF—number of fragments.

4. Vegetation history

4.1. Lower set

The till, varved clays and coarse sand and gravel below the lower peat bed is devoid of pollen but do contain abundant seed grains of *Schoenoplectus lacustris* and minor amounts of seed grains of *Nuphar lutea*, *Potamogeton* sp. (most probably *P. natans*), *Menyanthes trifoliata*, *Carex* spp. and Apiaceae (Heinsalu et al., 1999). The pollen content of the lower peat beds differs greatly from site to site, mostly in connection whether the site was inhabited by man or not.

The lower peat bed at Paikuse for instance is dominated by a *Salix* and *Betula* assemblage (Fig. 4). Lumps of *Salix* and *Betula* pollen grains, which have stuck together, suggest that the grains are of very local provenance and that the assemblage probably reflects the surrounding vegetation, a closed cover with *Salix* and *Betula* dominating the tree or shrub community. This is in accord with the very low NAP count. Similar local assemblages of pollen grains, as suggested by their lumping, are observed elsewhere in Preboreal peats (Veski, 1998). At Lõpe (Raukas et al., 1995a), Kõdu, and Pressi, the type of vegetation is a rather open *Betula*-*Pinus* forest.

The pollen content in the cultural layers differs remarkably from the natural ones. In the cultural layer at Pulli the AP and NAP values are equal showing the existence of open landscape with *Pinus* and *Betula* which dominate among the trees (Fig. 4). The NAP from the cultural layer is represented by a high variety of different ruderals and meadow indicators (Fig. 5), for example a large amount of *Artemisia*, Asteraceae (such as *Achillea*-type, *Cirsium*-type, *Solidago*-type) and Chenopodiaceae pollen, appearance of *Urtica*, *Rumex acetosa/acetosella*-type, Apiaceae and different Fabaceae (such as *Vicia cracca*-type and *Trifolium*-type) (Poska and Veski, 1999).

4.2. Upper set

The pollen grains from the peat bed of the upper set at Paikuse are mostly *Pinus*, *Betula* and *Alnus* and, with high NAP composed mainly of Poaceae and Cyperaceae. The presence in minor amounts of *Filipendula*, Rosaceae, Apiaceae, *Typha angustifolia/Sparganium* and *Equisetum* is indicative of a damp environment. In the sand layer above the peat bed, the presence of pollen indicative of aquatic environments, as well as the presence of algae such as *Hystrix,* suggest periodical flooding by brackish water.

Similar to Paikuse the pollen content of the pre-Litorina Sea peat bed at Sindi-Lodja is dominated by *Betula*, *Pinus* and *Alnus*. Thomson (1929) described those pre-Litorina peat beds in Pärnu region as early as 1929, and H. Kessel (unpublished manuscripts) gave a comparable pollen description with *Betula*, *Pinus* and *Alnus* communities.

5. Palaeoenvironmental conditions

5.1. Lower set

Diatoms are microscopic unicellular algae that are increasingly being utilised as indicators of environmental change because they are abundant in all aquatic environments and are highly sensitive to water quality changes (Stoermer and Smol, 1999). No diatoms were recovered from most of the lower parts of the sections. The first diatoms are found in layer 4 (Fig. 2) of the lower set at Sindi-Lodja II. The sandy layer contains many littoral epipsammic diatoms (living attached to sand and silt grains), including *Fragilaria* species, *Martyana martyi*, *Karayevia clevei*, *Cocconeis disculus* and *Cocconeis neodiminuta*. Also large-lake diatoms,

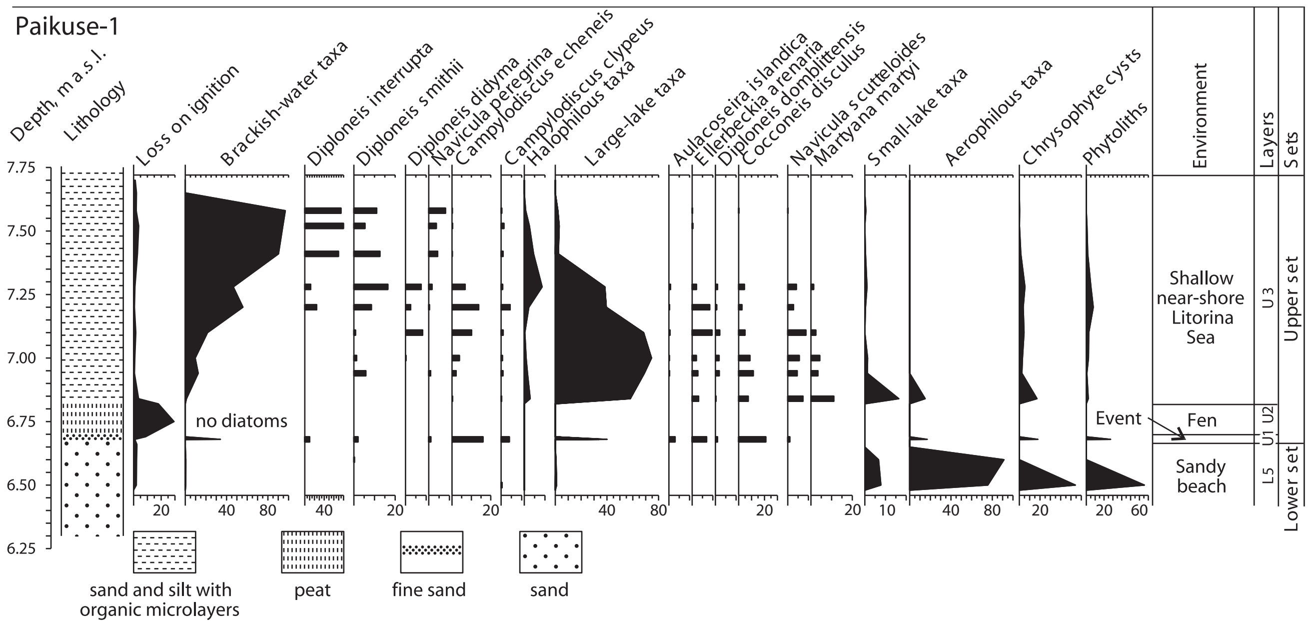

Fig. 3. A summary diatom diagram for Paikuse sediment sequence. Diatoms are grouped according to salinity and ecological preferences. Predominant brackish-water and large-lake diatom species are added to the diagram. The fine sand layer containing brackish-water diatoms represents an exceptionally high storm surge or tsunami-type event.

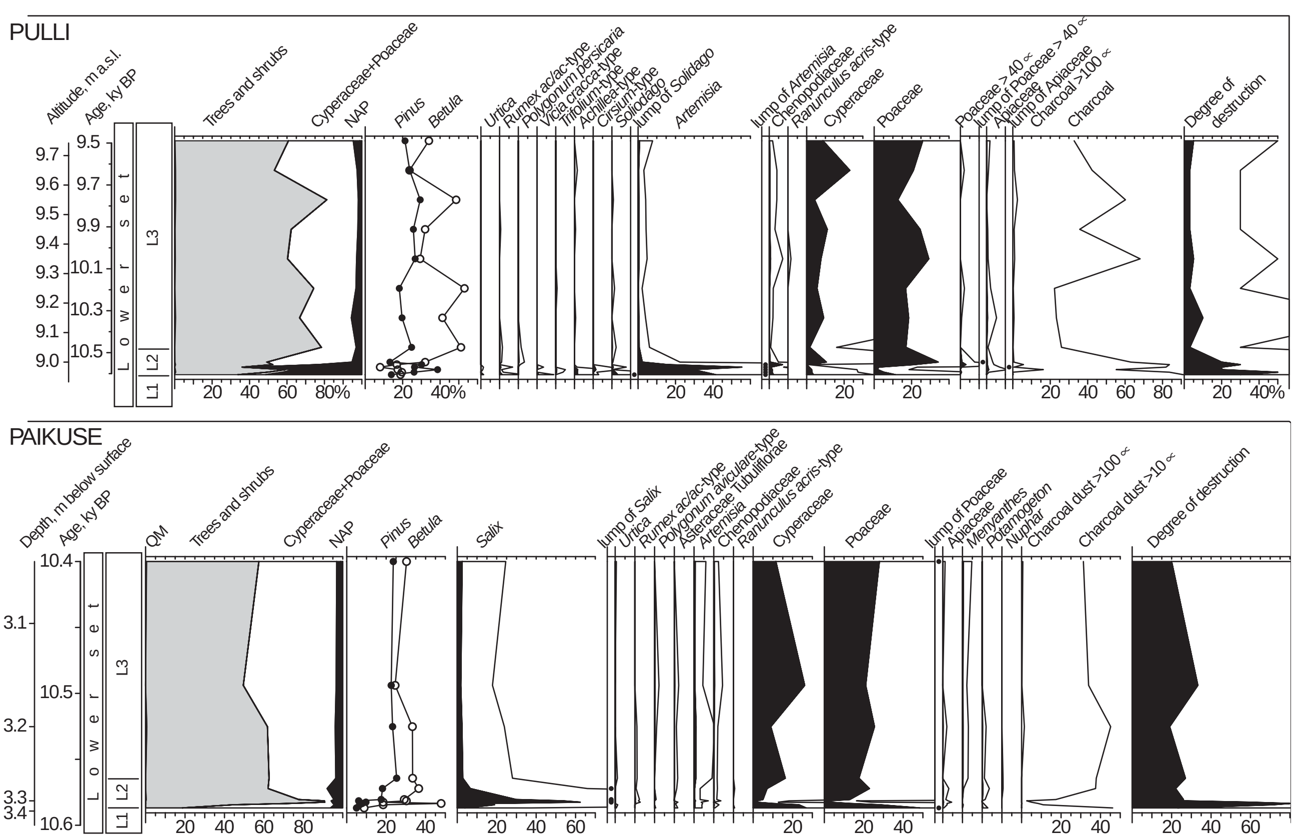

Fig. 4. Summary pollen diagrams for Pulli (Mesolithic settlement) and Paikuse (no human inhabitants) sediment sequences. For stratigraphic interpretation of the layers and sets see Fig 2.

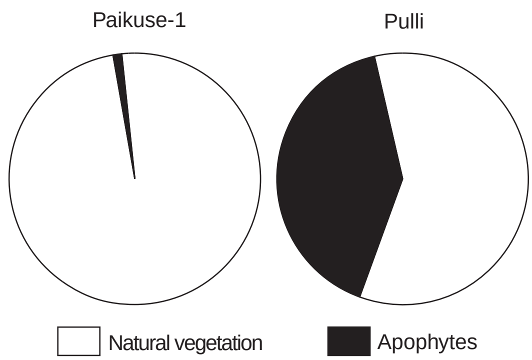

Fig. 5. Simplified pollen diagrams for Pulli (Mesolithic settlement) and Paikuse (no human inhabitants) sediment sequences encompassing the mean pollen sum of each of the buried organic layers. The proportion of apophytes (indigenous taxons of plants preferring moderate to strong human impact and/or communities changed by human activities) in Pulli is considerably larger than in Paikuse.

typical for the Ancylus Lake such as *Aulacoseira islandica*, *Diploneis domblittensis* and *Ellerbeckia arenaria* occur, the last one favours littoral areas, sandy bottoms in particular. This diatom assemblage suggests shallow coastal freshwater environment with widespread sandy deposits on the Ancylus Lake floor. Increasing abundance of littoral diatoms in the upper part of the sand section is interpreted as recording lowering water-level in the basin. Additional evidence for the shoreline regression has been found at Paikuse (Fig. 3). The upper part of the sands in layer 4 underlying the pre-Litorina Sea peat bed contains aerophilous taxa, e.g. *Pinnularia lata* and *Hantzschia amphioxys*, together with abundant chrysophycean cysts and phytoliths. Microfossil evidence implies that upper part of the layer 4 represents sedimentation on a sandy beach. A high abundance of chrysophycean cysts suggests some nutrient poor freshwater pools probably remained on the sandy coast of the retreating Ancylus Lake. A high number of phytolith fossils support the terrestrial environment, as does the existing diatom and chrysophyte cysts record. The largest concentration of phytoliths is in Poaceae and Cyperaceae.

5.2. Upper set

Hardly any diatoms are found in the upper peat bed. In layer 3, directly above the peat bed at Paikuse, diatoms are abundant. In the lower part of layer 3, the assemblages are dominated by large-lake species, but the amount of brackish water species increases progressively upwards to become the dominant assemblage. The most common brackish water species are littoral *Diploneis interrupta, D. smithii*, *D. didyma*, *Campylodiscus echeneis* and *Navicula peregrina*, whereas planktonic diatoms are entirely missing. Diatom record exhibits saline shallow water conditions in the area. At Sindi-Lodja II, sands above the pre-Litorina Sea cultural layer contain brackish-water diatoms predominated by *Catenula adhaerens*. This tiny diatom, often forming ribbon-shape colonies, lives attached to sandy grains. Epipsammic *Planothidium delicatula*, *Cocconeis neothumensis* and *Fragilaria* spp. are also common indicating shallow near-shore conditions with a sandy bottom. The salinity in these coastal areas was higher than it is today.

6. The Baltic Sea and coastal settlement during Early Holocene

The peat beds and settlement layers of the Pärnu area are at altitudes of about 0–13 m a.s.l. Since the sections are located in that part of Estonia which lies close to the isostatic hinge line where uplift was near-zero, the Pärnu area is susceptible to record even minor changes in relative water levels of the successive post-glacial water bodies in the eastern Baltic Sea basin. In the sections, each set of layers represents a succession of a regressive phase, exposing the site to terrestrial conditions, followed by a transgressive phase, where the site was either submerged or within a littoral or near-shore zone. Therefore, the described sections record three regressive phases, interrupted by two transgressive phases. The modern soil zone represents the base of a third set, the present terrestrial conditions at the sites. Based on the available archaeological and chronological information, the bio-stratigraphic palaeoenvironmental indicators, and the sedimentology of the successive layers, we propose the following interpretation for the Pärnu area.

6.1. Lower set

The lower set records the regression of the Baltic Ice Lake and the Yoldia Sea and the transgression by the rising water levels of the Ancylus Lake (Fig. 2). The drainage of the Baltic Ice Lake that lowered the water level approximately 25 m (from 42 to 17 m a.s.l. in the area) to the ocean level occurred at some 11,600 years BP (Björck, 1999). The varved clay at the base of several sections was deposited in the Baltic Ice Lake. The coarse sand and gravel overlying the varved clay probably deposited as the shoreline of the receding Yoldia Sea swept across the area (Fig. 2). The moderate land uplift in south-western Estonia surpassed the eustatic rise of the Baltic Sea basin and the shoreline near Pärnu area, thus, was regressive during the whole Yoldia Sea stage. The abundant seeds of aquatic macrophytes at Paikuse suggest shallow freshwater conditions. As the sand grades upward into the peat/soil together they represent a rapid sequence of emergence followed by the growth of a woody fen type of peat or fully terrestrial conditions at archaeological sites. The vegetation type at that time is probably *Betula–Salix* thickets and Bryales moss on wet mineral substrates (Paikuse, Lõpe, Kõdu and Pressi) and a rather open landscape in the vicinity of settlements (Pulli). As a comparison, in Hanö Bay, southern Sweden, the Baltic level was 15 m below present sea level and coastal lagoons existed 10,800 years BP (Björck and Dennegård, 1988). The environment was rather similar to the Estonian sites at Pärnu (Gaillard and Lemdahl, 1994) with the exception of settlement sites (Figs. 4 and 5).

The Early- and Middle-Mesolithic sites in Estonia are concentrated on shores of rivers and lakes to utilise a variability of resources. The main economy at Pulli was elk and beaver hunting and pikeperch fishing. Fishing of pike and perch was more important at other Mesolithic sites in Estonia. The hunters and fishermen probably followed the ancient Pärnu River downstream and the receding shoreline of the Yoldia Sea. Later, since about 10,700 years BP, they were forced to retreat inland in front of the transgressive Ancylus Lake shore. Probably the estuarine environment with especially varied resources attracted people to move with the changing coast. Thus, there is a possibility to find new Early Mesolithic sites associated with the buried organic beds from Pulli all the way down to the modern sea level as shown by numerous possibly Early Mesolithic artefacts at the bottom of Pärnu River between Pulli and the river-mouth of Reiu.

The terrestrial conditions in the area were interrupted by the submergence under the rising level of the Ancylus Lake. The alternating peat and sand layers, above the lower peat bed, probably reflect sedimentation in the local lagoons whereas organic material is derived from terrestrial peat beds and is abraded by rising water level, transported away and settled down in deeper settling environment. Alternatively, Raukas et al. (1995b) suggest that the laminated peat and sand layers could represent floodplain deposits of the ancient Pärnu River. However, since the pollen grains there suggest a very local provenance and are not indicative of alluvial transportation, we favour the interpretation of a near-shore environment. Moreover, similar alternating peat and sand layers have been recorded elsewhere in south-western Estonia without major river inlets. The waters of the Ancylus Lake first inundated the area at Sindi-Lodja II, reached the Paikuse area about 10,400 years BP, and finally Pulli and higher sites about 10,200 years BP. The last date represents the culmination of the Ancylus Lake transgression in the Pärnu area. It is difficult to estimate the total amplitude of the transgression, but considering that the pre-Ancylus transgression peats were inundated at 3–14 m a.s.l. it preceded 11 m in the area.

6.2. Upper set

The upper set records the regression of the Ancylus Lake, allowing emergence of the land and formation of the upper peat bed/cultural layers, and the transgression by the rising level of the Litorina Sea, with therefore a shift from freshwater to brackish conditions, as recorded by the diatom assemblage of the alternating reworked peat and sand layers, above the upper peat/soil bed. The up to 14 m relative regression of the Ancylus Lake reached levels around 0 m a.s.l. as shown by the elevation of the lowermost pre-Litorina Sea organic/cultural layers at Sindi-Lodja I. Again, the water first inundated the lower peat at Sindi-Lodja I and II after 8500 years BP and reached Paikuse i.e. 7 m a.s.l. after 8000–7800 years BP. The Litorina Sea transgression culminated probably some 7500 years BP in the Pärnu area.

An unusual thin sand layer within the lower part of the upper peat bed or just underlying the peat was recognised at Paikuse sections. The sand layer is overlain by peat dated to 8400–8200 years BP. It is relatively rich in diatoms indicating slightly brackish-water conditions (Fig. 3). Similar diatom composition was described in Rannametsa, 30 km south of Paikuse, from the littoral facies dated to 9000–8800 years BP and belonging to the Mastogloia Sea phase (8000 ^{14}C years BP; Hyvärinen et al., 1992). We propose that this layer of sand was laid down by landward directed storm surges of the Baltic Sea Basin waters. This is synchronous with the pronounced widespread cooling event at 8200 years BP (Alley et al., 1997). The most likely feedback associated with the colder climate re-organisation of the atmosphere circulation in the North Atlantic, which generated strengthened cyclonic activity, stronger westerly storm tracks and also increased storminess in the Baltic area. An aeolian or fluvial origin of the sand layer can be ruled out because it contains brackish-water diatoms. As a hypothesis, this sand sheet could have formed as a result of tsunami-type sedimentation, similar stratigraphic successions as at Paikuse are associated with tsunami wave activities along the coast of the Pacific Ocean (e.g. Atwater and Moore, 1992; Clague and Bobrowsky, 1994; Williams and Hutchinson, 2000). Andrén and Andrén (2001) discuss possible tsunami wave evidence of the Second Storegga slide (Bondevik et al., 1997) in sediments of the Bornholm Basin and in the coast of Blekinge, southeastern Sweden at ca. 8000 years BP, almost synchronous with the Paikuse sand layer. Alternatively, the tsunami wave could have been generated by a possible meteorite impact event, which has been recorded as a layer of siliceous microspherules in several peat bog sequences all over the West Estonian Archipelago and dated to 8450–8250 years BP (7600–7500 ^{14}C years BP; Raukas, 2000).

In between the Ancylus Lake regression and the Litorina Sea transgression, prehistoric man inhabited the Sindi-Lodja sites as concluded from the archaeological material. The main economy at that time was rather diverse: gathering, fishing, and hunting game and fowl. One can, though, see a turn from hunting game to hunting seal, which is clearly recorded in the archaeo-osteological material (see above). Stone Age men used sites, such as Sindi-Lodja, at environmental border-zones of the sea, river and lagoons to make the most of all resources and stay sedentary in the area (Kriiska, 2001b). Another interesting point in the archaeological material is the presence of dark flint in the Middle-Mesolithic Sindi-Lodja settlement layers. In that sense, those sites are unique in Estonia and even Latvia, which is closer to the impost source of the dark flint. It is yet unclear whether flint was imported from its original locality or it was recycled.

After the Litorina Sea receded from Sindi-Lodja the area was again inhabited by people as shown by fragments of ceramics and various artefacts of Middle- and Late-Neolithic Combed Ware Culture found at the bottom and on the shores of Pärnu River. The Mesolithic, Neolithic and modern sites on top of each other in the Pärnu area may suggest that, although years apart, they were inhabited by the same group of people who stayed in the area and moved back and forth together with the shifting shoreline of the Baltic Sea.

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