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EVOLUTION OF WATERWAYS AND EARLY HUMAN SETTLEMENTS IN THE EASTERN BALTIC AREA: RADIOCARBON-BASED CHRONOLOGY

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ABSTRACT. Newly obtained radiocarbon measurements are used to suggest that the initial settlement of the northeastern Baltic area was largely controlled by the Ladoga-Baltic waterway in the north of the Karelian Isthmus, which emerged ~11,500 cal BP and remained in action for ~7000 yr. The transgression of Ladoga Lake started ~5000 cal BP and reached its maximum at ~3000 cal BP (~1100–1000 cal BC). The formation of a new outlet via the Neva River led to a rapid regression of the lake that stimulated the spread of farming populations.

INTRODUCTION

The early human movements in the northeastern Baltic area occurred under the background of drastic environmental changes, the most important of which were related to the post-glacial evolution of the Gulf of Finland, Ladoga Lake, and the hydrological network linked to these basins. Series of radiocarbon dates make it possible to correlate the early stages of human settlement with the evolution of waterways in the entire northeastern Baltic area. This was achieved in 2003–2005 in the framework of an INTAS (International Association for the Promotion of Co-operation with Scientists from the New Independent States [NIS] of the Former Soviet Union)-sponsored field project conducted on the Karelian Isthmus and in the Ladoga Lake basin. The aims of the project included the detailed chronological assessment of the following processes:

1. Emergence and duration of the Baltic-Ladoga Strait;
2. Emergence and duration of the Ladoga Lake transgression;
3. Emergence of the Neva River;
4. The effect of changes in the waterways on the subsistence and movements of prehistoric communities.

METHODS

To investigate this, we have chosen coring and sampling of lake and mire deposits with subsequent high-resolution ^{14}C dating, pollen and diatom analyses. The techniques of pretreatment and ^{14}C measurement have been described elsewhere (Arslanov et al. 2003). The ^{14}C dates were subjected to a statistical analysis with the use of Bayesian methods.

Investigations have been focused on the areas that were considered of key importance for the attainment of our targets. They included a site in the northern part of the Karelian Isthmus, where the earliest evidence of human presence had been acknowledged; the Veshchevo area located on the Baltic-Ladoga watershed; as well as several clearly stratified sites on the Neva River and the southern coastal area of Ladoga Lake.

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RESULTS

Karelian Isthmus

The earliest evidence of human presence on the Karelian Isthmus came from the site of Antrea-Korpilahti (Figure 1, #11). At this site, Mesolithic artifacts were found in the sandy silt together with the remains of a willow bark net, objects of antler, bone, and stone (Pälsi 1920). The bark net yielded a calibrated ^{14}C age of 9200–8250 cal BC (Matiskainen 1989). During the current project, the organic-rich gyttya overlying the sandy silt was ^{14}C dated to 5650–5050 cal BC. This site, like those of a later age, was located along a channel through which Ladoga Lake discharged into the Baltic Sea.

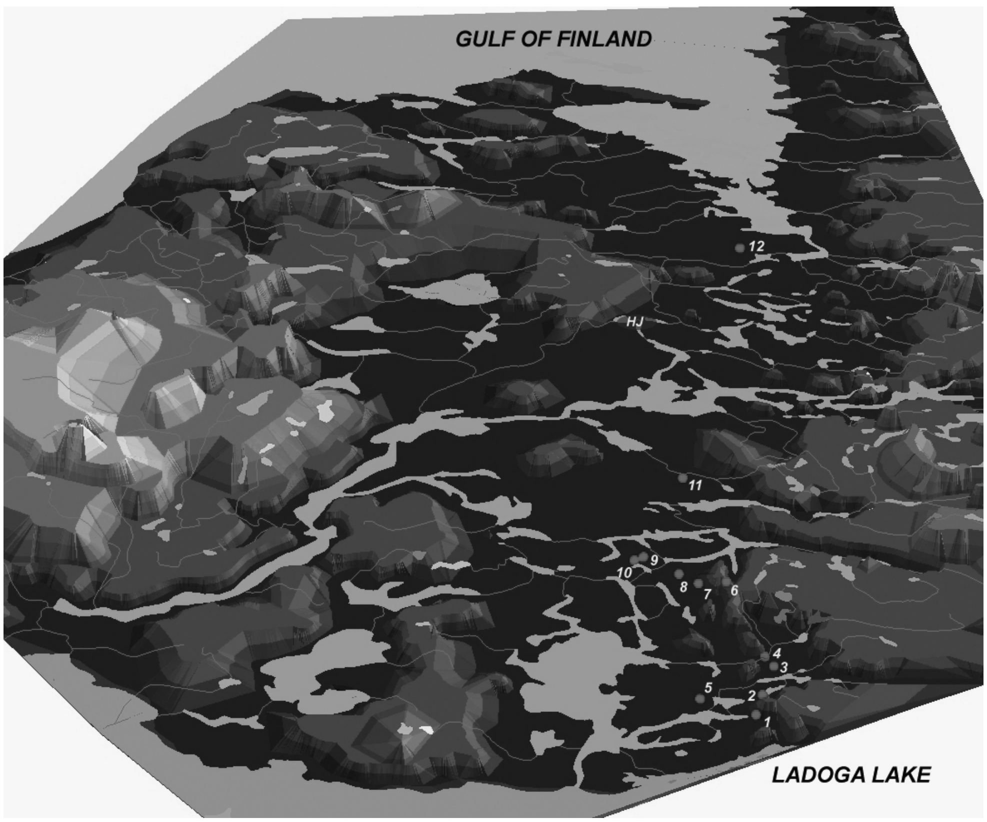

Figure 1 The Ladoga-Baltic Strait and investigated sites, GIS projection

A considerable amount of new evidence has been obtained in the Veshchevo area (formerly known as Heinijoki; "HJ" in Figure 1). The area constitutes the Baltic-Ladoga watershed and includes the "Vetokallio pass-sill" at 15.4 m above sea level (asl).

Our investigations included the Nizhne-Osinovskoe (NO) raised peat bog, located 5 km south of the Vetokallio pass-sill and 3 km west of Veshchevo railway station, with its surface at 23 m asl. Coring exposed a sequence of lacustrine and mire deposits spanning the entire Holocene.

Fine-grained light-blue silt was identified at the bottom (800–650 cm), overlain by fine-detritus gyttja at 650–570 cm. The upper part of the sequence consists of mire deposits and includes the following: low mire grass peat with *Carex*, *Equisetum*, and *Phragmites* (570–550 cm); low mire sedge-moss peat (550–530 cm); low mire sedge peat (530–450 cm); low mire sedge wood peat (450–410 cm); highly decomposed low mire wood peat (410–170 cm); low mire grass peat with *Sphagnum*, *Phragmites*, *Menyanthes*, and *Equisetum* (170–140 cm); mesotrophic grass peat and *Sphagnum* peat of transitional character (140–110 cm); and slightly decomposed *Sphagnum* and *Scheuchzeria* raised bog peat (110–0 cm).

Thirty-seven ^{14}C measurements covering the last 10,000 yr were obtained from the lake gyttja (depth range 650–570 cm): *Carex* peat (570–450 cm); low mire wood peat (450–130 cm); mesotrophic grass peat (130–60 cm); and raised bog peat (60–0 cm). The dates are presented in Table 1, calibrated with the use of OxCal v 4.0.1 (Bronk Ramsey 1995, 2001, 2007) using the IntCal04 calibration curve (Reimer et al. 2004). Constraints arising from the clear stratigraphic sequence of the samples were included using the *Sequence* deposition model option of OxCal. The prior and posterior probability distributions are very similar, and all the measurements have shown high levels of agreement (so that none of them had to be discarded) despite a small number of inversions in the uncalibrated dates. This confirms the high quality of both sampling and ^{14}C measurements. The calibrated dates are shown in Figure 2, where the prior (unconstrained) distributions are shown in light gray and the posterior distributions (constrained so that the calibrated age should increase with depth) in black.

Table 1 Lake gyttja ^{14}C ages.

			Calibrated age	
Lab code	Type of sample, depth (cm)	^{14}C age (BP)	AD/BC	BP
LU-5305	Fine detritus gyttja, 650–655	9980 ± 280	10,700–8600 BC	11,600 ± 1050
LU-5306	Fine detritus gyttja, 640–650	9580 ± 100	9250–8600 BC	10,875 ± 325
LU-5307	Fine detritus gyttja, 630–640	9440 ± 70	9150–8450 BC	10,750 ± 350
LU-5308	Fine detritus gyttja, 620–630	9530 ± 90	9250–8600 BC	10,875 ± 325
LU-5309	Fine detritus gyttja, 610–620	9400 ± 130	9150–8250 BC	10,650 ± 450
LU-5311	Fine detritus gyttja, 590–600	9300 ± 130	8900–8250 BC	10,525 ± 325
LU-5313	Fine detritus gyttja, 570–580	8730 ± 150	8250–7500 BC	9825 ± 375
LU-5315	*Carex* peat, 540–560	8810 ± 120	8250–7600 BC	9875 ± 325
LU-5316	Low mire sedge-moss peat, 530–540	8440 ± 110	7585–7350 BC	9417 ± 117
LU-5317	Low mire sedge peat, 510–520	8540 ± 80	7750–7100 BC	9375 ± 325
LU-5318	Low mire sedge peat, 490–500	8410 ± 70	7590–7310 BC	9400 ± 140
LU-5319	Low mire sedge peat, 470–480	8070 ± 100	7350–6650 BC	8950 ± 350
LU-5321	Low mire sedge peat, 450–460	7920 ± 140	7200–6450 BC	8775 ± 375
LU-5322	Low mire sedge wood peat, 430–440	7850 ± 140	7100–6400 BC	8700 ± 350
LU-5323	Low mire sedge wood peat, 410–420	7990 ± 70	7080–6680 BC	8830 ± 200
LU-5324	Low mire wood peat, 390–400	7620 ± 110	6690–6220 BC	8405 ± 235
LU-5326	Low mire wood peat, 350–360	7360 ± 110	6430–6010 BC	8170 ± 210
LU-5327	Low mire wood peat, 330–340	7270 ± 90	6270–5980 BC	8075 ± 145
LU-5328	Low mire wood peat, 310–320	7100 ± 100	6110–5740 BC	7875 ± 185
LU-5329	Low mire wood peat, 290–300	7000 ± 110	6070–5660 BC	7815 ± 205
LU-5331	Low mire wood peat, 250–260	6580 ± 80	5640–5360 BC	7450 ± 140
LU-5378	Low mire wood peat, 240–250	6080 ± 60	5210–4800 BC	6955 ± 205
LU-5332	Low mire wood peat, 230–240	5300 ± 70	4260–3970 BC	6065 ± 145
LU-5333	Low mire wood peat, 210–220	2880 ± 70	1290–840 BC	3015 ± 225
LU-5376	Low mire wood peat, 200–210	2480 ± 70	790–400 BC	2545 ± 195
LU-5334	Low mire wood peat, 190–200	2090 ± 60	360 BC–AD 60	2050 ± 100
LU-5335	Low mire wood peat, 170–180	1390 ± 50	AD 540–720	1300 ± 50
LU-5336	Low mire grass peat, 150–160	1490 ± 50	AD 430–660	1360 ± 50
LU-5380	Low mire grass peat, 140–150	1090 ± 60	AD 770–1040	1000 ± 60
LU-5337	Mesotrophic grass peat, 130–140	950 ± 60	AD 990–1220	860 ± 70
LU-5338	Raised bog peat, 90–100	570 ± 60	AD 1290–1440	590 ± 60

Table 1 Lake gyttja ^{14}C ages. *(Continued)*

Lab code	Type of sample, depth (cm)	^{14}C age (BP)	Calibrated age	
			AD/BC	BP
LU-5379	Raised bog peat, 80–90	580 ± 60	AD 1290–1440	590 ± 60
LU-5377	Raised bog peat, 60–70	570 ± 80	AD 1280–1470	590 ± 80
LU-5374	Raised bog peat, 40–50	180 ± 70	AD 1630–1960	200
LU-5342	Raised bog peat, 30–40	210 ± 80		200
LU-5373	Raised bog peat, 20–30	70 ± 50		200
LU-5343	Raised bog peat, 10–20	^{14}C = 1.22 ± 0.63%		Modern

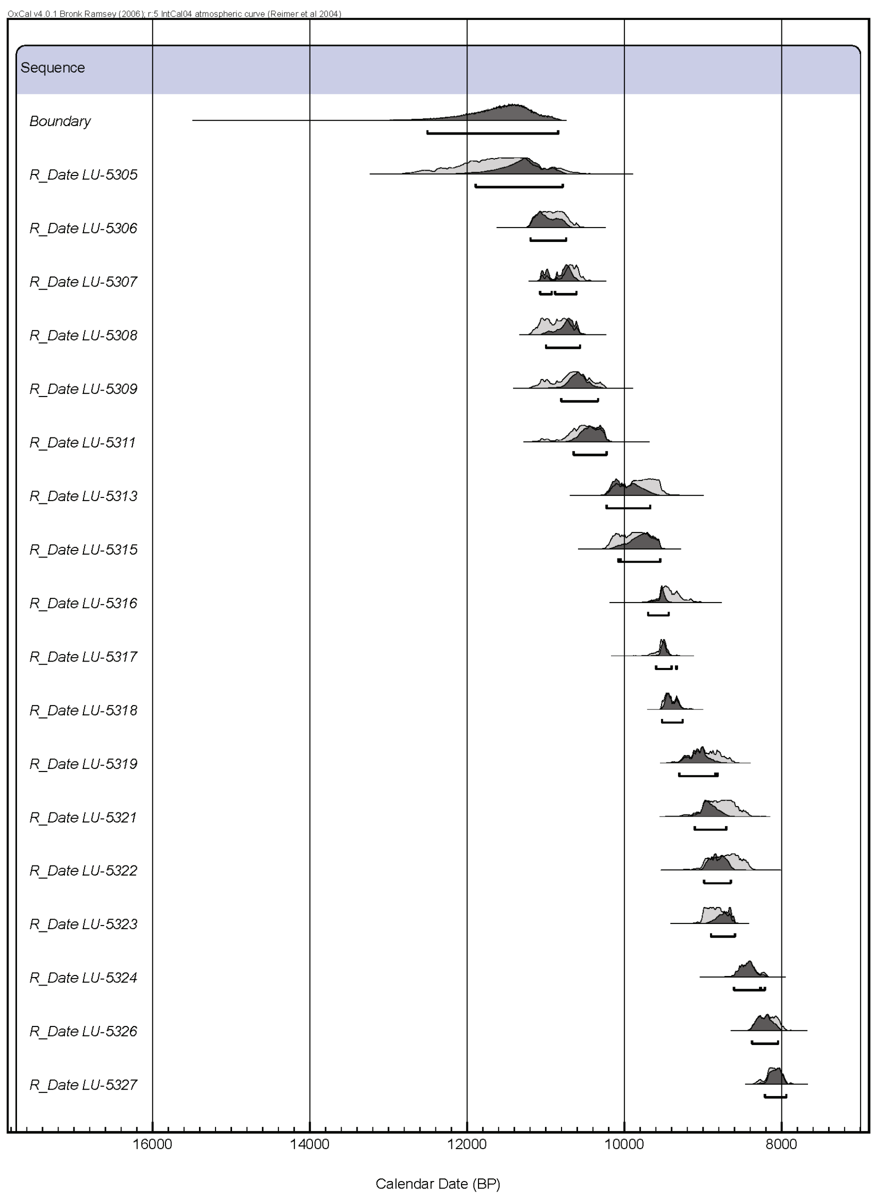

Figure 2 OxCal *Sequence* deposition model option for NO raised peat bog

The application of the *U_Sequence* function of OxCal's deposition models failed, thus demonstrating significant deviation from a uniform deposition rate. The deposition rate can be obtained from the dates of Figure 1 as follows. The middle of each age range obtained at the 95.4% confidence level, denoted T_n ($n = 0, \ldots, N$ with $N = 30$), was adopted as a representative age for each depth. For the sake of accuracy, the depth of the top of each layer z_n was used in the calculations, with $z = 0$ corresponding to the surface. Then, the deposition rate was calculated as $R_n = (z_{n+1} - z_n)/(T_{n+1} - T_n)$, with the uncertainty obtained by error propagation as

$$\delta R_n = [(z_{n+1} - z_n)/(T_{n+1} - T_n)^2]\sqrt{\delta T_{n+1}^2 + \delta T_n^2}$$

where δT_n is the error of the age shown in Table 1 (we have neglected any errors in the depth determinations). Results shown in Figure 3 reveal considerable fluctuations in the deposition rate in the time range 11,000–7000 cal BP, followed by a very low rate at 7000–3000 cal BP, followed by a slight increase during the last 3000 yr. A strongly deviating rate at 1340 BP (1 ± 1 cm/yr) is apparently an artifact resulting from the fact that the 2 calibrated dates involved are very close to each other (although the uncalibrated dates differ by ~120 yr, the calibrated ones only differ by 20 yr) and should be ignored.

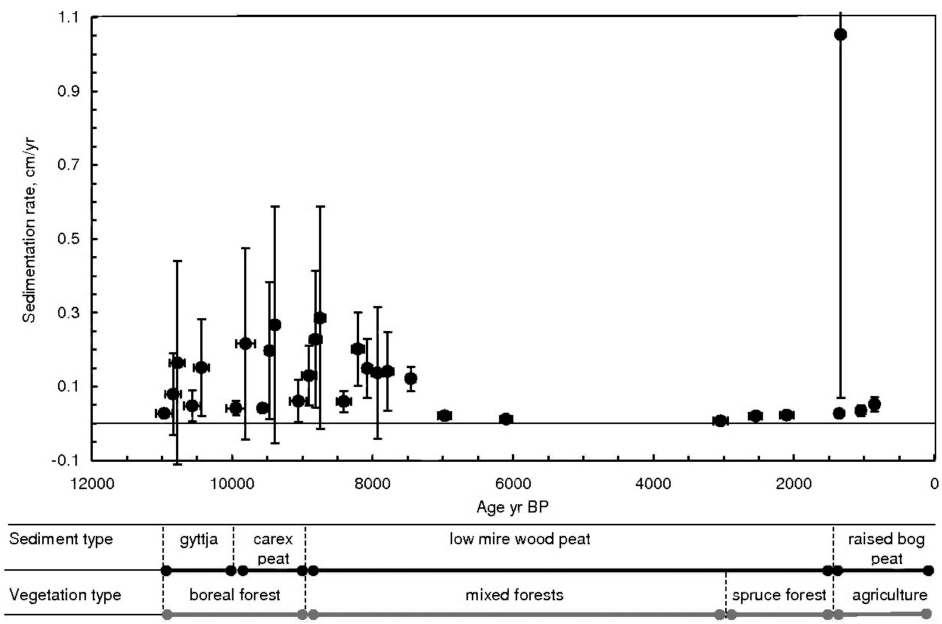

Figure 3 Sedimentation rate, as a function of time, for the NO raised peat bog. The lower part of the figure indicates the sediment vegetation types (the latter based on pollen analysis as described in the text).

Several pollen zones have been distinguished resulting from the pollen analysis of the NO sequence (Figure 4):

- NO-1 (700–665 cm; fine-grained light-blue silt; >11,600 cal BP): light birch forest with patchy occurrences of periglacial steppe-tundra;
- NO-2 (665–555 cm; fine-detritus gyttja; 11,000–9800 cal BP): boreal-type pine and birch forests with a Cyperaceae-Poaceae underwood;
- NO-2b (555–515 cm; *Carex* peat; 9800–8500 cal BP): birch and pine forests with hazel with a small admixture of elm, and hazel in the underwood;

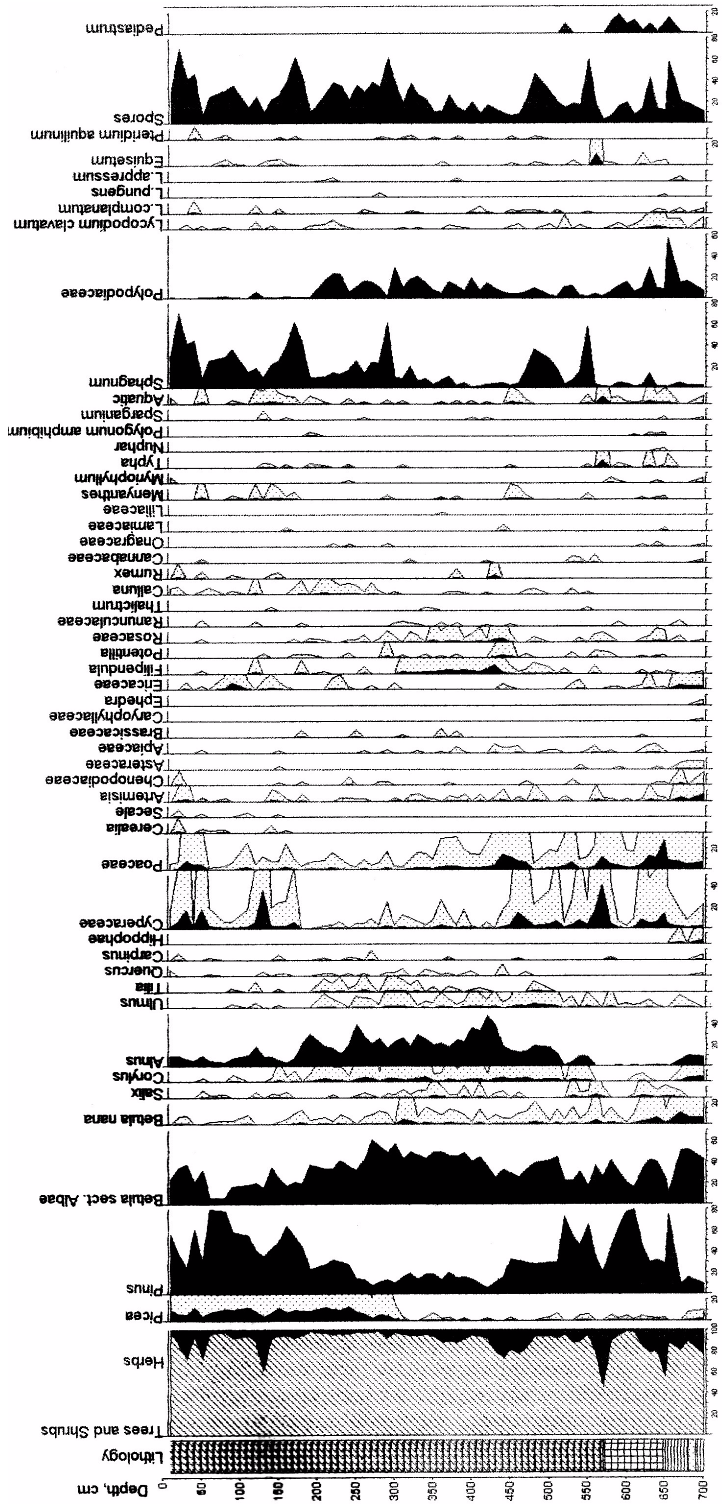

Figure 4 Pollen diagram for NO raised peat bog (analysis by L A Savelieva in 2005)

- NO-3a (515–435 cm; *Carex* peat; 8500–8700 cal BP): mixed forests consisting of birch, pine, and alder with an increasing admixture of elm and hazel;
- NO-3b (435–315 cm; low mire wood peat; 8700–7900 cal BP): mixed forests consisting of birch and alder forests with broad-leaved species and hazel present;
- NO-3c (315–240 cm; mire wood peat; 7900–7000 cal BP) birch and alder forests with rapidly expanding spruce;
- NO-4 (240–180 cm; mire wood peat; 7000–1300 cal BP) boreal-type forest with an increased presence of spruce and the gradual decline of broad-leaved species;
- NO-5a (180–125 cm; mire wood peat; 1300–900 cal BP): boreal pine forest alternating with spruce and birch, and increased open areas, apparently due to agricultural activities;
- NO-5b (125–55 cm; mesotrophic peat; 900–200 cal BP): boreal pine forest alternating with spruce and birch, and increased open areas, apparently due to agricultural activities, as witnessed by the occurrence of cereal pollen;
- NO-5c (55–0 cm; raised bog peat; 200–0 cal BP): open pine forest with the appearance of secondary birch forest.

The diatom analysis performed for the samples from the lower part of the sequence has identified several distinct assemblages (Figure 5):

- 800–780 cm, fine-grained light-blue silt. The assemblage is dominated by the freshwater planktonic species *Aulacoseira islandica* subsp. *helvetica*, with rare valves of other freshwater species; Baltic Ice Lake (BIL);
- 780–750 cm, fine-grained light-blue silt. The assemblage is dominated by the freshwater species *Gyrosigma attenuatum*; a short-lived regression of BIL, the Gyrosigma stage;
- 750–700 cm, fine-grained light-blue silt. The samples are dominated by brackish-water species, *Diploneis dydima*, *D. stroemii*, *D. smithii* et var., *Opephora marthyi*, *Mastogloia* spp., *Campylodiscus echeneis*. The deposits might be considered as being formed by the weakly saline Yoldia Sea. Rare occurrences of saline species, *Thalassiosira gravida*, *T. excentrica*, *T. angustelineata*, *T oestrupii*, *T. latimarginata*, *Coscinodiscus* sp., *Chaetoceros diadema*, *Actinocyclus curvatulus*, *Bacterosira fragilis*, are apparently redeposited from the interglacial deposits;
- 700–670 cm, fine-grained light-blue silt. The assemblage is dominated by freshwater benthic species, *Epithemia zebra*, *Gyrosigma attenuatum*, *Opephora marthyi*, with rare occurrences of saline species, *Mastogloia smithii* et var., *Diploneis stroemii*, *Nitzschia tryblionella*. The deposits are seen as corresponding to a regressive, freshwater stage of Yoldia Sea;
- 670–640 cm, fine-detritus gyttja (~11,000 cal BP). The assemblage includes the species adapted to freshwater small lake environment, dominated by *Pinnularia viridis*, *P. mesolepta*, *G. attenuatum*, *Epithemia zebra*, *Cocconeis placentula*, *Aulacoseira islandica* subsp. *helvetica.* The deposits are apparently formed in a small lake isolated from the Yoldia Sea;
- 640–610 cm, fine-detritus gyttja (~9800–9700 cal BP). The assemblage is dominated by planktonic freshwater species: *Aulacoseira islandica* subsp. *helvetica*, *A. italica*, *A. ambigua*; and by benthic species, *Cocconeis placentula*, *Nitzschia vermicularis*, *Amphora ovalis*, *Epithemia zebra.* The deposits reflect the maximum rise of Ancylus Lake transgression;
- 610–580 cm, fine-detritus gyttja (~9800–9700 cal BP). The highest frequencies of *Epithemia zebra*, followed by *E. sorex.* A regressive stage of Ancylus Lake;
- 580–560 cm, fine-detritus gyttja (~9800–9700 cal BP). The assemblage is dominated by a variety of periphytic species: *Cocconeis placentula*, *Fragillaria pinnata*, *F. construens* et var., *Epithemia zebra*, *Eunotia arcus* et var. The deposits were formed in a lake isolated from Ancylus Lake.

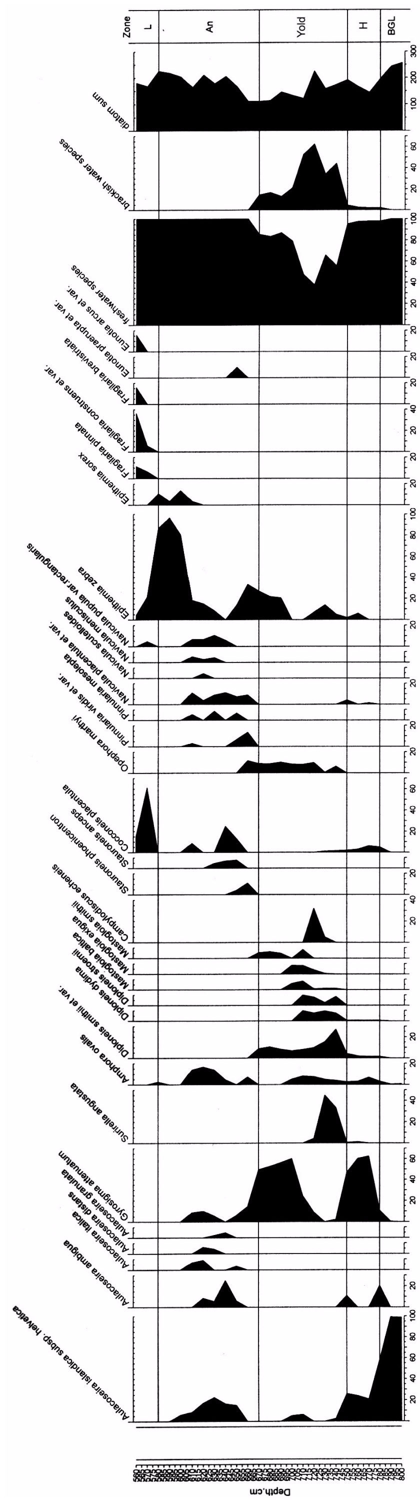

Figure 5 Diatom diagram for NO raised peat bog

Coring and sampling of bottom deposits was carried out in 2 lakes in the immediate proximity of the Vetokallio pass-sill: Lake Makarovskoye (11.6 m asl; Table 2) and Lake Lamskoye (14.2 m asl; Table 3). The sequences of lacustrine deposits are shown in Tables 2 and 3. ^{14}C measurements have been obtained from the bottom sediments of the both lakes are shown in Table 4.

Table 2 Sediment description for Lake Makarovskoe core (11.6 m asl).

Depth below water surface (cm)	Stratigraphy
0–90	Water
90–140	Dark-brown, homogeneous, slightly clayey fine-detritus gyttja
140–222	Dark-brown, faintly laminated FeS colored gyttja
222–285	Dark-brown gyttja
285–291	Brownish-gray gyttja clay
291–307	Brown, coarse, well-washed sand
307–322+	Gray silty clay

Table 3 Sediment description for Lake Lamskoye core (14.2 m asl).

Depth below water surface (cm)	Stratigraphy
0–240	Water
240–422	Dark-brown, homogeneous, slightly clayey fine-detritus gyttja
422–427	Gray gyttja clay with sand
427–487+	Brown, coarse, well-washed sand with bands of silt

Table 4 Bottom sediment ages of lakes Lamskoye and Makarovskoe.

			Calibrated age	
Lab code	Type of sample, depth (cm)	uncal. BP	BC	BP
Le-7006c	Gyttja, 422–427 Lake Lamskoye	3560 ± 160	2400–1500	3950 ± 450
Le-7006b	Gyttja, 422–427 Lake Lamskoye	3010 ± 120	1550–900	3175 ± 325
Le-7007c	Gyttja, 417–422 Lake Lamskoye	3860 ± 160	2900–1850	4325 ± 525
Le-7007b	Gyttja, 417–422 Lake Lamskoye	3100 ± 120	1700–1000	3350 ± 350
Le-7008	Gyttja, 310–320 Lake Lamskoye	2620 ± 230	1400–200	2750 ± 600
Le-7008b	Gyttja, 310–320 Lake Lamskoye	2620 ± 220	1400–200	2750 ± 600
LE-7309c	Gyttja, 190–200 Lake Makarovskoye	2130 ± 110	400 BC–AD 80	
LE-7309b	Gyttja, 190–200 Lake Makarovskoye	3010 ± 150	1650–800	
LE-7310c	Gyttja, 200–210 Lake Makarovskoye	3810 ± 120	2600–1900	
LE-7310b	Gyttja, 200–210 Lake Makarovskoye	2720 ± 170	1350–400	

Table 4 Bottom sediment ages of lakes Lamskoye and Makarovskoe. *(Continued)*

			Calibrated age	
Lab code	Type of sample, depth (cm)	uncal. BP	BC	BP
LE-7311c	Gyttja, 260–270 Lake Makarovskoye	3040 ± 90	1500–1020	
LE-7311b	Gyttja, 260–270 Lake Makarovskoye	3560 ± 200	2500–1400	
LE-7312c	Gyttja, 270–278 Lake Makarovskoye	2960 ± 100	1420–920	
LE-7312b	Gyttja, 270–278 Lake Makarovskoye	2690 ± 160	1300–400	

The dates for Lamskoye Lake have been analyzed using the deposition model of OxCal with the *Sequence* function. The prior and posterior probability distributions are very similar, and all the measurements have shown high levels of agreement, with the exception of Le-7007c, which deviates very strongly from the remaining dates and therefore has to be discarded. The calibrated dates are shown in Figure 6, where the prior (unconstrained) distributions are shown in light gray and the posterior distributions in black.

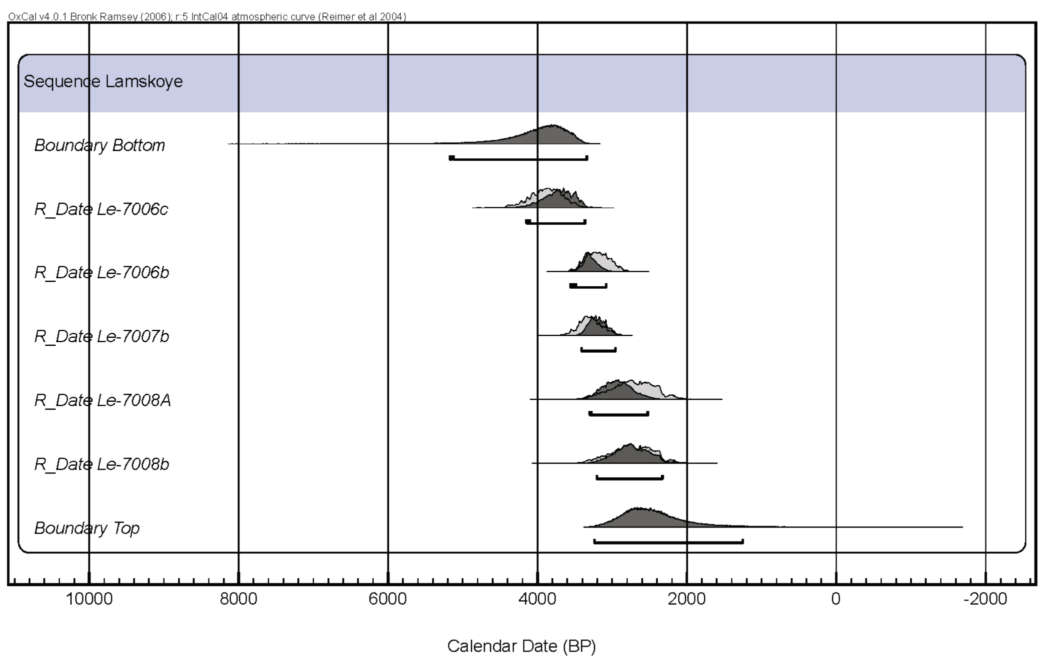

Figure 6 OxCal *Sequence* deposition model option for Lamskoye Lake

The pollen analysis performed for both sequences shows that the accumulation of gyttya preceded in an environment of boreal pine and spruce forests, with the varying presence of alder and broad-leaved species (oak, lime, elm, and ash), culminating in the level postdating one dated to 3010 ± 120 BP and 3500 ± 160 BP. Remarkably, that level signals the presence of Cerealea and indicators of agriculture (notably *Plantago*).

The diatom analysis of the bottom silt and sand deposits shows the presence of the species typical of Ladoga Lake, together with other planktonic taxa indicative of meso-eutrophic conditions. The later samples show that the transition from the running water to stagnant conditions was accompanied by an increase in the relative abundance of planktonic taxa, which might be indicative of an increased water depth. The subsequent assemblage shows the disappearance of Ladoga Lake species, suggesting the isolation of the studied lakes from the influx of the Ladoga water. The samples taken from the gyttya show eutrophication (either natural or human-driven), as well as an increase in the accumulation rate, resulting in a decrease in the water depth.

Ladoga Lake–Neva River

Investigations carried out in 2005–2006 were focused on the detailed chronology of the Ladoga transgression and the establishment of the Neva River. This included the coring and sampling of several key sites along the Neva River and the rivers falling into Ladoga Lake from the south. Two key sites have been investigated along the Neva River: the Nevsky Lesopark (the Neva Forest Reserve) and Nevsky Pyatachok (the Neva Bridgehead).

In the Nevsky Lesopark sequence (Figure 7, #1), the organic sediments, gyttja, and peat were overlain by the gray silt and fine-grained sand, deposited in the course of the major Ladoga transgression. The following ^{14}C measurements were obtained for the samples of organic sediments (Table 5).

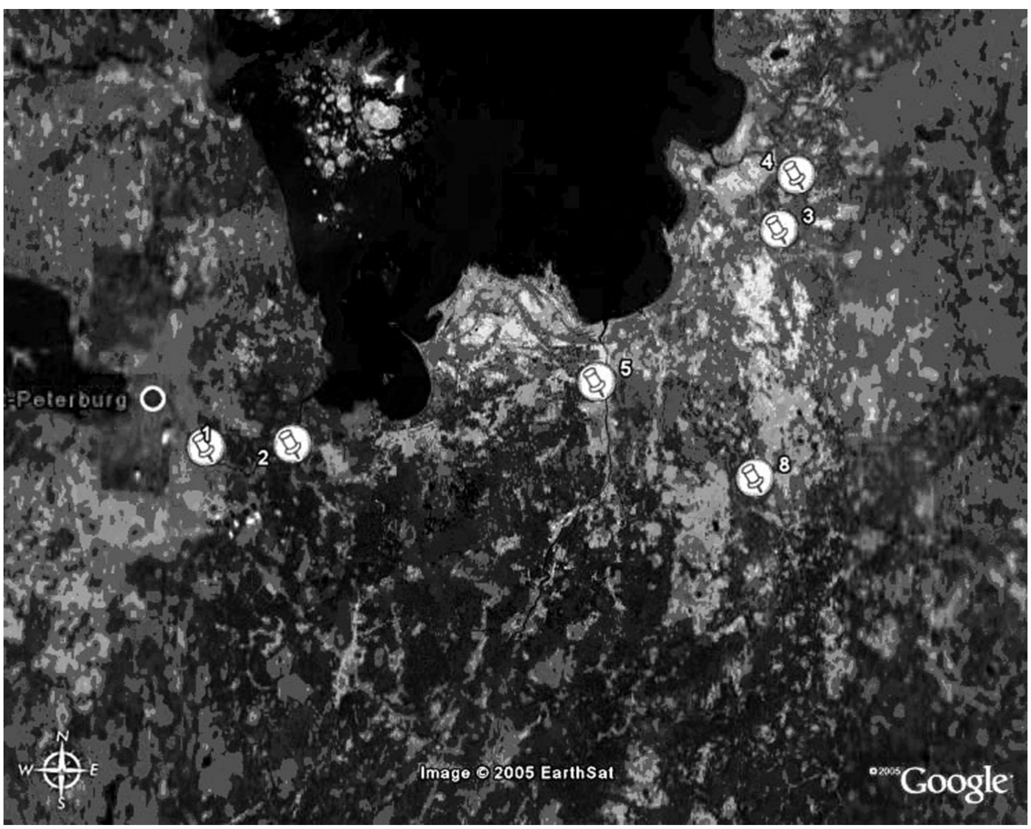

Figure 7 Investigated sites along the Neva River and in the southern Ladoga area (image courtesy Google®)

Table 5 Nevsky Lesopark sequence sample ^{14}C measurements.

				Calibrated age	
Lab code	Depth (m) from below	Material	uncal. BP	BC	BP
LU-5443	0.95; gyttja layer	Wood	4630 ± 40	3499–3359	5380 ± 70
LU-5449	1.12–1.15; top of gyttja layer	Gyttja	4540 ± 70	3363–3101	5180 ±130
LU-5447	1.52–1.55; bottom of peat layer	Peat	4260 ± 50	2917–2707	4760 ± 105
LU-5444	1.15–1.88; bottom of peat layer	Wood	4570 ± 50	3493–3105	5250 ± 190
LU-5446	1.52–1.55; top of peat layer	Peat	3070 ± 50	1403–1265	3280 ± 70
LU-5445	1.52–1.55; top of peat layer	Wood	2940 ± 60	1257–1047	3100 ± 105
LU-5448	1.55–1.65; bottom of silt layer	Wood	3120 ± 50	1487–1317	3350 ± 85

These dates have been analyzed using the *Sequence* deposition model function of OxCal, with the *Phase* option to isolate 2 groups of samples recovered from similar depths. The date of the boundary between the 2 phases was obtained at about 4000 BP. The upper (most recent) phase boundary, which presumably preceded the maximum rise of the Ladoga transgression, has been estimated to be about 3000 BP (Figure 8).

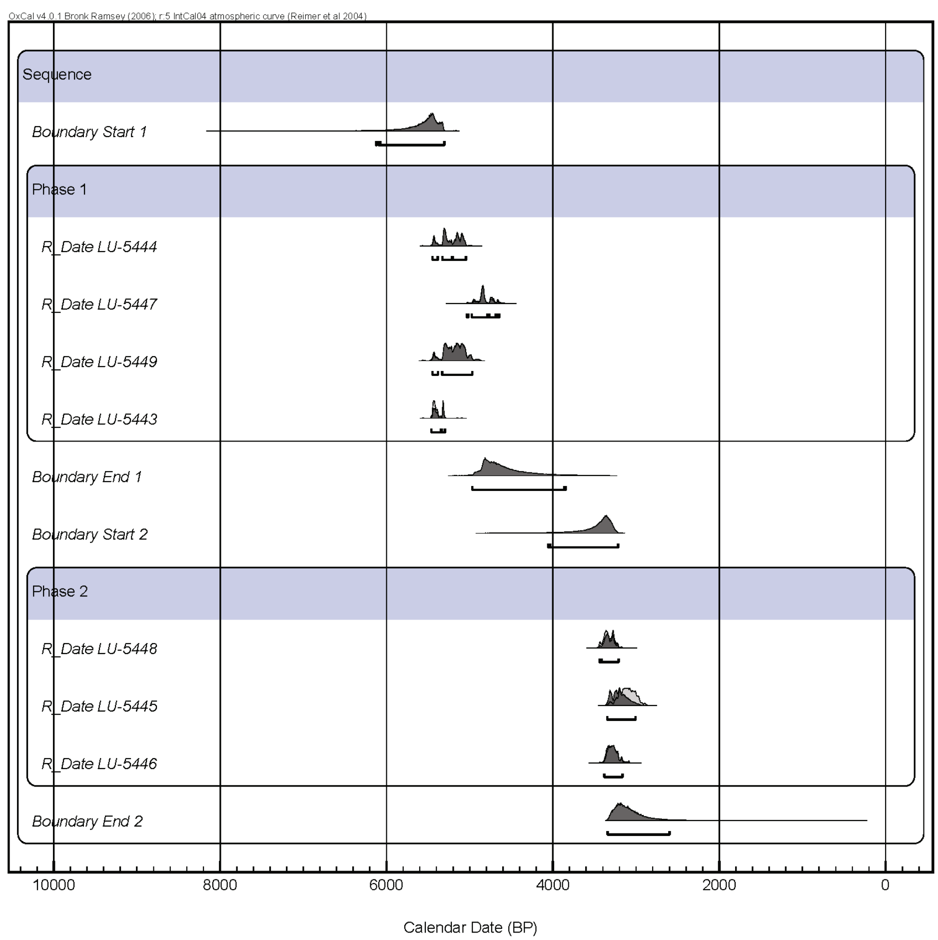

Figure 8 OxCal *Sequence* deposition model with the *Phase* option for Nevsky Lesopark

In the sequence of Nevsky Pyatachok (Figure 7, #2), the silt apparently deposited during the Ladoga transgression was overlain by the gyttya and peat that had been formed immediately after the breakthrough of the Neva River and the rapid fall of the Ladoga Lake level. The obtained measurements are shown in Table 6.

Table 6 Nevsky Pyatachok sample ^{14}C measurements.

				Calibrated age	
Lab code	Depth (m) from above	Material	uncal. BP	BC	BP
LU-5459	0.8–0.82; bottom of gyttya	Gyttja	2870 ± 50	1125–945	2985 ± 90
LU-5460	0.76–0.78; gyttja layer	Gyttja	3560 ± 50	801–549	2625 ± 125
LU-5461	0.62–0.64; peat layer	Peat	2260 ± 50	393–209	2250 ± 90

Detailed geomorphologic and stratigraphic observations were performed in the river valleys of the Volkhov, Svir, Pasha, and Oyat, south of Ladoga Lake. In the sequence on the left bank of the Oyat River, near the Lenenergo settlement (Figure 7, #4), organic deposits consisting of peat alternating with gyttja have been found buried under the stratified silt and sand, apparently accumulated in the course of the Ladoga transgression. Several ^{14}C dates have been obtained (Table 7).

Table 7 Oyat River sample measurements.

				Calibrated age	
Lab code	Depth (m) from above	Material	uncal. BP	BC	BP
LU-5454	1.91; peat layer	Wood	4220 ± 70	2903–2677	4740 ± 110
LU-5458	2.0–2.2; gyttja layer	Wood, peat	4000 ± 40	2567–2469	4470 ± 50
LU-5456	2.67–2.7; gyttja layer, bottom	Wood	4380 ± 90	3305–2889	5050 ± 210
LU-5453	2.7; peat layer, top	Wood	5860 ± 70	4829–4619	6725 ± 60

DISCUSSION

As follows from the earlier studies (Dolukhanov 1979; Subetto 2003), the waterway between Ladoga Lake and the Baltic in the northern lowland of the Karelian Isthmus emerged following the ice-sheet retreat at ~14,000–12,000 cal BP. During that period, and prior to the catastrophic drop of the Baltic Ice Lake (BIL) at ~11,500 cal BP, Ladoga Lake remained an easternmost extension of the BIL. In the northern part of the Karelian Isthmus, the highest shoreline BIL reached ~50–60 m asl. The BIL encompassed Ladoga Lake and covered an entire area of the Karelian Isthmus (except the Central Karelian Heights). The sediments of BIL have been identified in the bottom deposits of Nizhne-Osinovskoe bog sequence.

The opening of the Billingen channel in central Sweden and the drop in the level of the Baltic Ice Lake (11,500–11,000 cal BP) led to the emergence of the weakly saline Yoldia Sea (Arslanov et al. 1996; Saarnisto et al. 2000). The Yoldia Sea reached the Heinijoki area, as weakly saline Yoldia Sea diatom species have been identified in the deposits of Nizhne-Osinovskoe bog.

The land uplift in central Sweden led to the isolation of the Baltic Sea from the ocean and the emergence of the Ancylus Lake at around 9500 cal BP. For about 300 yr (9500–9200 cal BP), the sea level rose by 15–25 m (Eronen 1990; Björck 1995). During the ensuing regression, large expanses of dry land emerged. The waterway connecting Ladoga with the Baltic was still in place, often taking the shape of numerous bays with a labyrinth of islands (Tikkanen and Oksanen 1999). One such basin was located in the Heinijoki area, and corresponding deposits were recovered in the sequence of Nizhne-Osinovskoe bog. Following the regression of the Ancylus Lake 9800–9700 cal BP, this basin became isolated and turned into a mire, while the lakes with running water remained at the lower levels.

The ocean's eustatic rise above the threshold in the Straits of Denmark led to the penetration of saline water into the Baltic basin at around 8400–8300 cal BP and the emergence of the Littorina Sea. Its deposits became evident in Finland by ~7500 BP (Eronen 1974; Björck and Svensson 1994). Yet, the lack of diagnostic diatom assemblages proves that the Littorina Sea never reached the Heinijoki area.

One notes considerable fluctuations in the sedimentation rate in the time range 11,000–7000 cal BP. With the establishment of boreal-type forest that prevailed 7000–3000 BP, the sedimentation rate markedly decreased.

The earliest evidence of human settlement in the northeastern Baltic area is attested to at Antrea-Korpilahti (11,200–10,250 cal BP), where artifacts were found in the deposits of a channel between the Baltic and Ladoga Lake. This was a major waterway via which the entire area was settled by Mesolithic and Neolithic hunter-gatherers. There is a general increase in population density and sedintism, signalled by intensive pottery-making starting at 5560–5250 cal BC. This may be related to the general increase in biomass and biodiversity, as indicated by the establishment of mixed boreal–broad-leaved forests observable in the pollen records.

Saarnisto (1970) has demonstrated that from 5000 cal BP, Saimaa Lake started to drain into Ladoga Lake via the Vuoksa (Vuoksi) River. The resulting influx of fresh water led to the rapid rise of Ladoga Lake and the ensuing Ladoga transgression.

Investigations carried out in Lake Makarovskoye and Lake Lamskoye shed light on the final stages of the Ladoga-Baltic waterway. Following 3100–2600 BP, one may witness a transition from running water to more stagnant conditions in these basins. The disappearance of Ladoga Lake species indicates the isolation of the studied lakes from the influx of the Ladoga water. The eutrophication of these basins as well as the increased rate of sedimentation in NO peat bog following 3000 cal BP may be seen as signatures of agricultural impact, which is further substantiated by the presence of farming-related pollen in the deposits of that age.

Our data, including the reliable series of ^{14}C dates, indicate that the Ladoga transgression in the south reached its peak between 2900–1800 cal BP (1100–900 cal BC). The lake level abruptly fell when a new outflow via the River Neva was formed at ~1000–900 cal BC.

The fall of the lake level opened the way for the agricultural colonization of low-lying terraces of Ladoga Lake and the Volkhov-Ilmen system. This may be exemplified by the Shkurkina Gorka site, located on the 18-m-high terrace on the left bank of the River Volkhov, with the evidence of stock-breeding and early metal-working (Yushkova 2003). A series of ^{14}C dates shows its age as 950–350 cal BC.

The lower lake levels led to the emergence of a network of agricultural settlements, and, eventually, the establishment of urban-type trade and military centers along the waterway. The peaty soil that was accumulated on the 6-m-high terrace at Staroya Ladoga, prior to the emergence of the fortified hill fort, has ^{14}C ages of 1800 ± 60 and 1400 ± 50 BP (cal AD 319–667). The lowermost strata of archaeological sequence of Staraja Ladoga settlement yielded a ^{14}C age of 1360 ± 50 BP (or cal AD

641–761), in agreement with the archaeological estimate (Figure 7, #5). These dates are shown in Table 8.

Table 8 Staraja Ladoga settlement sample ^{14}C measurements.

				Calibrated age	
Lab code	Depth (m) from below	Material	uncal. BP	AD	BP
LU-5462	Base of the lower archaeological layer, 1.2–1.21	Wood	1360 ± 50	641–761	1250 ± 60
LU-5463	Top of paleosoil, 1.16–1.2	Wood	1400 ± 50	603–667	1315 ± 30
LU-5464	Top of paleosoil, 0.9–1.0	Wood	1800 ± 60	133–31	1725 ± 90

CONCLUSIONS

The investigations described above have demonstrated the existence of a major Baltic-Ladoga waterway in the Karelian Isthmus that emerged ~9200–8250 cal BC. The predominant location of prehistoric sites in the catchment area proves that this waterway effectively controlled the movements of hunter-gatherer groups during the greater part of the Holocene.

Our data show that a general increase of population density and sedentism, signaled by the beginning of intensive pottery-making at 5560–5250 cal BC, occurred in an environment of increased biodiversity and the establishment of mixed boreal–broad-leaved forests observable in the pollen records.

The data obtained indicate that the transgression of Ladoga Lake reached its peak between 2900–1800 cal BP (or 1100–900 cal BC) and was immediately followed by the breakthrough of the Neva River and the general fall in the levels of lakes and rivers. The availability of low-lying fertile soils stimulated the rapid expansion in agriculture, evident in the occurrence of farming-related pollen and changes in the sedimentation rate.

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