RADIOCARBON, Vol 41, Nr 1, 1999, p 25–45

CHRONOLOGY OF VEGETATION AND PALEOCLIMATIC STAGES OF NORTHWESTERN RUSSIA DURING THE LATE GLACIAL AND HOLOCENE

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ABSTRACT. We have studied 6 reference sections of bog and lake sediments in the Leningrad and Novgorod provinces to develop a geochronological scale for vegetational and paleoclimatic changes in northwestern Russia during the Late Glacial and Holocene. Every 10-cm layer along the peat and gyttja sections (4–8.5 m thick) was investigated palynologically and the great majority of them were radiocarbon dated. Using the data obtained, standard palynological diagrams were plotted and vegetation history reconstructed. The palynozones indicated on the diagrams were related to the climatic periods and subperiods (phases) of the Blytt-Sernander scheme. On the basis of 230 ^{14}C dates obtained, we derived the geochronology of climatic periods and phases, as well as the chronology for the appearance and areal distribution of forest-forming tree species. The uppermost peat layers were dated by using the "bomb effect". We compared the stages of Holocene vegetation and paleoclimatic changes discovered for the Leningrad and Novgorod provinces with the those obtained for Karelia, which we had studied earlier using the same methodology.

INTRODUCTION

The climatic-geochronological division of the Holocene has been based on recognition of climatic periods and phases using the Blytt-Sernander scheme. This relative scale was originally linked with the absolute radiocarbon one only by means of ^{14}C dating of the borders between climatic periods and phases identified in the Ageröds Mosse bog sediments (Nilsson 1964). Later, similar, climatic-geochronological scales supported by ^{14}C dating were developed for many regions of Western Europe. The Holocene geochronological scale of northwestern Russia is also based on the Blytt-Sernander scheme, but the climatic periods and phases identified here are not correlated well enough with the ^{14}C scale, owing to a shortage of Holocene sections investigated in detail by palynological and geochronological methods. The basis of our research project has been to study thoroughly the Holocene sediments in continuous sequences and to relate the pollen zones discovered to the climatic periods and phases, and to the ^{14}C time scale. Another goal has been to reconstruct Late Glacial and Holocene climatic parameters based on palynological and geochronological data.

METHODS

The most appropriate natural objects for the reconstruction of Late Glacial and Holocene vegetation and paleoclimates are thick layers of raised bog and lake sediments that have accumulated continuously over time. The records from bog and lake organic sediments complement each other. The bog peat consists of organic carbon formed in situ. It also contains moss, plant fragments, and microfossils that are necessary for the study of paleovegetation and paleoclimates. However, the palynological spectra of bog sediments reflect the local, regional, and zonal components of vegetation while the palynological spectra of lake sediments reflect mostly the regional and zonal ones (Khomutova 1995). The lake sediments occasionally contain microfossils and old redeposited carbon or organic carbon produced in a hard-water medium, which makes comparison of lake and bog records difficult, as we will demonstrate below.

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https://doi.org/10.1017/S0033822200019317 Published online by Cambridge University Press

During the last 5 years, we have studied 5 reference sections of bogs and one of lake sediments located in the provinces of Leningrad and Novgorod. We previously studied 2 sections of bog sediments located in Karelia (Elina et al. 1996). We used the same methods for all sections under study: every 10–12 cm layer along the whole thickness was investigated palynologically and generally geochronologically (by the ^{14}C dating method). The botanical composition of bogs was also studied. The bog samples were taken using a hand drill, and the lake ones with a Livingstone piston sampler. In all, 320 ^{14}C dates (90 dates for the sections in Karelia) have been obtained at the geochronological laboratory at St Petersburg State University. For ^{14}C dating, we used the liquid scintillation method described in Arslanov et al. (1993). Peat samples were pretreated by heating in 1% HCl for 30 min and then by keeping them in 1% NaOH overnight at room temperature. Humus from lake sediment samples was extracted by a 5-h treatment in hot 2% NaOH (after first heating in 1% HCl and removing Ca^{++}). Li_2C_2 was synthesized from charcoal obtained by pyrolysis from the pretreated peat samples and humic acids. When the amounts of samples were small enough (<3 g), we carried out synthesis with excess of Li (in a ratio of 1 g humic acid to 2 g Li) without pyrolysis. To synthesize benzene from acetylene we used a $V_2O_5 \cdot Al_2O_3 \cdot SiO_2$ catalyst, which allowed us to obtain benzene of high purity (with 90%–95% yield). The reliability of the laboratory work was demonstrated by our results of dating 25 samples for the IAEA and TIRI programs (also the Wrangel mammoth dates); all dates were consistent with the control figures within the limit of 2σ (Arslanov et al. 1998; Scott et al. 1997).

We carried out precise dating of the upper layers of peat stratum formed during last 45 years by measuring the "bomb radiocarbon" content in layers 2 cm thick. To determine calendar years for these layers, the curve of ^{14}C content–peat depth was matched to the well-known curve of ^{14}C excess in the atmosphere (Broecker and Walton 1959; Levin et al. 1980; McNeely 1994).

Sample Treatment for Palynological Analysis

The peat samples were pretreated by boiling in 10% NaOH for 5 min and then washing with distilled water by centrifuging; the residue was then analyzed. The mineral samples were treated initially in 10% HCl at room temperature to fully dissolve the carbonates, then the residue was washed with distilled water. Thereafter the residue was treated by boiling in 10% NaOH for 5 min, followed by washing in distilled water. The organic and mineral fractions were separated by adding a heavy liquid (PD-6 or KK-2,6), the density of which was adjusted to 2.28–2.29, and then the mineral residue was separated by centrifuging. A small amount of water and a few drops of HCl were added to the suspension bearing pollen and sporae to separate them: the precipitate was finally divided by centrifuging. The percentages of pollen (AP and NAP) and spores (Sporae) were calculated taking the total pollen and spores sum as 100%; the percentage of pollen and spores of the AP, NAP, and Sporae groups was calculated by taking the pollen or spores sum as 100% for each group.

RESULTS

Figures 1–5 are chrono-palynological diagrams of the sections of bog and lake sediments which were studied, and run from south to north: the Nikokolsko-Lutinskoye bog, the Shirinsky Mokh bog, the Lammin-Suo bog, Vishnevskoye Lake and the Sakkala bog. The diagram of the northernmost section, the "Suo" bog, located near the city Priozersk in the Leningrad province, was recently published in Chernova et al. (1997) and is not presented here. Two sections, the Nilosko-Lutinskoye bog and the Vishnevskoye lake, were studied earlier but only a few ^{14}C dates were obtained for these sections at that time (Arslanov et al. 1992; Kuzmin et al. 1985).

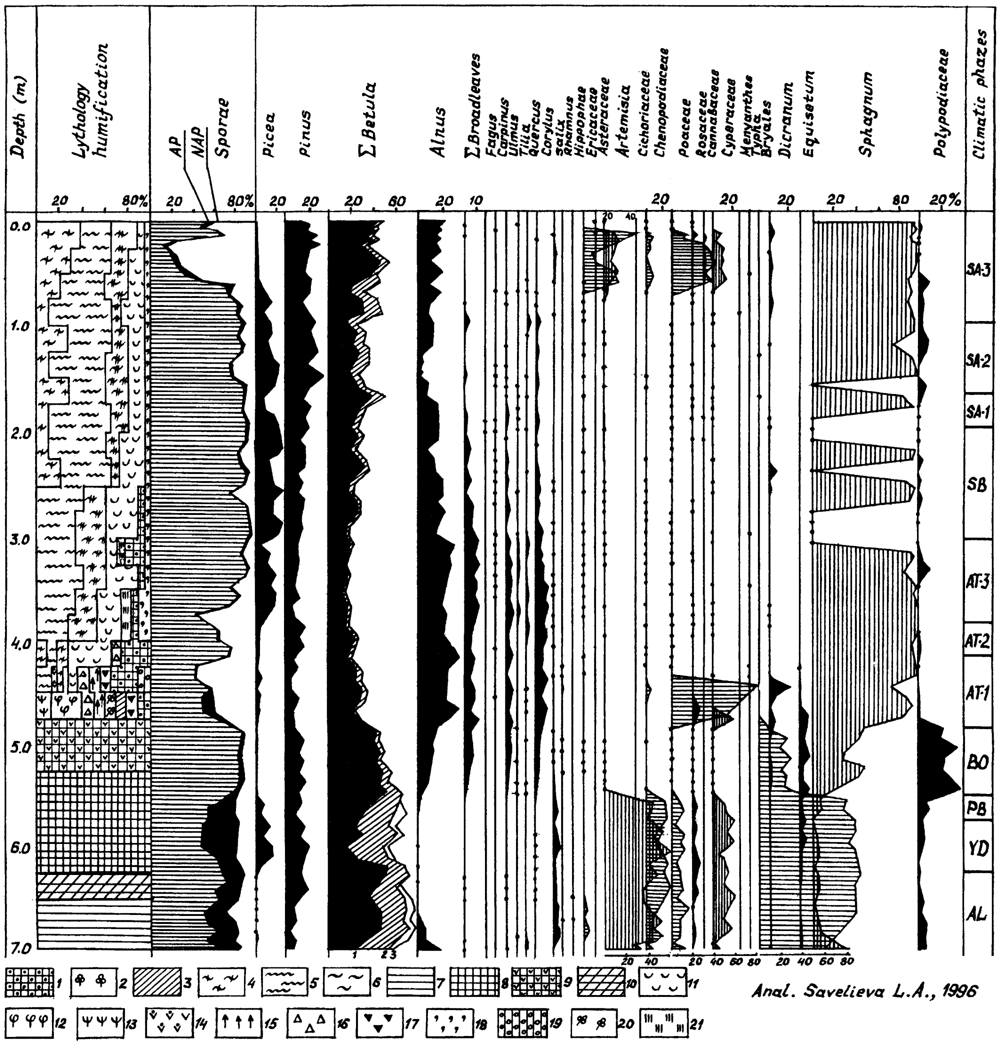

Figure 1 Chrono-palynological diagram of the Nikolsko-Lutinskoye raised bog sediments. Symbols: 1. *Pinus* peat; 2. *Menyanthes*; 3. *Carex* peat; 4. *Sphagnum fuscum*; 5. *S. magellanicum*; 6. *S. angustifolium*; 7. clay; 8. sapropel (gyttja); 9. peaty sapropel (gyttja); 10. clayey sapropel (gyttja); 11. *Eriophorum vaginatum*; 12. *Sphagnum platiphillum*; 13. *S. contortum*; 14. *S. terres*; 15. *Equistetum limosum*; 16. *Phragmites communis*; 17. herbaceous remains; 18. small shrubs; 19. *Betula pubescens*; 20. *Menyanthes trifoliata*; 21. *Scheuchzeria* peat.

Nikolsko-Lutinskoye Bog

The Nikolsko-Lutinskoye bog is located in the southwestern part of the Lake Ilmen shore lowland (depression) within the watershed of the Ljuta and Lemenka rivers and occupies an area of about 37.1 km^2. The section of peat (4.9 m thick) and sapropel (1.7 m thick) with clay (0.4 m thick) at the bottom was recovered by drilling to 7 m depth. We determined 11 stages of vegetation change beginning with the Allerød (AL) interstadial in this section. The pollen and ^{14}C data (Fig. 1; Table 1) show that sparse pine-birch forests with a small amount of spruce dominated during the Allerød interstadial (*Betula sect. Albae*: 30%–55%, *Pinus*: 5%–20%). Shrub and small shrub species of birch with willow were widespread (*Betula sect. Fruticosae*: 30%, *Betula nana*: 3%–5%, *Salix*: 2%–7%). *Artemisia* (25%–40%) and Chenopodiaceae (5%–15%) were the dominant herbaceous pollen types.

https://doi.org/10.1017/S0033822200019317 Published online by Cambridge University Press

Table 1 ^{14}C dates of Nikolsko-Lutinskoye raised bog sediments

Depth (cm)	Lab code	$\delta^{14}C$ (‰) or ^{14}C age (yr BP)[a]	Calibrated age (AD/BC)
0–2	LU-3432	*102.3 ± 10.5*	1989 AD–1993 AD
4–6	LU-3433	*188.2 ± 9.8*	1980 AD–1984 AD
8–10	LU-3434	*287.9 ± 7.1*	1971 AD–1975 AD
12–14	LU-3436	*465.6 ± 7.1*	1962 AD–1966 AD
16–18	LU-3435	*56.4 ± 7.6*	1953 AD–1957 AD
20–22	LU-3437	*26.3 ± 5.9*	1944 AD–1948 AD
40–42	LU-3438	200 ± 60	1750 AD–1948 AD
50–52	LU-3440	160 ± 30	1750 AD–1948 AD
50–60	LU-3441	600 ± 50	1306 AD–1404 AD
80–90	LU-3444	720 ± 170	1060 AD–1420 AD
90–100	LU-3445	780 ± 70	1181 AD–1294 AD
110–120	LU-3447	880 ± 30	1062 AD–1219 AD
120–130	LU-3448	1170 ± 50	792 AD–959 AD
150–160	LU-3451	1350 ± 40	652 AD–760 AD
160–170	LU-3452	1380 ± 40	636 AD–680 AD
170–180	LU-3453	1520 ± 40	460 AD–614 AD
180–190	LU-3454	1580 ± 30	446 AD–534 AD
190–200	LU-3455	1700 ± 70	252 AD–424 AD
200–210	LU-3456	2140 ± 70	352 BC–48 BC
210–220	LU-3457	2090 ± 80	192 BC–6 AD
220–230	LU-3458	2320 ± 80	506 BC–202 BC
230–240	LU-3459	2200 ± 60	364 BC–184 BC
240–250	LU-3460	2570 ± 60	806 BC–548 BC
250–260	LU-3461	2510 ± 40	772 BC–536 BC
260–270	LU-3462	2780 ± 70	992 BC–838 BC
270–280	LU-3463	3050 ± 60	1396 BC–1214 BC
280–290	LU-3464	3300 ± 80	1678 BC–1462 BC
290–300	LU-3465	3680 ± 80	2184 BC–1936 BC
300–310	LU-3466	4320 ± 60	3032 BC–2880 BC
310–320	LU-3467	4350 ± 80	3090 BC–2884 BC
320–330	LU-3468	4520 ± 60	3342 BC–3104 BC
330–340	LU-3469	4710 ± 60	3620 BC–3376 BC
340–350	LU-3470	4970 ± 110	3940 BC–3650 BC
350–360	LU-3471	5070 ± 70	3950 BC–3796 BC
360–370	LU-3472	5250 ± 110	4230 BC–3970 BC
380–390	LU-3474	5710 ± 90	4682 BC–4460 BC
390–400	LU-3475	5730 ± 120	4760 BC–4460 BC
410–420	LU-3477	6140 ± 90	5210 BC–4946 BC
420–430	LU-3478	6450 ± 90	5440 BC–5284 BC
440–450	LU-3480	6620 ± 100	5580 BC–5440 BC
450–460	LU-3481	6760 ± 70	5676 BC–5531 BC
460–470	LU-3482	6920 ± 60	5814 BC–5688 BC
470–480	LU-3489	7060 ± 80	5968 BC–5812 BC
490–510	LU-3491	7900 ± 110	7000 BC–6600 BC
500–510	LU-3492	8250 ± 240	7530 BC–6790 BC
510–520	LU-3493	8130 ± 100	7300 BC–6820 BC
520–530	LU-3494	9040 ± 160	8330 BC–7935 BC
530–540	LU-3495	9040 ± 250	8400 BC–7710 BC
550–560	LU-3497	9650 ± 240	9120 BC–8400 BC
570–580	LU-3499	10,360 ± 140	10,525 BC–9975 BC
580–590	LU-3500	10,680 ± 120	10,775 BC–10,525 BC
590–600	LU-3501	11,300 ± 240	11,525 BC–11,025 BC
600–610	LU-3502	10,670 ± 140	10,800 BC–10,500 BC
630–640	LU-3505	12,030 ± 250	12,400 BC–11,775 BC

[a]$\delta^{14}C$ measurements in *italics.*

https://doi.org/10.1017/S0033822200019317 Published online by Cambridge University Press

During the Younger Dryas (YD) the pine-birch forests were sharply reduced (*Betula sect. Albae* <15%) and shrubs and small shrub species of birch and willow occupied relatively large areas (*Betula sect. Fruticosae* 18%–38%, *Betula nana* 3%–7%; *Salix* 2%–7%). Also, xerophytes began to be widespread: *Artemisia* (40%–60%) and Chenopodiaceae (10%–20%).

An expansion of arborescent species of birch began in the Preboreal (PB): *Betula sect. Albae* 30%–55%; sparse birch forests, with some pine and spruce, dominated (*Pinus* 15%–20%, *Picea* 5%–10%). The share of steppe species such as *Artemisia* and Chenopodiaceae decreased sharply.

During the Boreal (BO), pine-birch forests were dominant (*Betula sect. Albae*: 45%–55%, *Pinus*: 13%–18%); alder (10%–14%) and hazel (5%–7%) appeared in shrub layers. Some broad-leaved tree species appeared at the same time, mostly elm.

Throughout the Atlantic (AT), pine-birch forests predominated with an admixture of broad-leaved trees. At the beginning of the Atlantic (AT-1) the proportion of birch in the forest community decreased and that of broad-leaved trees (7%–13%) such as elm, linden, and oak increased. Toward the middle of the Atlantic (AT-2) the share of broad-leaved trees decreased again to 5%–6%. Toward the end of pollen zone AT-2 beech appeared in the forests but conditions that suited the broad-leaved species only became established in pollen zone AT-3. During the whole period, alder forests with hazel in the undergrowth were widespread in areas with excess moisture.

During the Subboreal (SB), spruce expansion was maximal: spruce, together with birch, became the forest-forming species (*Picea* 12%–29%, *Betula sect. Albae* 20–40%). The proportion of the broad-leaved trees remained significant (5%–8%). In the wetter areas spruce was replaced by alder (*Alnus* 10%–20%).

During the Early Subatlantic (SA-1), birch, pine, and spruce continued to be the main forest-forming species, but the proportion of spruce decreased (*Picea* 6%–15%). Oak and elm predominated among broad-leaved species. Spruce-pine-birch forests were widespread from pollen zone SA-2, then pine-birch forests with an admixture of spruce. At the end of the zone, that is, the recent phase, pine-birch forests with a small proportion of spruce were predominant in the territory. The broad-leaved species were rare during the Subatlantic and the alder forests occupied only a limited area.

Shirinsky Mokh Bog

The Shirinsky Mokh bog is located in the basin of the Volkhov River, 25 km to the southeast of the town of Kirishy, in Leningrad province. The borehole was drilled to a depth of 7.1 m in the center of the bog and uncovered a peat stratum (6.65 m thick) with underlying clay (0.50 m thick).

The palynological and ^{14}C data (Fig. 2; Table 2) suggest that the sediments formed during the Preboreal–Subatlantic (PB–SA). During the first half of the Preboreal (PB-1), the shrub (*Betula sect. Fruticosae*) and dwarf birch (*Betula nana*) formation was widespread (27%–34%) in lowland areas, and the willow percentages were significant (to 7%). The more elevated land was occupied by the restricted areas of single trees, partly by sparse, small pine-birch-spruce-alder forests (*Pinus* 10%–15%, *Picea* 3%–7%) with a moss covering. Steppe taxa such as *Artemisia* (22%–25%) and Chenopodiaceae (18%–22%) were widespread. During the second half of the Preboreal (PB-2), arborescent birch began its expansion: sparse birch and pine forests began to develop and elm and hazel (in undergrowth) appeared. The share of xerophytes in the landscape diminished sharply; they were replaced by a gramineous-*Carex* association.

At the beginning of the Boreal (BO-1), birch forests (*Betula* to 90%) with a small proportion of pine spread everywhere. Among the broad-leaved species, oak and linden appeared after elm. During the

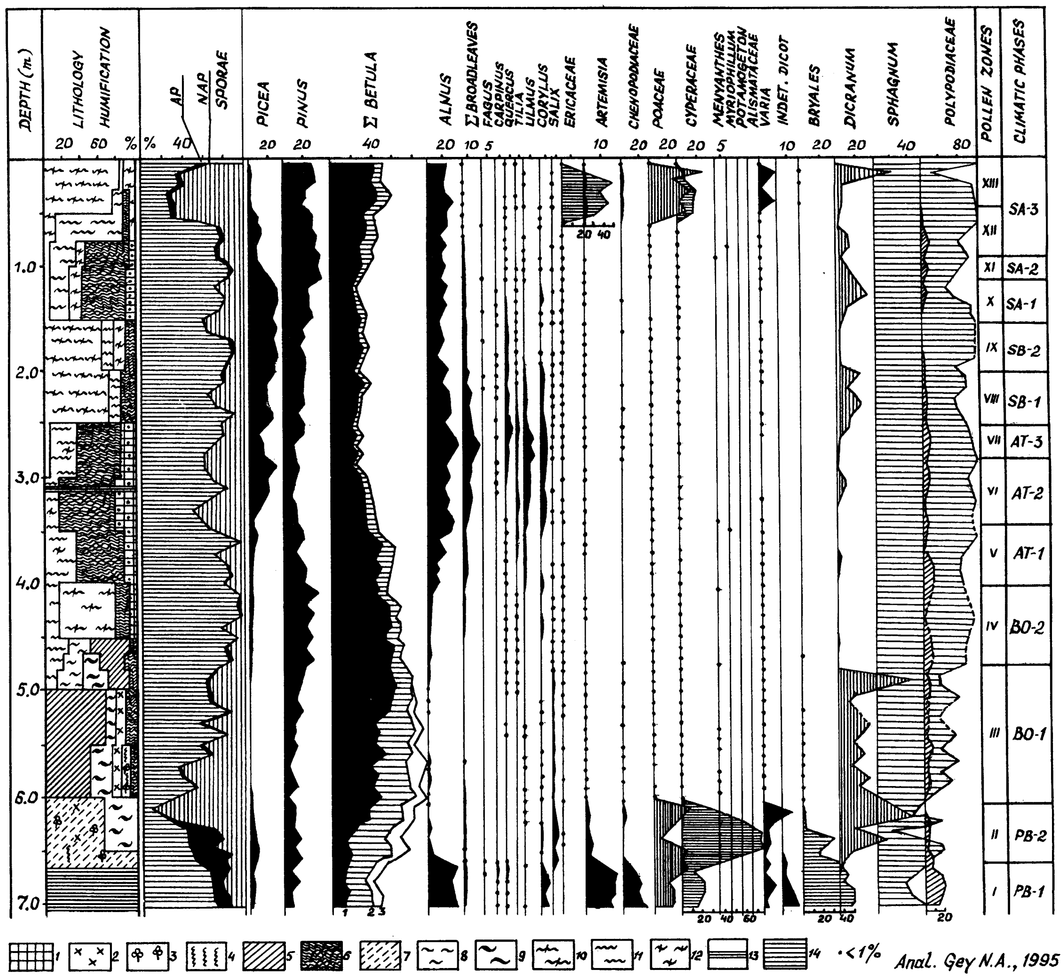

Figure 2 Chrono-palynological diagram of the Shirinsky Mokh raised bog sediments. Symbols: 1. *Pinus* peat; 2. *Equisetum* peat; 3. *Menyanthes*; 4. *Phragmites* peat; 5. *Carex* peat; 6. *Eriophorum* peat; 7. *Scorpigium*; 8. *Sphagnum sect. cuspidata*; 9. *S. subsecundum*; 10. *S. fuscum*; 11. *S. magellanicum*; 12. *S. angustifolium*; 13. charred layer of peat; 14. clay.

second half of the Boreal (BO-2), pine percentages began to rise (21%–34%) and pine-birch forests became dominant. Some broad-leaved species (such as elm, oak, and linden) were present constantly. Alder and spruce were no longer present in the forests. The spore-pollen spectra characteristic for the Atlantic and the development of vegetation during this period are similar to those of the Nikolsko-Lutinskoye bog section (Figs. 1, 2). Beginning in the Subboreal, the territory was part of the dark coniferous taiga zone. Early in the period (SB-1) birch was the relatively dominant species in the forest. In pollen zone SB-2, spruce was expanding intensively in birch-pine forests and gradually became a dominant species (21%–27%). The share of broad-leaved species decreased (to 3%–6%) and beech replaced oak.

The dominant and subdominant vegetation and spore-pollen spectra of the Subatlantic (SA) are similar to those of the Nikolsko-Lutinskoye bog section, except for the first phase (SA-1). The proportion of spruce was much higher in this section (Figs. 1, 2).

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Table 2 ^{14}C dates of the Shirinsky Mokh raised bog sediments

Depth (cm)	Lab code	$\delta^{14}C$ (‰) or ^{14}C age (yr BP)[a]	Calibrated age AD/BC (1σ)
0–2	LU-3312	*68.9* ± *10.6*	1989 AD–1993 AD
2–4	LU-3313	*139.5* ± *8.6*	1985 AD–1989 AD
4–6	LU-3314	*176.3* ± *9.9*	1980 AD–1985 AD
6–8	LU-3401	*244.4* ± *8.8*	1976 AD–1980 AD
8–10	LU-3399	*320.7* ± *9.1*	1972 AD–1976 AD
10–12	LU-3315	*345.7* ± *10.5*	1968 AD–1972 AD
12–14	LU-3400	*464.7* ± *9.4*	1963 AD–1968 AD
14–16	LU-3402	*211.7* ± *9.8*	1959 AD–1963 AD
16–18	LU-3316	*23.1* ± *9.7*	1955 AD–1959 AD
22–24	LU-3317	60 ± 50	1750 AD–1959 AD
28–30	LU-3318	180 ± 80	1750 AD–1959 AD
34–36	LU-3319	30 ± 60	1750 AD–1959 AD
40–42	LU-3320	30 ± 50	1750 AD–1959 AD
46–48	LU-3321	100 ± 40	1750 AD–1959 AD
70–80	LU-3325	240 ± 50	1534 AD–1936 AD
80–90	LU-3326	410 ± 50	1440 AD–1620 AD
90–100	LU-3327	480 ± 60	1404 AD–1472 AD
100–110	LU-3328	980 ± 40	1014 AD–1158 AD
110–120	LU-3329	1320 ± 50	664 AD–770 AD
120–130	LU-3330	1600 ± 60	416 AD–540 AD
130–140	LU-3331	1820 ± 40	142 AD–246 AD
140–150	LU-3332	2010 ± 30	36 BC–54 AD
150–160	LU-3333	2380 ± 90	760 BC–370 BC
160–170	LU-3334	2460 ± 60	760 BC–412 BC
170–180	LU-3335	2430 ± 60	756 BC–402 BC
180–190	LU-3336	2600 ± 60	826 BC–554 BC
190–200	LU-3337	2820 ± 60	1036 BC–854 BC
210–220	LU-3339	3230 ± 70	1600 BC–1414 BC
220–230	LU-3340	3800 ± 90	2398 BC–2044 BC
230–240	LU-3341	4030 ± 70	2848 BC–2460 BC
240–250	LU-3342	4090 ± 60	2862 BC–2500 BC
250–260	LU-3343	4250 ± 70	2920 BC–2694 BC
260–270	LU-3344	4590 ± 80	3500 BC–3106 BC
270–280	LU-3345	5030 ± 90	3946 BC–3714 BC
280–290	LU-3346	5050 ± 70	3948 BC–3782 BC
290–300	LU-3347	5230 ± 80	4220 BC–3964 BC
300–310	LU-3348	5500 ± 100	4460 BC–4250 BC
310–320	LU-3349	6120 ± 100	5210 BC–4920 BC
330–340	LU-3351	6640 ± 80	5579 BC–5450 BC
340–350	LU-3352	7030 ± 110	5960 BC–5750 BC
350–360	LU-3353	6980 ± 90	5940 BC–5726 BC
360–370	LU-3354	7310 ± 100	6190 BC–6000 BC
370–380	LU-3355	7540 ± 70	6422 BC–6240 BC
400–410	LU-3358	7630 ± 70	6532 BC–6376 BC
410–420	LU-3359	7960 ± 70	7000 BC–6708 BC
420–430	LU-3360	7890 ± 60	6994 BC–6602 BC
440–450	LU-3362	8240 ± 80	7416 BC–7052 BC

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Table 2 (Continued)

Depth (cm)	Lab code	^{14}C age (yr BP)	Calibrated age AD/BC (1σ)
450–460	LU-3363	8190 ± 80	7264 BC–7046 BC
460–470	LU-3365	8230 ± 70	7410 BC–7050 BC
470–480	LU-3366	8160 ± 80	7262 BC–7038 BC
480–490	LU-3367	8400 ± 60	7498 BC–7324 BC
490–500	LU-3368	8580 ± 50	7588 BC–7504 BC
500–510	LU-3369	8400 ± 70	7502 BC–7314 BC
510–520	LU-3370	8360 ± 50	7486 BC–7312 BC
520–530	LU-3371	8590 ± 70	7692 BC–7504 BC
530–540	LU-3372	8720 ± 80	7890 BC–7594 BC
540–550	LU-3373	8790 ± 80	7935 BC–7702 BC
560–570	LU-3375	8980 ± 70	8046 BC–7962 BC
580–590	LU-3377	9080 ± 60	8122 BC–8028 BC
590–600	LU-3378	8960 ± 80	8046 BC–7935 BC
600–610	LU-3379	9140 ± 130	8340 BC–8040 BC
610–620	LU-3380	9360 ± 80	8518 BC–8262 BC
640–650	LU-3383	9380 ± 110	8840 BC–8260 BC
650–660	LU-3384	9410 ± 90	8832 BC–8278 BC
660–670	LU-3385	9850 ± 100	9380 BC–8980 BC

[a]$\delta^{14}C$ measurements in *italics*.

Lammin-Suo Bog

The Lammin-Suo bog is located on the Karelian Isthmus near the settlement of Iljichovo, 12 km north of the town of Zelenogorsk. A section of peat 4.0 m thick was obtained by drilling to a depth of 4.1 m; there was sand at the bottom, and a layer of strongly decomposed peat (0.2 m thick) was found at depths of 2.5–2.7 m. These sediments formed during the Boreal–Subatlantic (BO-SA-3).

The palynological and ^{14}C data (Fig. 3; Table 3) show that the predominant forest formation during the Boreal was pine-birch forest (*Betula* 60–75%, *Pinus* 18–32%). Alder and spruce were not among the forest-forming species and the only thermophyl species was elm (but this appeared only sporadically) and hazel was in the undergrowth. The gramineous-*Carex* community dominated in the herbaceous cover. The climatic change in pollen zone AT gave rise to a number of broad-leaved species in forests—in AT-1 the pine-birch forests with some elm; linden and oak occurred sporadically (pollen of broad-leaved species contributed up to 3%); in AT-2 mixed broad-leaved forests in which the frequency of linden along with elm was significant, and beech appeared as well (broad-leaved species 6–11%). During the whole period, alder forests were widespread on the outlying sides of the bog (*Alnus* 10–15%). Spruce began to expand to the end of pollen zone AT-2. Sediments of the final phase of AT were absent.

The spore-pollen spectra of the Subboreal are similar to those of the Shirinsky Mokh section for the same period (Figs. 2, 3). The sporae-pollen spectra of the Subatlantic (SA), which show the development of vegetation during the period, bear a close resemblance to those of the Nikolsko-Lutinskoye bog section (Figs. 1, 3).

Vishnevskoye Lake

Vishnevskoye Lake (Table 4) is located on the lacustrine-glacial plain to the north of the central highland of Karelian Isthmus (15 m asl). It is a shallow basin with an average depth of about 2 m and

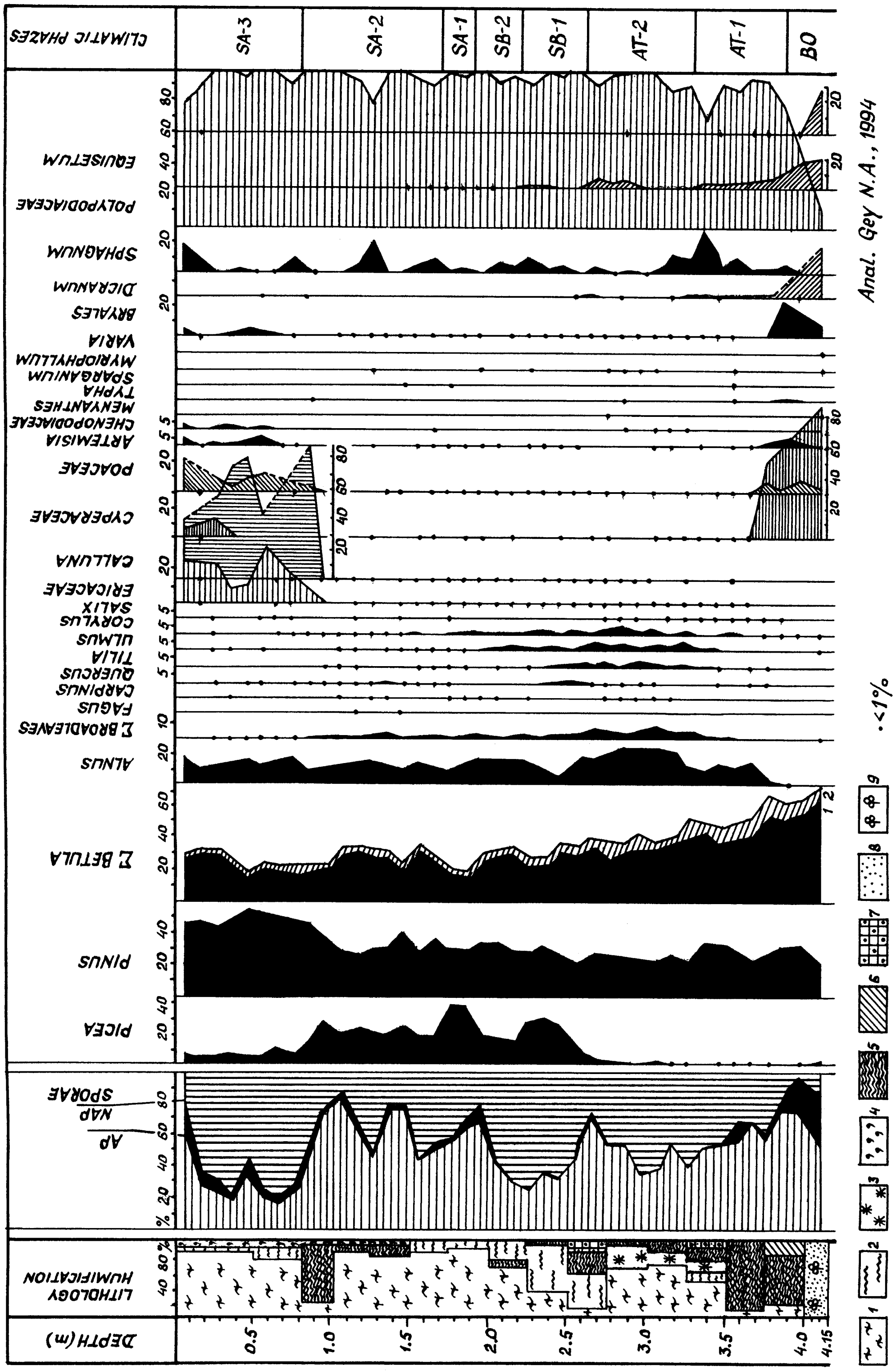

Figure 3 Chrono-palynological diagram of the Lammin-Suo raised bog sediments. Symbols: 1. *Sphagnum fuscum*; 2. *S. magellanicum*; 3. *S. terres* 4. small shrubs; 5. *Eriophorum* peat; 6. *Carex* peat; 7. *Pinus* peat; 8. sand; 9. plant remains.

TABLE 3. ^{14}C Dates of the Lammin-Suo Raised Bog Sediments

Depth (cm)	Lab code	$\delta^{14}C$ (‰) or ^{14}C age (yr BP)[a]	Calibrated age AD/BC (1σ)
0–10	LU-3080	*113.2 ± 8.6*	1978 AD–1993 AD
10–15	LU-3081	*271.6 ± 7.9*	1967 AD–1978 AD
15–20	LU-3082	*390.4 ± 9.1*	1956 AD–1967 AD
20–25	LU-3083	*17.5 ± 7.2*	1945 AD–1956 AD
25–30	LU-3084	*18.7 ± 8.6*	1750 AD–1956 AD
30–35	LU-3085	*−2.1 ± 7.8*	1750 AD–1956 AD
35–40	LU-3086	*−9.7 ± 8.5*	1750 AD–1956 AD
40–45	LU-3087	*5.4 ± 7.7*	1750 AD–1956 AD
45–50	LU-3088	*0.7 ± 7.5*	1750 AD–1956 AD
50–60	LU-3063	*6.3 ± 9.4*	1750 AD–1956 AD
70–80	LU-3064	490 ± 60	1402 AD–1469 AD
90–100	LU-3065	650 ± 80	1292 AD–1396 AD
100–110	LU-3168	1410 ± 50	610 AD–668 AD
110–120	LU-3066	1800 ± 40	144 AD–324 AD
120–130	LU-3169	1940 ± 50	18 AD–124 AD
150–160	LU-3068	1950 ± 50	14 AD–120 AD
170–180	LU-3069	2230 ± 70	372 BC–200 BC
180–190	LU-3171	2370 ± 60	752 BC–376 BC
200–210	LU-3172	2800 ± 60	1004 BC–848 BC
210–220	LU-3071	2790 ± 60	996 BC–846 BC
220–230	LU-3173	3080 ± 50	1400 BC–1268 BC
240–250	LU-3174	3210 ± 60	1520 BC–1416 BC
250–260	LU-3073	3780 ± 40	2278 BC–2062 BC
260–270	LU-3175	5610 ± 70	4500 BC–4358 BC
270–280	LU-3074	6320 ± 50	5314 BC–5222 BC
280–290	LU-3176	6590 ± 60	5564 BC–5444 BC
310–320	LU-3076	6860 ± 60	5738 BC–5628 BC
330–340	LU-3077	7170 ± 70	6108 BC–5892 BC
350–360	LU-3078	7490 ± 90	6388 BC–6214 BC
370–380	LU-3079	7770 ± 50	6598 BC–6484 BC

[a]$\delta^{14}C$ measurements in *italics*.

maximum depth of about 3.5 m. The thickness of lake sediments extracted was 10 m (sapropel, 8.6 m; clayey sapropel, 0.8 m; clay, 0.8 m [Fig. 4]). Sediment accumulation began in the lake since the Younger Dryas (Table 4). Palynological data show that the ratio between the main components of the sporae-pollen spectra is almost identical to that of the Nikolsko-Lutinskoye bog section for the same period (Figs. 1, 4).

During the Preboreal, arborescent birch and pine expanded rapidly (*Betula sect. Albae* 30–60%, *Pinus* 10–50%); however, during the first half of the pollen zone PB-1 period, sparse birch forests with some shrub and dwarf birch and willow persisted. At the beginning of pollen zone PB-2, pine-birch forests predominated (*Betula sect. Albae* 25–65%, *Pinus* 20–45%); at the end of the period, alder and the broad-leaved species appeared (elm was first). The herbaceous cover was characterized by dominance of graminoides.

During the Boreal, pine-birch forests were replaced by pine forests (*Pinus* 45%–80%) when birch (*Betula sect. Albae* 25%–35%) and alder (*Alnus* 5%–15%) and broad-leaved species appeared. The proportion of herbs was sharply reduced.

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During the first half of the Atlantic (AT-1), pine forests with an admixture of birch and alder continued to dominate, but the share of the broad-leaved species increased (5%–11%, mostly *Ulmus* 3%–7%). In the Mid-Atlantic (AT-2) the share of the broad-leaved species in the forests decreased (2%–6%) and spruce began to expand (*Picea* 10–20%). Spruce-pine and birch-pine forests (*Pinus* 35%–45%, *Betula sect. Albae* 17%) with an admixture of thermophilous plants (elm, linden, oak, beech, and hazel) were spreading then. At the end of the Atlantic (AT-3), the share of broad-leaved species began to rise again (to 8%) and this phase was characterized by dominance of spruce-birch-pine forests with a noticeable proportion of broad-leaved species (hazel and alder).

At the beginning of the Subboreal (SB-1), pine and spruce became the forest-forming species (*Pinus* 60% max, *Picea* 24% max). Spruce-pine forests with an admixture of birch (*Betula sect. Albae* max 7%) and alder (*Alnus* ca. 4%) developed but the contribution of the broad-leaved species remained rather small (ca. 5%).

In the middle of pollen zone SB (SB-2) the maximal expansion of spruce took place (*Picea* 32%). Pine (*Pinus* 45%) and spruce forests with birch (*Betula sect. Albae* 10–13%) were widespread but spruce was replaced by alder in moist areas (*Alnus* 4%–7%). Toward the end of the Subboreal (SB-3) the share of spruce decreased (*Picea* 18%–25%) and spruce-pine and birch-pine forests became common.

By and large, the spore-pollen spectra characteristics for the Subatlantic (SA) are identical to those of the Nikolsko-Lutinskoye bog section (Figs. 1, 4).

Sakkala Bog

The Sakkala bog is located in the northeastern part of the Karelian Isthmus, near the Gromovo railway station. The peat bed consists of highbog (0–2 m), with carex peat in between (2.0–2.5 m) and fen arboreal-carex, carex, arboreal, and arboreal-grass peat (2.5–4.35 m) below this (Fig. 5). Peat accumulation began during the middle of the Atlantic.

Based on the palynological and ^{14}C data, we recognize several vegetational changes (Fig. 5; Table 5): in the middle of the Atlantic (AT-2), alder-birch forests with some pine (*Betula sect. Albae* 14%–36%, *Alnus* 8%–65%, *Pinus* 8%–48%) were developed in the region and broad-leaved species (not <4%) and hazel (*Corylus* ca. 2%) were present as an admixture. Toward the end of the phase, spruce began to expand in the forests. Toward the end of the Atlantic, birch and pine became the forest-forming species (*Betula sect. Albae* 30%–45%, *Pinus sylvestris* to 30%) while alder occupied the low-lying and moister areas (*Alnus* 15–30%). Broad-leaved species were also important, such as elm and linden with some oak and hazel (max 9.6%), but the share of spruce was insignificant (*Picea* 5% max).

At the beginning of the Subboreal (SB-1), pine-birch forests dominated (*Betula sect. Albae* 30%–50%, *Pinus* 25–35%) with an admixture of spruce (*Picea* 10%–20%) and broad-leaved species (4%–8%); alder occupied the damp areas. During the second part of the Subboreal (SB-2) spruce began to predominate (*Picea* 30% max) and pine-spruce (*Pinus* 30%–35%) and birch-spruce (*Betula sect. Albae* 20%–30%) forests developed.

Changes in the sporae-pollen spectra suggest that during the Subatlantic vegetation changes occurred here the same way as in the Nikolsko-Lutinskoye bog section (Figs. 1, 5).

Suo Bog

The Suo bog is 2 km to the south of Suuri Lake, near the settlement of Kuznechnoye in Priozersk region of Leningrad province. The peat is 6.3 m at maximum thickness, and it documents all stages

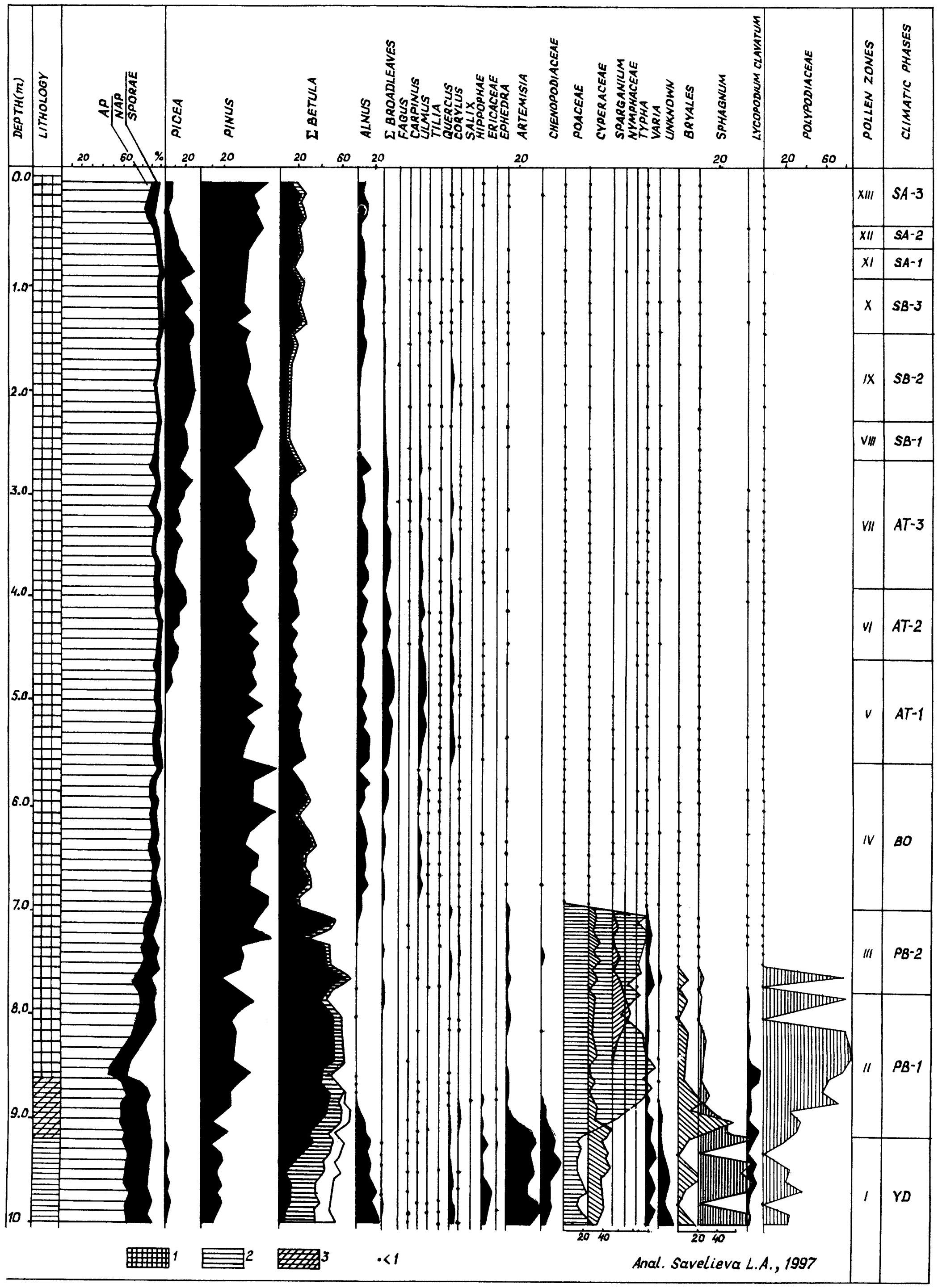

Figure 4 Chrono-palynological diagram of the Vishnevskoye Lake sediments. Symbols: 1. sapropel (gyttja); 2. clay; 3. clayey sapropel (gyttja).

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Table 4 ^{14}C dates of the Vishnevskoye Lake sediments

Depth (cm)	Lab code	^{14}C age (yr BP)	Calibrated age AD/BC (1σ)
30–40	LU-3763	1600 ± 80	392 AD–590 AD
50–60	LU-3764	1670 ± 100	250 AD–530 AD
90–100	LU-3766	2580 ± 150	840 BC–420 BC
110–120	LU-3767	2990 ± 140	1390 BC–1030 BC
130–140	LU-3768	4270 ± 160	3090 BC–2610 BC
150–160	LU-3769	4100 ± 170	2890 BC–2410 BC
170–180	LU-3770	3840 ± 140	2470 BC–2040 BC
190–200	LU-3771	3710 ± 120	2280 BC–1930 BC
210–220	LU-3772	4150 ± 80	2872 BC–2616 BC
230–240	LU-3773	3930 ± 90	2564 BC–2214 BC
250–260	LU-3774	4420 ± 90	3298 BC–2918 BC
270–280	LU-3775	4610 ± 90	3508 BC–3108 BC
290–300	LU-3776	4730 ± 130	3650 BC–3350 BC
310–320	LU-3777	4940 ± 90	3902 BC–3640 BC
330–340	LU-3778	4990 ± 170	3980 BC–3550 BC
350–360	LU-3779	5450 ± 110	4450 BC–4100 BC
370–380	LU-3780	5600 ± 100	5440 BC–4340 BC
410–420	LU-3782	5560 ± 170	4660 BC–4170 BC
430–440	LU-3783	6310 ± 150	5430 BC–5070 BC
450–460	LU-3784	6570 ± 210	5600 BC–5290 BC
470–480	LU-3785	7030 ± 330	6180 BC–5530 BC
530–540	LU-3788	7690 ± 190	6710 BC–6230 BC
590–600	LU-3791	8270 ± 260	7540 BC–6780 BC
610–620	LU-3792	8260 ± 190	7490 BC–7040 BC
670–680	LU-3795	8680 ± 240	7980 BC–7490 BC
690–700	LU-3796	8860 ± 180	8040 BC–7620 BC
700–720	LU-3868	9170 ± 170	8390 BC–8030 BC
720–740	LU-3969	9510 ± 180	8490 BC–8420 BC
740–760	LU-3870	9710 ± 210	9130 BC–8480 BC
760–780	LU-3871	10,940 ± 180	11,075 BC–10,725 BC
800–820	LU-3873	10,290 ± 220	10,500 BC–9270 BC
840–860	LU-3875	10,580 ± 390	11,075 BC–9390 BC

of bog evolution: lake, fen, intermediate, and raised bogs. The oligotrophic stage of the bog took place at the boundary of pollen zones SB-1 and SB-2 (3980 ± 120 BP).

The palynological and geochronological data (Chernova et al. 1997) indicate that xerophytic herbs (*Artemisia,* Chenopodiaceae) and low shrubs dominated here during the Younger Dryas. Sparse birch and pine forests were also found in the area.

In the Preboreal, sparse pine-birch forests developed, and thickets of dwarf birch, willow, and shrub heath were widespread. We dated the Younger Dryas/Preboreal boundary at around 10,520 BP.

During the Boreal, the forest-forming species were birch and pine. The broad-leaved species (elm and hazel first of all) found their way in, but their share of the forest composition was not significant. Sedges and graminoides dominated among the herbs. In the diagram, the upper boundary of the Boreal is defined by the important rise in pollen of the broad-leaved species. It was dated at 8120 ± 220 BP.

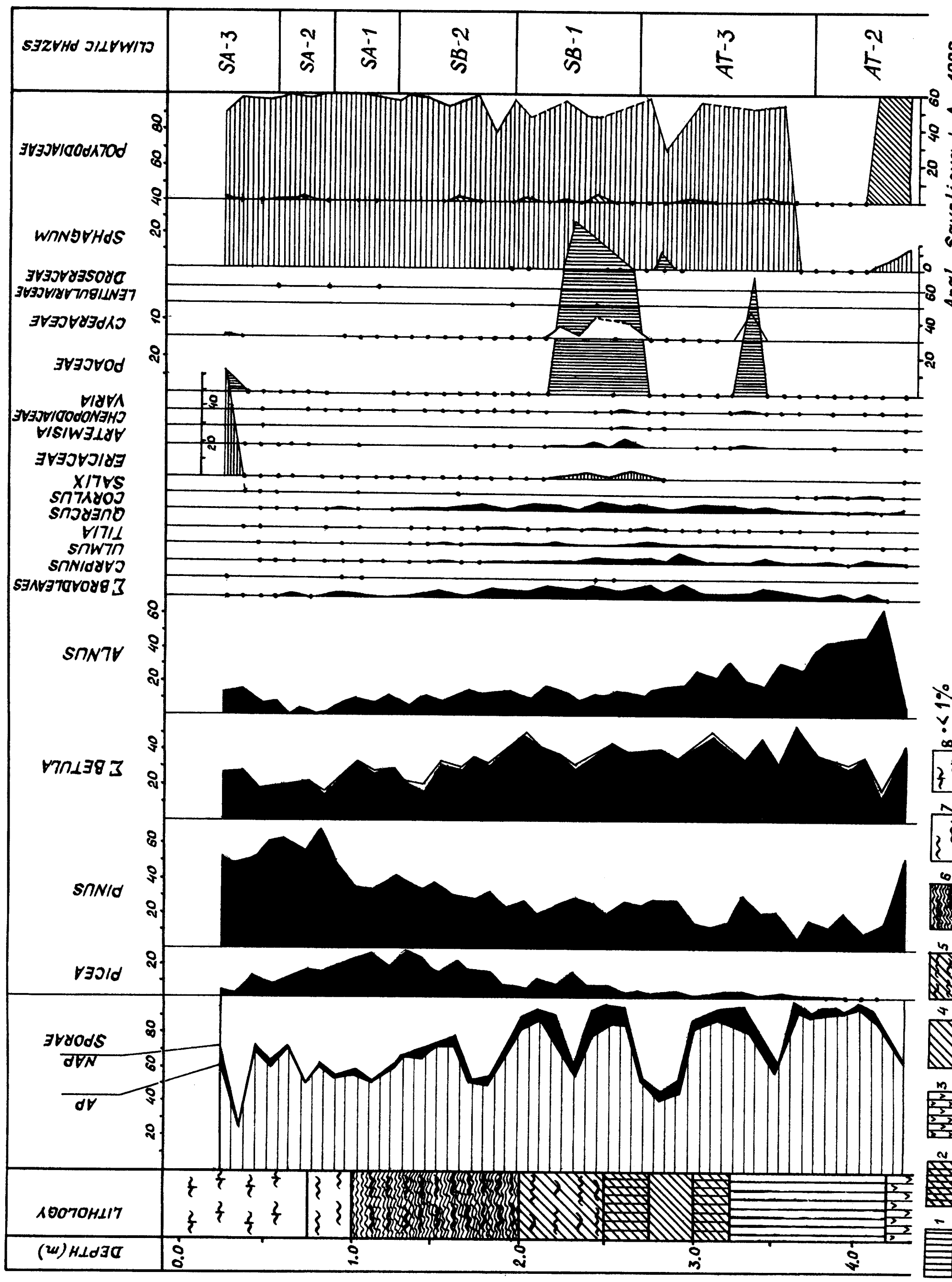

Figure 5 Chrono-palynological diagram of the Sakkala raised bog sediments. Symbols: 1. woody fen peat; 2. woody *Carex* fen peat; 3. woody grass fen peat; 4. *Carex* fen peat; 5. *Carex transitiona* peat; 6. *Eriophorum* - *Sphagnum* highbog peat; 7. *magellanicum* peat; 8. *foscum* peat.

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TABLE 5. ^{14}C Dates of the Sakkala raised bog sediments

Depth (cm)	Lab code	^{14}C age (yr BP)	Calibrated age AD/BC (1σ)
20–30	LU-3718	270 ± 60	1514 AD–1802 AD
40–50	LU-3719	730 ± 50	1248 AD–1376 AD
70–80	LU-3754	1170 ± 60	792 AD–961 AD
80–90	LU-3721	1440 ± 70	554 AD–664 AD
90–100	LU-3798	1430 ± 70	554 AD–668 AD
110–120	LU-3799	1570 ± 80	422 AD–594 AD
120–130	LU-3723	2150 ± 60	350 BC–60 BC
140–150	LU-3724	2430 ± 100	760 BC– 400 BC
150–160	LU-3755	2650 ± 50	890 BC–790 BC
170–180	LU-3800	3430 ± 70	1872 BC–1626 BC
180–190	LU-3726	3360 ± 80	1736 BC–1526 BC
200–210	LU-3727	3830 ± 80	2450 BC–2142 BC
220–230	LU-3728	3880 ± 40	2452 BC–2292 BC
240–250	LU-3729	4150 ± 50	2870 BC–2618 BC
260–270	LU-3730	4330 ± 60	3032 BC–2884 BC
270–280	LU-3801	4490 ± 100	3340 BC–3040 BC
290–300	LU-3802	4790 ± 90	3658 BC–3380 BC
300–310	LU-3732	5380 ± 50	4326 BC–4102 BC
340–350	LU-3734	5170 ± 50	4038 BC–3822 BC
350–360	LU-3803	5720 ± 70	4674 BC–4470 BC
360–370	LU-3735	5840 ± 50	4780 BC–4620 BC
380–390	LU-3736	5950 ± 50	4904 BC–4784 BC
400–410	LU-3737	6130 ± 40	5196 BC–4960 BC
410–420	LU-3810	6320 ± 100	5420 BC–5080 BC
420–426	LU-3738	6370 ± 60	5422 BC–5258 BC

The damp and warm climate of the Atlantic was responsible for expansion of pine-birch forests with an admixture of broad-leaved species (elm, linden, and oak) and dark alder forests (*Alnus*, max 20% in AT-2). The upper boundary of the Atlantic was synchronous with the time of decreased pollen percentage of the broad-leaved species and also with increasing spruce pollen frequencies. Pollen zone AT-3 was characterized by the maximum percentage of broad-leaved pollen, including oak and beech (7%–9%).

During the Subboreal the contribution of broad-leaved species gradually reduced; however, in pollen zone SB-1 (as well as in AT-3) mixed broad-leaved forests were still widespread. Their share in the vegetation cover of the area declined in pollen zone SB-2; *Ulmus* pollen appeared first on the diagram but disappeared last (ca. 1140 ± 40 BP). The expansion of dark coniferous forests caused by increasing climatic moisture took place during pollen zone SB-2, SB-3, and most of the Subatlantic (SA-1 and SA-2), that is, within the age range of 3200–1000 BP.

During the Subatlantic, pine and birch-pine forests were widespread and the share of spruce gradually decreased. The percentage of spruce in the pollen spectra reached 40% within the time period ca. 3200–3000 BP, 20% within the limit ca. 2200–1100 BP, and did not exceed 4–5% from ca. 850 ± 40 BP to the present.

DISCUSSION

The arboreal (AP), herb (NAP), and spore (Sporae)-curves throughout the Holocene were compared for all the diagrams (Figs. 1–5). In pollen zone SA-3, the abrupt reduction in pollen percentages of arboreal species (AP) and increase of *Sphagnum* spores (with the exception of the Vishnevskoye Lake section) was clear-cut. All sections had similar *Picea*-curves including clear maxima in pollen percentages during the Subboreal. Toward the end of pollen zone SA-3 the frequency of spruce pollen decreases sharply (to 2–5%). The *Pinus*-curve was continuous throughout the entire Holocene with a noticeable increase of *Pinus* pollen value in the Subatlantic. The percentages of *Pinus* pollen in the bog sediments studied was less (on average) than in the Vishnevskoye Lake ones, where its percentages varied from 30% to 65% during the Holocene. This makes the reconstruction of forest composition using palynological data of these lake sediments difficult. The *Betula* curve was also unbroken throughout the Late Glacial and Holocene. The maximum amount of *Betula sect. Albae* pollen was noted in PB and BO and a relatively smaller maximum of it in SA. The maximum amount of *Betula sect. Fruticosae* pollen was observed in the Late Glacial, with smaller (except for one) in the Subatlantic sediments (see the Nikolsko-Lutinskoye and Sirinsky Mokh sections). The maximal amount of *Betula nana*-pollen was found in Late Glacial sediments.

All diagrams showed similarities in the *Alnus* curves and time-transgressive changes from alder on a north-south axis (Table 6). The appearance of alder in the southernmost section, Nikolsko-Lutinskoye, was dated at 9650 ± 240 BP and in the more northern Suo at 7770 ± 50 BP.

The beginning of the continuous curve for pollen of the broad-leaved species occurred in the BO. The distinct time-transgressive change in representation of the thermophilous flora from south to north and then its disappearance from the forests after the end of SB is notable (Table 6). The maximal total amount of the broad-leaved and hazel pollen corresponds to the end of the Atlantic (AT-3) in all bog sediments studied and to the beginning of AT (AT-1) in the lake sediments (the section from Vishnevskoye Lake).

The palynozones indicated on chrono-palynological diagrams (Figs. 1–5) were related to the ^{14}C scale by dating of nearly every 10 cm layer of sediments (Tables 1–5).

About 300 dates were obtained for 6 sections located in Leningrad and Novgorod provinces (Tables 1–5) and for 2 in Karelia (the results from the last 2 sections were published in Elina et al. (1996)). Such detailed investigations were carried out for the first time in this area. As a whole, we found that the palynological zones conformed with natural events equated to the climatic periods of the Blytt-Sernander scheme and subperiods (phases) according to Khotinsky (1977). Consideration of all the data obtained makes it possible to define the chronological boundaries between palynozones and the climatic phases (Table 7).

We used information-statistical methods (Klimanov 1976) to reconstruct the quantitative characteristics of the Late Glacial and Holocene climates. This method is based on the statistical correlation between data from recent spore-pollen spectra and recent climatic conditions; the average statistical error in determining the mean temperature for July and per year is ±0.6 °C, the mean for January is ±1 °C, and the average annual precipitation is ± 25 mm.

Paleoclimatic reconstructions were made for all 6 sections. The paleoclimatic curves show that they complement each other: for example, the Little Ice Age is reflected in more detail by the Lammin-Suo and Shirinsky Mokh sections, and the Subboreal by the Suo section. Figure 6 shows the correlation between the average annual paleotemperatures for all the sections studied and the time scale.

Table 6 Dynamics of the indicator arboreal species and alder during the Holocene in the area of modern Leningrad and Novgorod provinces

Section names	*Picea*		*Alnus*	Broad-leaved species						*Corylus*	
				Total pollen sum			*Ulnus*	*Tilia*	*Quersus*		
	EB[a]	Abrupt reduction	EB	EB	Maximum	Abrupt reduction	EB	EB	EB	EB	Abrupt reduction
Nikolsko-Lutin-skoye	9040 ± 250	Between 600 ± 50 and 720 ± 170	Between 9650 ± 240 and 10,360 ± 140	9040 ± 160	Between 4320 ± 60 and 4350 ± 80	780 ± 70	9040 ± 160	7060 ± 80	6450 ± 90	9040 ± 250	2320 ± 80
Shirinsky Mokh	8400 ± 50	Between 100 ± 40 and 240 ± 60	8230 ± 70	Between 8400 ± 70 and 8590 ± 70	Between 4590 ± 60 and 5030 ± 90	980 ± 40	Between 8400 ± 70 and 8590 ± 70	7630 ± 70	Between 6120 ± 100 and 6640 ± 80	8580 ± 50	2820 ± 60
Lammin-Suo	Between 6590 ± 60 and 6860 ± 60	Between 490 ± 60 and 650 ± 80	7770 ± 50	7770 ± 50	5610 ± 70	Between 1410 ± 50 and 650 ± 80	7770 ± 50	7170 ± 70	Between 6590 ± 60 and 6860 ± 60	7490 ± 90	3120 ± 60
Vishnevskoye Lake	Between 7690 ± 190 and 8270 ± 260	<1600 ± 80	9170 ± 170	9170 ± 170	Between 7030 ± 330 and 7690 ± 190	Between 2580 ± 150 and 2990 ± 110	9170 ± 170	Between 7690 ± 190 and 8270 ± 260	Between 5560 ± 170 and 5600 ± 100	9670 ± 200	Between 4610 ± 90 and 4730 ± 130
Sakkala	5950 ± 50	<730 ± 50	—	—	4490 ± 1000	2650 ± 50	—	5840 ± 50	5170 ± 50	—	3830 ± 80
Suo	Between 4620 ± 160 and 6110 ± 60	850 ± 40	Between 6770 ± 180 and 9000 ± 230	Between 6780 ± 180 and 9000 ± 230	Between 4620 ± 160 and 6110 ± 220	3210 ± 80	Between 6780 ± 180 and 9000 ± 230	Between 4620 ± 160 and 6110 ± 220	Between 4140 ± 120 and 4250 ± 90	Between 6780 ± 180 and 9000 ± 230	Between 4140 ± 130 and 425 ± 90

[a]The empirical boundary (EB) is a level after which pollen of a particular species occurs constantly (Neustadt 1965).

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The values of annual precipitation could not be averaged because there was no clear correlation between precipitation and temperatures in different sections and the data only show local changes.

In the graph, the changes of paleotemperatures ($\Delta t°_a$) are represented as variations from recent temperature values (Fig. 6). Recent climatic parameters (Climatic Atlas 1990) for the sections under study were, on average, as follows: mean July temperatures around 17–18 °C, mean January temperatures 8–9 °C, average annual temperature 3–5 °C and average precipitation of 600 mm per year.

We will not discuss here the quantitative characteristics of $\Delta t°_a$ because they are shown in the figures. We shall consider the time of extremes of climatic deterioration and amelioration. The oldest ^{14}C date (ca. 11,270 BP) obtained for the section Nikolsko-Lutinskoye delineated the maximum of the Allerød climatic amelioration. The date of ca. 10,680 BP registers the maximum of the climatic deterioration in DR-3, a date very close to the those for climatic deterioration in other regions of Northern Eurasia (ca. 10,500 BP). It should be noted that during all periods of the Late Glacial, there was less precipitation than now; when the natural conditions changed to cold ones, the quantity of precipitation was reduced, and vice versa. During the Preboreal we noted 2 climatic ameliorations (ca. 10,000 and 9400 BP) and 2 deteriorations (ca. 9600 and 9100 BP). In the Boreal we recorded 3 climatic ameliorations and 3 deteriorations with one average maximal climatic amelioration, which took place in the territory of Northern Eurasia around 8500 BP.

One more climatic deterioration was noted at the boundary of BO and AT. It was dated at ca. 8200 BP. After that, the temperatures did not fall below recent values during the entire Atlantic; this fact had been observed earlier in Karelia (Elina et al. 1996). A number of climatic ameliorations separated by deteriorations have been reconstructed for the Atlantic (see Fig. 6). As a whole, their ^{14}C dates are very similar for all sections and have been found to be in good agreement with dates obtained earlier for other regions of Northern Eurasia. We recorded a climatic deterioration at the boundary of the AT and SB dated at ca. 4500 BP. In the Subboreal, a number of climatic ameliorations with a maximum ca. 3500 BP was noted. At the boundary of SB and SA, the climatic deterioration was dated 2500 BP. During the Subatlantic, a number of climatic ameliorations are clearly evident in Figure 1 of the Nikolsko-Lutinskoye section. The little climatic optimum of the Middle Ages and the Little Ice Age are well expressed here; during the Little Ice Age, climatic ameliorations and deteriorations were repeated again and the maximal deterioration was dated at ca. 200 BP.

Thus, this meticulous study of the sections, both palynologically and using the ^{14}C method, enables us to trace the detailed dynamics of climatic changes during the Holocene. It is evident from the paleoclimatic curves that the trend was towards warmer natural conditions from the Late Glacial to the Holocene optimum (ca. 5000–6000 BP) and then toward colder ones. The trend toward climatic deterioration during the Little Ice Age is very clear. The amplitudes of changes in winter temperatures were greater than those of summer ones. As a whole, the ^{14}C dates of climatic ameliorations and deteriorations (within the limits of the method's error) confirm each other well, with both the data of the sections under study and those studied earlier (Klimanov 1989; Elina et al. 1996); thus, they support the hypothesis that large climatic changes (above all, temperatures) were synchronous in the past. As for precipitation, there is no distinctive correlation for different regions and different periods, but it can be said that in the region under study, climatic ameliorations were followed by increased precipitation, and vice versa, decreased precipitation followed the deteriorations.

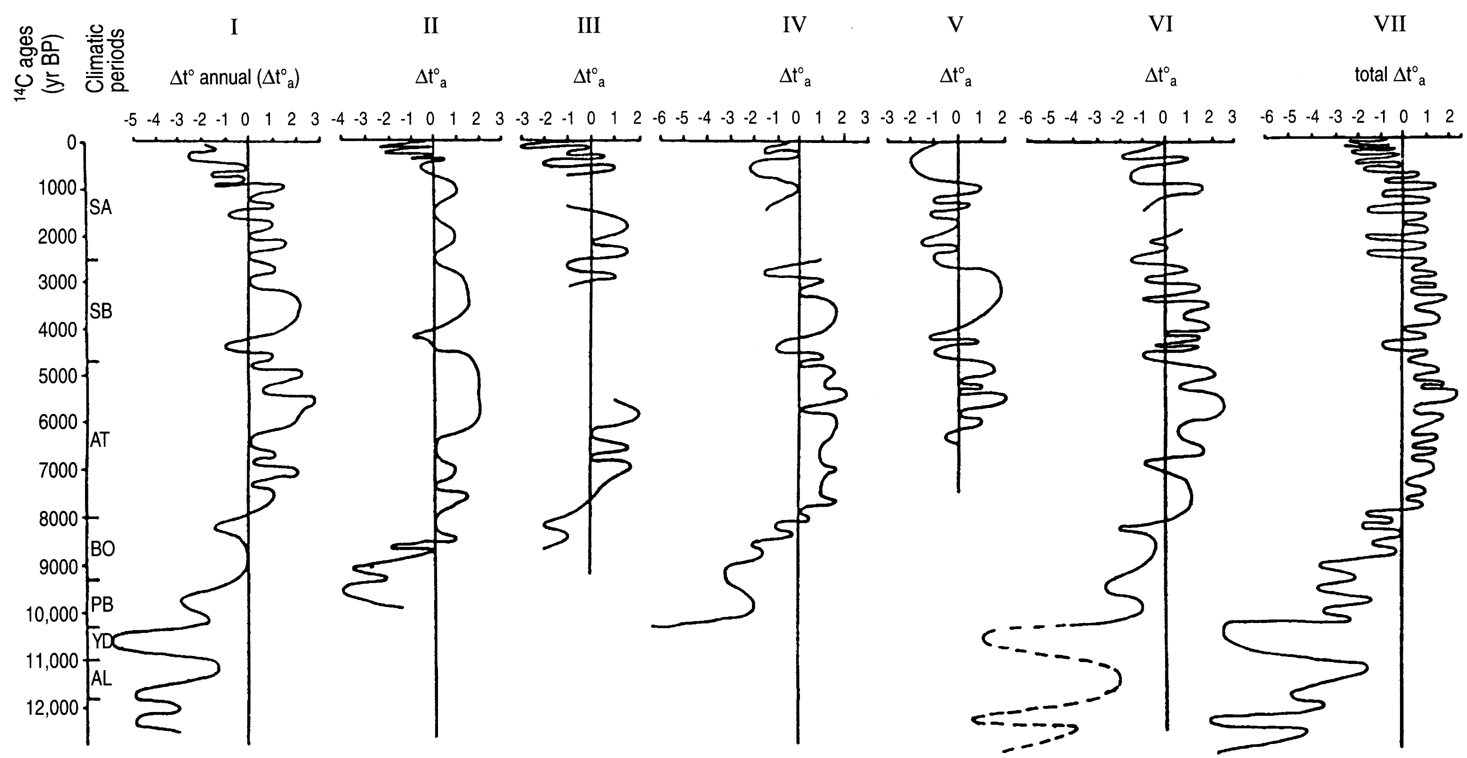

Figure 6 Deviations of the average annual temperatures ($\Delta t°_a$) from the recent temperature values during the Late Glacial and Holocene in Northwestern Russia reconstructed on the basis of chrono-palynological data of the bog and lake sediments studied. I. Nikolsko-Lutinskoye bog section; II. Shirinsky Mokh bog section; III. Lammin-Suo bog section; IV. Vishnevskoye Lake section; V. Sakkala bog section; VI. Suo bog section; VII. Total curve of annual temperature deviations.

https://doi.org/10.1017/S0033822200019317 Published online by Cambridge University Press

Table 7 ^{14}C Chronology of Holocene climatic periods and subperiods (phases) in northwestern Russia[a]

Climatic period	Climatic phase	^{14}C age (yr BP)
Preboreal	PB-1	10,000–9800
	PB-2	9800–9300
Boreal	BO-1	9300–9000
	BO-2	9000–8500
	BO-3	8500–8000
Atlantic	AT-1	8000–7000
	AT-2	7000–6000
	AT-3	6000–4700
Subboreal	SB-1	4700–4200
	SB-2	4200–3100
	SB-3	3100–2500
Subatlantic	SA-1	2500–1700
	SA-2	1700–800
	SA-3	800–0

[a]As new data become available, this scale will be made more precise.

CONCLUSION

For the first time, detailed palynological and geochronological studies have been made of sections of continuous bog and lake sediments of northwestern Russia to mark out palynological zones, date them by the ^{14}C method, and correlate them with climatic periods and phases. The data obtained enable us to reconstruct a vegetation history and to monitor the forest dynamics of northwestern Russia as well as the gradual appearance of the indicator species of trees from the Preboreal onwards. We have set up a ^{14}C chronology for the stages of vegetation development and paleoclimate changes during the Holocene.

ACKNOWLEDGMENTS

We are grateful to Fedor Maksimov, Elena Makarova, and Valentina Andrutskaya for the chemical treatment of samples, for dating, and for palynological analysis. This work was supported by the Russian Foundation of Fundamental Research (Grants N 94-05-17670 and N 96-05-6167).

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