

First Data on the Middle to Late Holocene Dynamics of Vegetation in the Upper Kama Region

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Abstract—A detailed palynological record and the results of radiocarbon dating of sediments from the Dedyukhinskii floodplain massif in the vicinity of Lake Chashkinskoe (the Upper Kama region; 59°23' N, 56°34.5' E) have been used to reconstruct basic stages in the Middle to Late Holocene dynamics of vegetation. The results show that in the Atlantic period broadleaf tree species played a secondary role in forest formations of taiga and subtaiga types. Broadleaf–conifer forests became dominant in the Subboreal period, with fir widely spreading in the forests during its second half. During the Subatlantic period, forest formations acquired their recent taiga character.

Keywords: palynological analysis, radiocarbon dating, vegetation, mammal fauna, archaeological sites, Middle and Late Holocene, Upper Kama region

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Studies on reconstructing paleoecological conditions in the Upper Kama region have been initiated only in recent years [1, 2]. On the other hand, numerous archaeological sites have been investigated there [3], and paleoecological data are therefore important for reconstructing the environment of ancient man.

In the territory of Perm Krai, only fragmentary palynological data supported by the results of radiocarbon analysis have been obtained to date [4–6]. Palynological research in the Upper Kama region, in the vicinity of Lake Chashkinskoe, began with studies on cultural layers in archaeological sites Lake Chashkinskoe IV and Lake Chashkinskoe II, which provided a basis for characterizing plant paleocommunities of the Neolithic and Eneolithic periods [7, 8].

The purpose of this study was to integrate the initial palynological data and the results of radiocarbon dating of organogenic deposits from Dedyukhinskii Island (adjoining the Lake Chashkinskoe sites) in order to reconstruct the paleovegetation of the region during the Middle and Late Holocene.

STUDY REGION, OBJECTS, AND METHODS

The swamped floodplain massif named Dedyukhinskii Island is near the cities of Solikamsk and Berezniki, Perm Krai (59°23' N, 56°34.5' E). It consists of seven different-aged floodplain generations

(Fig. 1) and is bordered on the right (in the downstream direction) by the Kama River channel opposite of the village of Pyskor and on the left by Lake Chashkinskoe. This lake is actually a system of interconnected oxbow lakes that separates the island from the accumulative terrace of the Kama where all archaeological sites are concentrated [9].

The climate of this region is moderately continental, with warm summers and cold winters: the January and July isotherms of –16°C and 17.5°C pass near Berezniki. Annual precipitation is about 600–700 mm [10].

The study region is near the boundary of middle and southern taiga fir–spruce forests [11] that are dominated by *Picea obovata* Ledeb. and *Abies sibirica* Ledeb. and also include pines (*Pinus sylvestris* L. and *P. sibirica* Du Tour) and larch (*Larix sibirica* Ledeb.). Birches (*Betula pendula* Roth. and *B. pubescens* Ehrh.), aspen (*Populus tremula* L.), and alder (*Alnus incana* (L.) Moench.) form small-leaved forests, particularly along riverbanks and peatland margins, and occur as an admixture in dark conifer stands. In southern taiga forests, linden (*Tilia cordata* Mill.) grows in the understory, and elms (*Ulmus laevis* Pall. and *U. glabra* Huds.) often occur in river valleys. The herb–dwarf shrub layer is composed by boreal and nemoral species. The moss layer is thin and discontinuous. Today, secondary pine–birch and spruce–birch

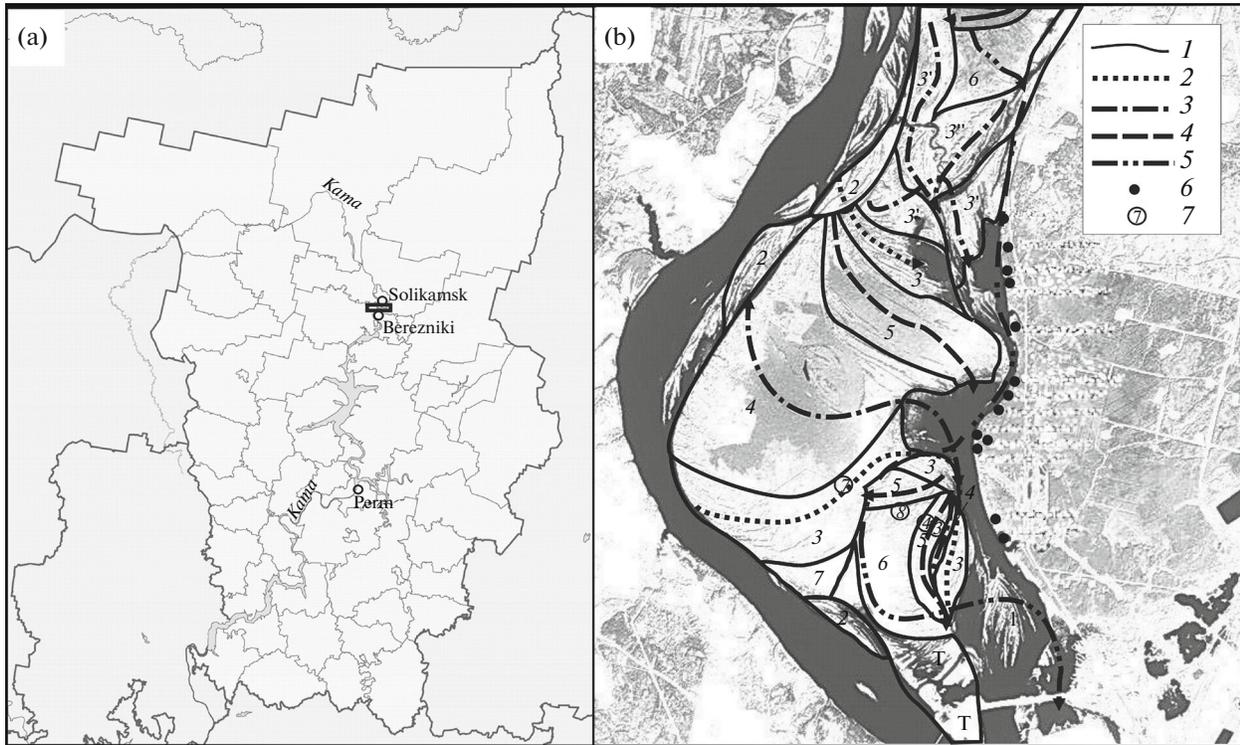


Fig. 1. Schemes of (a) location of the study region and (b) geomorphology of the Dedyukhinskii floodplain massif and Lake Chashkinskoe: (1–6) numbers of different-aged floodplain generations ($3'$ and $3''$ are different variants of the 3rd generation formed during the development of watercourses that straightened the Chashkinskii floodplain massif); (1) boundaries between different-aged floodplain generations; (2–5) reconstructed positions of the channel during the formation of (2) the third, (3) fourth, (4) fifth, and (5) sixth floodplain generations; (6) archaeological sites; (7) core sampling sites, with the figure in the circle indicating core number (DED-3, DED-4, DED-7, DED-8).

forests are widespread in the Lake Chashkinskoe region.

Core samples for radiocarbon, palynological, and paleocarpological analyses from swamped paleochannels on Dedyukhinskii Island were collected using manual drilling equipment (Eijkelkamp Soil & Water, The Netherlands). Samples for palynological analysis were taken at 5-cm intervals from four cores (DED-4, DED-3, DED-7, and DED-8) belonging to different floodplain generations (Fig. 1) and processed in the laboratory by the conventional procedure [12]. In each sample, no less than 500 pollen grains of tree species were counted and, in parallel, record was taken of shrub and herb pollen and spores of higher sporophytes. On the whole, 122 samples of organogenic deposits were analyzed. The contents of pollen of individual tree species were calculated relative to the sum total of tree pollen grains taken as 100%; the contents of pollen of shrub and herb species and spores of higher sporophytes, relative to the sum total of tree, shrub, and herb pollen. Spore–pollen diagrams (SPDs) were constructed with TILIA and TILIA-Graph software [13]. Based on the results of visual examination and cluster analysis with CONISS software, spore–pollen spectra (SPSs) were combined

into local palynozones (LPZs), which were numbered using a unified system [14].

Vegetation types were identified by the biomization method, which was developed for vegetation and climate modeling based on the biome concept [15, 16, etc.]. Its essence is that the paleovegetation is reconstructed using not an individual palynotaxon but a group of taxa belonging to a certain functional vegetation type, which are combined into biomes.

The radiocarbon age of the samples was determined in the Laboratory of Isotope Geochemistry and Geochronology (Geological Institute, Russian Academy of Sciences, Moscow) and Laboratorium Datowań Bezwzględnych (Krakow, Poland). Radiocarbon dates were calibrated using CALIB software and the IntCal13 calibration curve [17]. The age–depth models for the core samples were constructed with Bchron 3.1 [18]. The subdivision of the Holocene into periods and phases in the development of vegetation followed the modified Blytt–Sernander system [19], with the Middle–Late Holocene boundary being delimited according to Walker et al. [20].

Radiocarbon dates and their calendar values for core samples from Dedyukhinskii Island

Pit	Depth, cm	Material	Laboratory index and number	¹⁴ C date, years	Calibrated age, years BP		
					median*	1σ, 68% probability	2σ, 95% probability
DED-8	195–200	Peat	MKL-2654	5110 ± 70	5837	5924–5749	5993–5662
	225–230	Peat	MKL-2653	5590 ± 100	6387	6478–6291	6634–6208
	255–270	Peaty loam	GIN-15049	6150 ± 40	7059	7156–6991	7164–6943
DED-4	130–135	Peat	MKL-2655	3320 ± 40	3547	3592–3481	3640–3453
	205–210	Peat	MKL-2656	4790 ± 40	5518	5589–5476	5602–5333
	230–240	Peaty loam	GIN-15045	5220 ± 100	6000	6178–5904	6269–5746
DED-3	105–110	Peat	MKL-2657	2950 ± 50	3107	3177–3007	3320–2957
	130–135	Peat	MKL-2658	3410 ± 60	3665	3811–3576	3835–3494
	220–230	Peaty loam	GIN-15044	4350 ± 40	4921	4960–4859	5038–4843
DED-7	50–55	Peat	MKL-2651	1570 ± 60	1464	1530–1404	1597–1337
	125–130	Peat	MKL-2652	2240 ± 50	2234	2331–2159	2348–2146
	140–150	Peaty loam	GIN-15048	2610 ± 50	2744	2784–2712	2846–2501

* The medians were calculated for the intervals in which the true date was included with probabilities of 68 and 95%.

RESULTS AND DISCUSSION

Radiocarbon analysis. Twelve radiocarbon dates were obtained for peat and peaty loam samples from the deposits filling four paleochannels and found to be well coherent with each other within each core (table). These dates and four age–depth models constructed on their basis were used for determining the calendar ages of deposits and corresponding SPSs and for periodization and correlation of SPDs and time boundaries of successions in plant paleocommunities.

The age–depth models reflected, in general, the accumulation rate of organogenic deposits in the second half of the Holocene (Figs. 2a–2d). Since only three dates were obtained for each well, no distinct trends of change in the rate of peat accumulation could be revealed, as in the case of wells DED-4 and DED-8 where the depth–age relationship was almost linear. The rate of peat accumulation in the DED-3 model was found to decrease between approximately 3800 and 3000 cal. BP (Fig. 2a), which could be explained by less favorable climatic conditions than in the previous and subsequent periods. In the DED-7 model, conversely, an increase in this rate was revealed in the interval of ~2400–1500 cal. BP, which could be due to regional climatic events and/or local transformation of vegetation in a given bog.

Palynological analysis. Among four SPDs based on the results of palynological analysis, the most detailed one was obtained for core DED-4 and complemented by data for DED-8 (Fig. 3). The data for cores DED-3 and DED-7 were fairly similar to those on DED-4 and are therefore presented in an abridged form in the correlation scheme (Fig. 4). Their comparative analy-

sis was performed with regard mainly to changes in the contents of pollen grains of tree species, since their proportion in all SPSs exceeded 80% (spectra of the forest type). On this basis, two LPZs were distinguished.

LPZ-1 (~7600–3400 cal. BP) was identified in the SPDs of cores DED-8 (depth 280–180 cm), DED-4 (235–125 cm), and DED-3 (175–120 cm). It is characterized by a gradual increase in the total proportion of broadleaf tree species (*Quercetum mixtum*) to a maximum of over 10% and sporadic occurrence of *Abies sibirica* in certain SPSs, against the background of high contents of *Picea*, *Betula* sect. *Albae*, and *Pinus sylvestris* pollen (20–40, 40–60, and 20–50%, respectively). The total proportion of pollen grains from broadleaf species and spruce exceeds the contents of these palynotypes in the subrecent SPSs for the study region [7]. The majority of spectra in LPZ-1 include stomata of the *Picea* type, indicating that spruce was growing in this region. The proportion of *Pinus sylvestris* pollen grains in some SPS is no higher than 25%, indicating that the contribution of pine to tree stand composition was probably insignificant, with the occurrence of its pollen being due to long-distance transfer by wind. On the other hand, certain SPSs contain up to 50–55% of pine pollen grains, which is evidence that the proportion of pine in the forest was increasing during short time intervals. The presence of pine in the stand is confirmed by the occurrence of single *Pinus*-type stomata. Some spectra include single *Abies sibirica* pollen grains. In single SPSs, birch pollen (*Betula* sect. *Albae*) is dominant (50–60%), indicating a probable increase in the proportion of

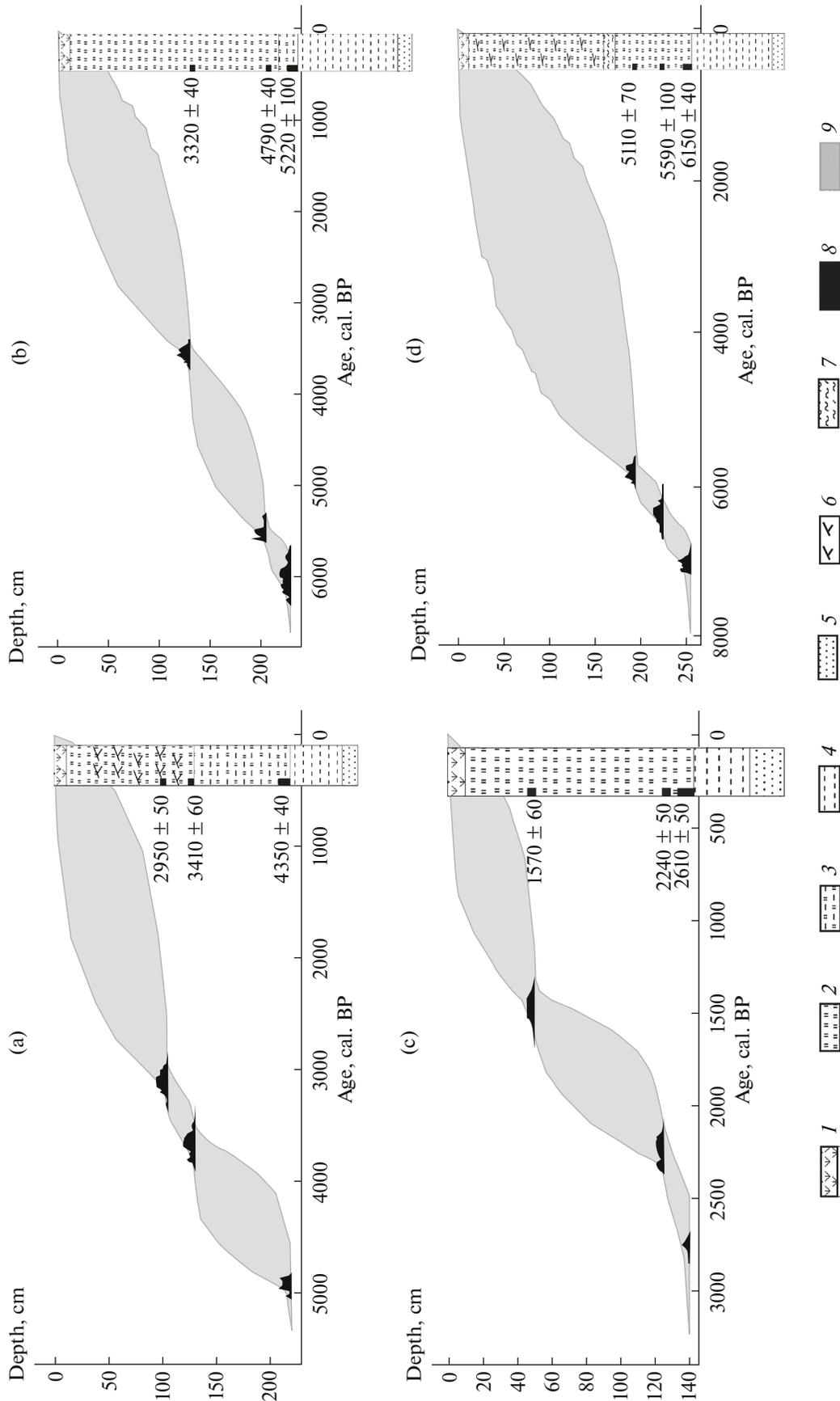


Fig. 2. Lithology and depth–age models of deposits from Dedyukhinskii island: (a) DED-3, (b) DED-4, (c) DED-7, (d) DED-8. Lithological column legend (here and in Fig. 3): (1) sod, (2) brown to black peat, (3) peaty loam, (4) heavy gray loam, (5) sand, (6) wood remains in peat, (7) saproel; (8) points of sampling for radiocarbon analysis; (9) age model (95% probability).

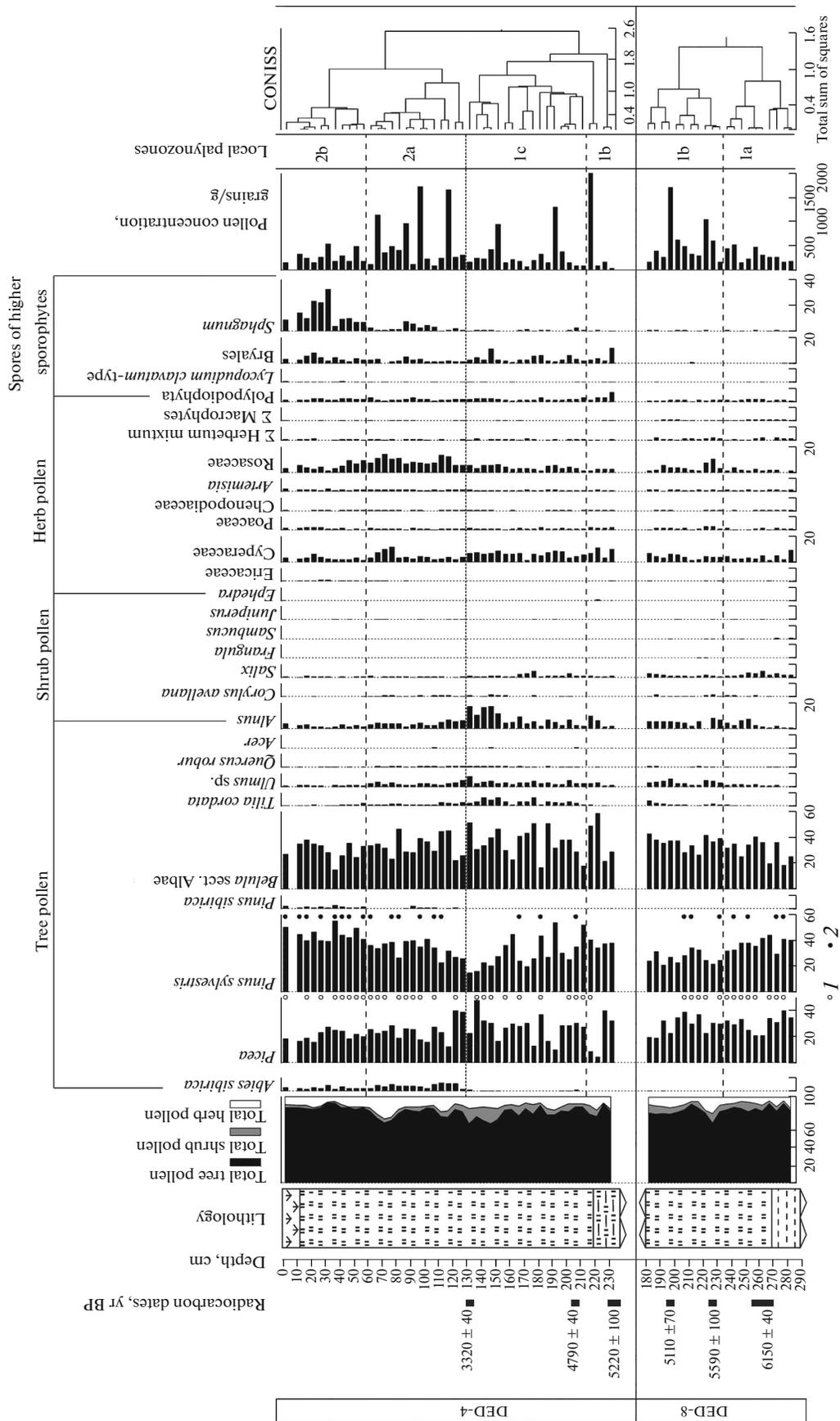


Fig. 3. Abridged spore–pollen diagrams of deposits in cores DED-4 and DED-8 from Dedyukhinskii island (1, *Picea*-type stomata; 2, *Pinus*-type stomata).

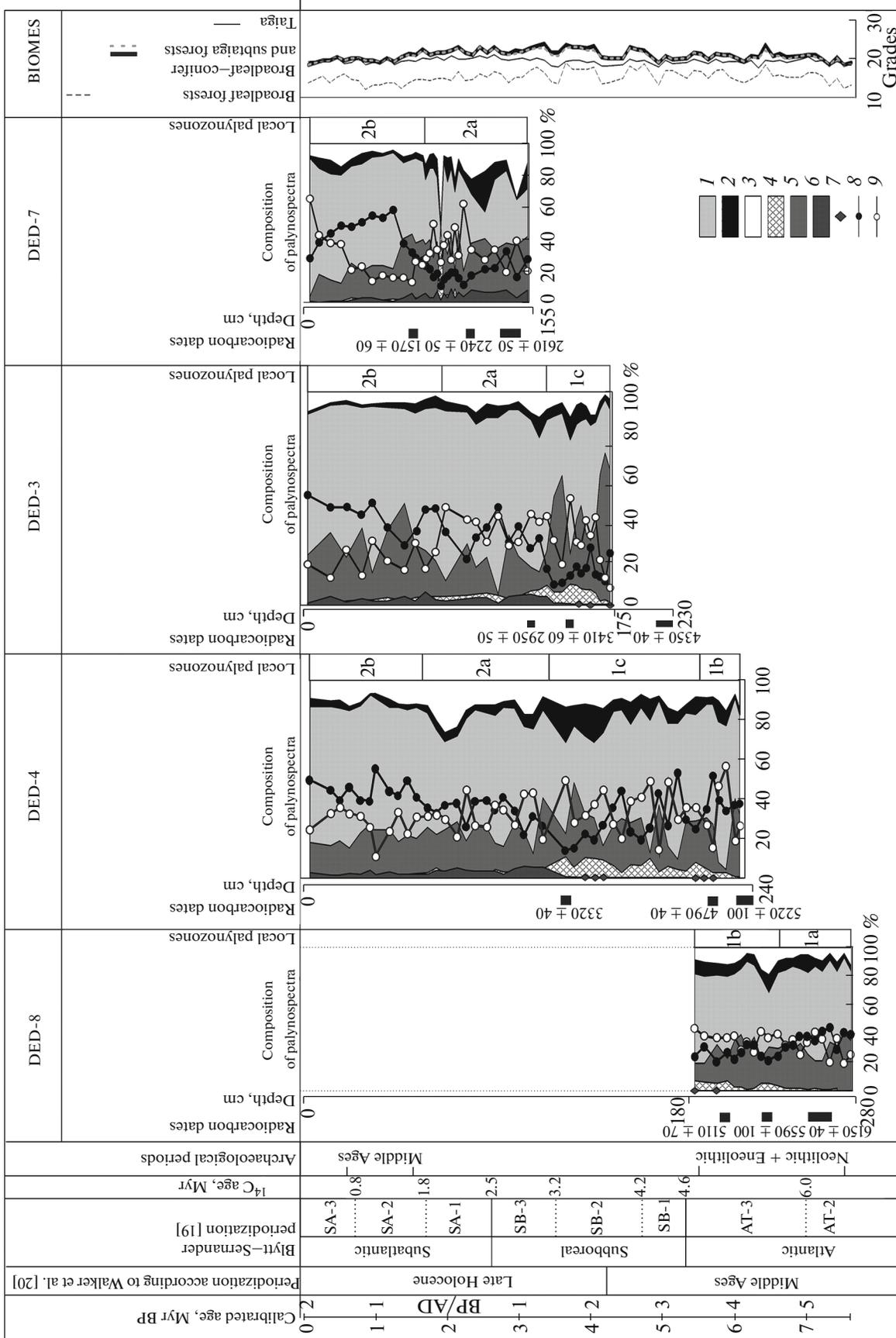


Fig. 4. Comparison of palynological data for core samples from Dedyukhinskii island and reconstruction of biomes for the study region: (1) total tree pollen, (2) total shrub pollen, (3) total land herb pollen, (4) total broadleaf tree pollen (Quercetum mixtum: *Tilia cordata*, *Quercus robur*, *Ulmus* sp.), (5) spruce pollen (*Picea*), (6) fir pollen (*Abies sibirica*), (7) pine pollen (*Pinus sibirica*), (8) birch pollen (*Betula* sect. *Albae*).

birch species in the stand. Birch is a permanent companion for spruce, and the increase in the content of its pollen against the background of decrease in the content of spruce pollen is likely to reflect mainly natural, successional changes in tree stand composition. Three subpalynozones can be distinguished within LPZ-1, which characterize the Middle Holocene and early Late Holocene [20] within the second half of the Atlantic to the first half of the Subboreal period [19] (Figs. 3, 4).

LPZ-2 (3400 cal. BP–present time) was identified in the SPDs of cores DED-4 (125–0 cm), DED-3 (120–0 cm), and DED-7 (150–0 cm) by the maximum content of fir pollen and minimum content of *Quercetum mixtum* pollen (Figs. 3, 4). This LPA is characterized by a continuous curve for *Abies sibirica* pollen and dropping curves for *Ulmus* and *Tilia cordata* pollen, which is clearly seen in the SPD of DED-4 (Fig. 3). The contents of spruce and birch pollen in the majority of SPSs do not differ from those in LPZ-1, except for their short-term fluctuations. *Pinus sylvestris* pollen begins to prevail in the SPS of subpalynozone 2b. LPZ-2 characterizes the Late Holocene [20] within the late Subboreal and Subatlantic periods [19] and is subdivided into two subpalynozones (Figs. 3, 4).

Using the method of biome reconstructions, high scores were obtained only for forest biomes in all SPSs of the core samples (Fig. 4), with the biomes of taiga, broadleaf–conifer, and subtaiga forests of the temperate zone having comparable weights. The weight of the taiga biome remains almost unchanged throughout the time interval under study. Significant changes take place within intervals of 6600–6300, 4800–4500, and 4000–3000 cal. BP, where the broadleaf–conifer and broadleaf forest biomes gain weight. At about 1300 cal. BP, the scores of mixed forest biome decrease to the level of the taiga biome, which, in turn, gains the maximum scope in some SPSs. Fluctuations of the biome curves coincide in most cases with the boundaries of subpalynozones and LPZ.

Reconstruction of paleocommunities. As reconstructed on the basis of palynological data on the Lake Chashkinskoe microregion, the dynamics of vegetation in the Upper Kama region during the Late Holocene were as follows.

The period of about 7600 to 6500 cal. BP was characterized by dominance of taiga and subtaiga vegetation types (Fig. 4). Spruce forests (possible with pine) were dominant until 7100 cal. BP; the proportion of birch was insignificant, and elm occurred sporadically. A decrease in the prevalence of dark conifer forest formations, with an increase in the proportion of birch, took place in 7100 to 6900 cal. BP. Also dated to this period are the first Neolithic sites of the Volga–Kama culture that appeared in the study region (campsites Lake Chashkinskoe IV, VI, and VIII [21]). The recovery of dark conifer formations began at about 6900 cal.

BP. Linden appeared in the tree stand (Fig. 3), and forest formation acquired a subtaiga pattern.

Between 6600 and 6300 cal. BP, the proportions of elm and linden in birch–spruce formations increased, with that of pine being insignificant (Figs. 3, 4). The increase in the proportion of nemoral elements in forests can be attributed to the Holocene climatic optimum (AT-3, 6000–5500 ¹⁴C years [19]). The majority of Neolithic sites of the Kama culture (Khutorskie campsites, Lake Chashkinskoe I) date from that time [21].

During the period of 6300 to 5900 cal. BP, broadleaf species dropped out of the stand composition, probably as a result of short-term cooling (Figs. 3, 4), and taiga-type formations dominated in forests. The Novoiyinsky complex of Lake Chashkinskoe I site was dated to that period [21].

The vegetation acquired a subtaiga pattern in 5900 to 4800 cal. BP: broadleaf species recovered their positions, and elm–linden–spruce forests (probably with fir) became widespread. Our studies confirm that fir expanded to the Cisural region during the late Atlantic period [6, 22] but its proportion in the stand was not significant as yet. The same follows from the results of carpological analysis of cores from Dedyukhinskii Island [2]. The contribution of birch to forest composition increased. The development of the Garinskaya Eneolithic culture (sites Lake Chashkinskoe II and Lake Chashkinskoe III) dates from that period. Small amounts of the archaeological material pertaining to this culture also occur in almost all sites of earlier times, which is evidence that the region had been actively settled by ancient people [21].

The period of 4800 to 3400 cal. BP was the time of dominance of broadleaf–conifer forests (Fig. 4). The peak of expansion of linden–spruce forests with elm, oak, and birch is largely associated with mid-Subboreal thermal maximum between ~4700 and 3400 cal. BP (SB-2, 4200–3200 ¹⁴C years [19]). However, the contents of *Quercetum mixtum* pollen dropped to a minimum of less than 2% at about 4200 cal. BP (Figs. 3, 4) which could be due to the global but short-term cooling between 4200–3800 cal. BP, at the Middle–Late Holocene boundary [20]. After this cooling (by 3400 cal. BP), single grains of fir pollen appeared again in the SPS, forming a continuous curve in the SPDs of cores DED-4 and DED-3 (Figs. 3, 4).

The formation of the recent mammal fauna in the study region was completed by the end of the Middle Holocene. Its core consisted mainly of species belonging to the taiga theriocomplex: the taiga shrew (*Sorex isodon* Turov, 1924), Siberian flying squirrel (*Pteromys volans* L., 1758), red squirrel (*Sciurus vulgaris* L., 1758), Siberian chipmunk (*Tamias sibiricus* Laxmann, 1769), northern birch mouse (*Sicista betulina* Pallas, 1779), wood lemming (*Myopus schisticolor* Liljeborg, 1844), gray red-backed vole (*Craseomys rufocanus* Sundevall, 1846), bank vole (*Myodes glareolus* Schreber, 1780), northern red-backed vole (*M. rutilus* Pallas, 1779),

sable (*Martes zibellina* L., 1758), wolverine (*Gulo gulo* L., 1758), Eurasian lynx (*Lynx lynx* L., 1758), moose (*Alces alces* L., 1758). This fauna also included eurybiotic and azonal species such as the common shrew (*Sorex araneus* L., 1758), mountain hare (*Lepus timidus* L., 1758), Eurasian beaver (*Castor fiber* L., 1758), root vole (*Microtus oeconomus* Pallas, 1776), field vole (*M. agrestis* L., 1761), brown bear (*Ursus arctos* L., 1758), and reindeer (*Rangifer tarandus* Smith, 1827); in addition, species characteristic of deciduous and conifer–deciduous forests were represented by the pine marten (*Martes martes* L., 1758) and badger (*Meles* sp.) [22, 24].

The role of broadleaf species in the composition of forests decreased between 3400 and 1600 cal. BP, and they acquired a subtaiga pattern (Fig. 4). This could be attributed to the Subboreal cooling in 3400–2600 cal. BP (SB-3, 3200–2500 ¹⁴C years [19]). Most prevalent were fir–spruce or spruce–fir formations with birch, pine, and an admixture of broadleaf species. The expansion of fir at that time is confirmed by the results of carpological analysis [2].

In about 1600 cal. BP, forests began to acquire the recent taiga pattern: Siberian stone pine appeared in forest communities, while broadleaf species almost disappeared from the stand. The prevalence of pine was increasing increased along with reduction in the area of broadleaf fir–spruce formations in the vicinities of Lake Chashkinskoe. This was largely due to intensification of economic activities. This microregion was being actively settled by people in the 8th to 14th centuries [21], and their economy was based on livestock and crop husbandry [25, 26]. An important role was also played by metallurgy, for which large amounts of fuel and, consequently, intensive forest cutting were required [3]. These activities stimulated forest succession, which resulted in the expansion of birch and pine formations in place of dark conifer stands.

Today, forests in the vicinities of Lake Chashkinskoe are represented mainly by pine and birch formations that have replaced dark conifer stands and infrequent fir–spruce formations with Siberian stone pine in the overstory and linden in the undergrowth [11].

CONCLUSIONS

A combined analysis of the results of palynological analysis and radiocarbon dating of deposits from the Dedyukhinskii floodplain massif provided data on the main stages in the development of forest vegetation in the region during the Middle and Late Holocene.

From the second half of the Atlantic to the first half of the Subboreal period (~7600–3400 cal. BP), the study region was occupied by mixed spruce-dominated forests of subtaiga type, with broadleaf tree species. Broadleaf–conifer forests were prevalent during intervals of 6500–6300 and 4700–3400 cal. BP, which correlate with the late Atlantic and mid-Subboreal climatic optima, respectively. Judging from the total pro-

portion of broadleaf tree pollen, the mid-Subboreal optimum in the Upper Kama region was more distinct than the late Atlantic optimum, which is in agreement with data on the Vyatka–Kama region [27]. The contribution of broadleaf species to the stand dropped to a minimum at about 4200 cal. BP, probably reflecting the short-term global cooling between 4200–3800 cal. BP, at the Middle–Late Holocene boundary [20]. The late Subboreal cooling (3400–2600 cal. BP) resulted in still lower proportion of broadleaf species and stimulated the development of subtaiga and taiga formations similar to recent southern taiga forests in the study region. Fir began to play a significant role at that time, giving rise to fir–spruce and spruce–fir formations. Beginning from 1600 cal. BP, pine became dominant in the stand. The distribution pattern of different forest types during the Middle and Late Holocene is in good agreement with the results of studied on the history of mammal fauna in the study region [23, 24].

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