Changes of vegetation in the eastern part of Khanka Plain (south of the Russian Far East) at the transition from the Late Pleistocene cryochron (MIS 2) to the Early Holocene

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Abstract. Reconstructions of the vegetation in the eastern part of the Khanka Plain have been performed for the time interval at the transition from the Late Pleistocene cryochron (MIS 2) to the Holocene. New evidence of considerable changes in the vegetation structure were provided by the palynological studies supplemented with radiocarbon dates on wood fragments and plant detritus recovered from alluvial, lacustrine and mires sediments. It has been found that at the glacial stage MIS 2 the Khanka Plain was dominated by open birch forests with larch and spruce, alternating with Sphagnum mires with shrub birch. Later, at the interstadial, formations typical of southern boreal dark coniferous (needle-leaved) taiga became widely spread. The Early Holocene was marked by wide expansion of broadleaf trees (and first of all, elm and Mongolian oak) in the Khanka Plain ecosystems. Mixed forests with Korean pine became widely spread in the mountains surrounding the lowland. Mires, patches of dark coniferous forests, and open forests of larch persisted on the plains adjoining the lake and on swampy valley floors.

1. Introduction
The transition from the Pleistocene glacial epoch MIS 2 to the Holocene occurred ~11,700 cal BP [1] and was marked by a sharp warming that resulted in conspicuous changes of biota in the natural systems. The changes were particularly conspicuous in the middle latitudes. Under conditions of a fast warming of climate, the ecosystems were actively restructuring, their constituents relatively quickly responding to the changing environments [2; 3]. A considerable rise of annual temperature led to essential changes in phytocoenoses, which resulted from the activated migrations of plants. Therefore the structural vegetation units typical of MIS 2 have no analogs in the modern vegetation of the southern Far East. The predicted global warming could activate once more a migration of plants, which would change the landscape appearance and would have various, including negative, consequences for humans. That accounts for a great significance attached to the analysis of the landscapes and climate at the transition from the MIS 2 glacial time to the Holocene; the data obtained are shedding light on the current processes and help in modeling the ecosystem response to the expected climate changes.

The recent decades are marked by accumulation of a great volume of paleogeographic data on the state of the ecosystem components in the southern Far East at the end of the Late Pleistocene – beginning of Early Holocene [4; 5; 6; 7]. The biostratigraphic data on the Khanka Plain were insufficient for estimating adequately the changes in vegetation at the Late Pleistocene/Holocene boundary – probably due to scarcity of investigated sequences including the Late Pleistocene – Early Holocene deposits. This paper presents some new data that can expand the understanding of the evolution of vegetation on the
Khanka Plain under conditions of an abrupt climate change at the transition from the Late Pleistocene to Early Holocene.

The climate of the Khanka Plain is determined by the interaction of two baric areas. The direction of their gradients changes twice a year. In winter western winds and strong frosts usually predominate. In summer air masses are transported from the ocean to the continent. The cyclonic activity is the most intensive one between June and August. In the east of the plain the mean annual temperature is 2.4°C, mean annual precipitation is 660 mm.

Thin forests of oak (*Quercus mongolica*), birch (*Betula dahurica*), and tree – scrub thickets of oak, lespedeza, and hazel dominate in vegetation of the eastern part of the Pre-Khanka plain. Meadows were formed in situ of arable fields. The reed-grass, sedge and grass swamps, meadows, and forbs occupy the eastern shores of Lake Khanka and the river floodplains. The mountain frame of the eastern part the Pre-Khanka plain is covered by coniferous-broad-leaved forests with Korean pine (*Pinus koraiensis*) [8].

2. Materials and methods

2.1. Object and material of research

Samples were taken from cross-section 6276 and from boreholes 579 and 508 in the eastern sector of the Khanka Plain (figure 1; table 1). Cross-section 6276 was laid manually in the eastern sector on the floodplain terrace of the Belaya River (table 2). Using a drilling rig based on a GAZ-66 automobile, borehole 579 was drilled from the ice surface of Lake Khanka, where its depth is 1.3 m (1.3 km from its eastern shore) (table 3). Borehole 508 was drilled in the lower reaches of the Sorochevka River by the same method (table 4).

![Figure 1. Locations of the boreholes and cross-section.](image-url)

**Table 1.** Location and geomorphological position of boreholes (bor.) and cross-section.

| Boreholes (bor.), cross-section | Location and geomorphological position                                      | Altitude (m a.s.l.) |
|--------------------------------|---------------------------------------------------------------------------|---------------------|
| cross-section 6276             | 44°57'30" N, 133°08'03" E Small dry valley near Novorusanovka settlement | 70                  |
| bor. 579                       | 44°52'44" N, 132°39'48" E Lake Khanka water area, 1.3 km from its eastern coast | 67 (water depth 1.5 m) |
| bor. 508                       | 44°51'16" N, 133°02'47" E Floodplain of the Sorochevka River near Chkalovskoye settlement | 78                  |
### Table 2. Lithology of the sediments from cross-section 6276.

| Lithology                              | Interval, m |
|----------------------------------------|-------------|
| Brown peat                             | 0-0.87      |
| Dark-grey loam                         | 0.87-2.0    |

### Table 3. Lithology of the sediments from borehole 579.

| Lithology                                      | Interval, m |
|-----------------------------------------------|-------------|
| Dark-grey sand, fine                          | 0.0-0.7     |
| Dark-grey sandy-loam                          | 0.7-1.5     |
| Gray sand, fine                               | 1.5-1.8     |
| Gray loam                                     | 1.8-2.0     |
| Dark-grey sand                                | 2.0-4.3     |
| Gumified sand with plant detritus             | 4.3-5.6     |
| Gray-green sand with gravel                   | 5.6-6.1     |
| Greenish-gray loam                            | 6.1-7.3     |
| Greenish-gray loam with fine sand lenses      | 7.3-9.0     |
| Greenish-gray sand крупнозернистый             | 9.0-12.1    |
| Greenish-gray loam                            | 12.1-13.3   |
| Greenish-gray sandy loam                      | 13.3-14.9   |
| Gray sand                                     | 14.9-15.9   |

### Table 4. Lithology of the sediments from borehole 508.

| Lithology                                     | Interval, m |
|-----------------------------------------------|-------------|
| Brown-gray loam with wood                     | 0-4.0       |
| Gray sandy loam                               | 4.0-4.5     |
| Sand gray                                     | 4.5-5.5     |

**2.2. Method**

The pollen and spores were identified from 34 samples by N.I. Belyanina and I.G. Gvozdeva using the Micmed-6 and Axio Scope light microscopes at ×400 magnification. The samples were prepared using the technique suggested by L. von Post [9]. The pollen and spores were identified, when possible, to a level of species. In case of microfossils poorly identifiable morphologically, they were determined to a level of genus or family. Proportion of plant groups (trees and shrubs – AP, herbs, grass, and dwarf shrubs – NAP, spores) was calculated in percent of the total amount of microfossils. Individual taxa participation was also expressed as a percentage of total pollen quantity. The results of the palynological analysis are demonstrated in diagrams using Tilia software [10].

Tree and plant remains were dated by radiocarbon in the Institute of Geology (Academy of Sciences of Ukraine, Kiev) by N.N. Kovalyukh. The radiocarbon dates were calibrated using the "CalPal" program (calpal online, quickcal2007, version 1.5, http://www.calpal-online.de) [11] (table 5). The correlation of the biostratigraphic data was based on the stratigraphic scheme of the Quaternary developed by the Subcommission on the Quaternary Stratigraphy and the Working Group INTIMATE [1].
Table 5. Radiocarbon dates.

| Boreholes (bor.) and cross-section | Depth, m | Dated material         | Laboratory number | $^{14}$C Age, BP | $^{14}$C-Calibrated Age, cal BP |
|-----------------------------------|----------|------------------------|-------------------|------------------|-------------------------------|
| cross-section 6276                | 1.0      | wood                   | Ki-2174           | 18.580 ± 225     | 22.197 ± 405                  |
| bor. 579                          | 5.2      | humified loam          | Ki-2166           | 17.840 ± 200     | 21.402 ± 453                  |
| bor. 508                          | 4.5      | wood                   | Ki-2171           | 9.680 ± 130      | 11.003 ± 186                  |

3. Results

3.1. Late Pleistocene (MIS 2)

Pollen assemblage which were forming under conditions of cold climate in the glacial epoch (MIS 2), were recovered from layer of the dark brown loam at a depth of 1 m in the small flat-bottom valley ("balka") near Novorusanovka settlement (cross-section 6276). That is suggested by the taxonomic structure of pollen assemblages abounds in shrub birch (*Betula* sect. *Nanae*) and tree of birch (*Betula* sp.), as well shrub alder (*Duschekia* sp.). Pollen grains of alder (*Alnus* sp.), birches (*Betula* sect. *Albae* and *Betula* sect. *Costatae*) are also present. Coniferous plants are represented in the pollen spectra by spruce (*Picea* sp.), larch (*Larix* sp.), as well as by two subgenera of pines (*Pinus* s/g *Haploxylon* and *Pinus* s/g *Diploxylon*). The NAP group includes nettles (*Urtica* sp.) and some members of sedges (Cyperaceae) and Asteraceae families. In the spore group, there were identified Polyopodiaceae and Ophioglossaceae families, as well as clubmosses *Lycopodium* sp. and *Selaginella* sp. The pollen assemblage taxonomy reflects the structure of plant formations typical of cold epoch of the Late Pleistocene, as evidenced by the radiocarbon date 22.197 ± 405 cal BP (Ki-2174) (figure 2).

![Figure 2. Spore-pollen diagram from of the small dry valley near Novorusanovka settlement cross-section 6276. 1 – peat, 2 – loam, 3 – wood. Relationship between plant groups: 4 – trees and shrubs, 5 – herbs and dwarf shrubs, 6 – spores, 7 – the taxa present in the assemblage in amounts less than 3%](image-url)
A slight climate mitigation during an interstadial within MIS 2 is indicated by pollen assemblages recovered from the silt with plant detritus (at a depth of 4.5-6.3 m) of borehole 579. It is dominated by *Picea* pollen, together with an assortment of coniferous and broad-leaved plants: *Pinus s/g Haploxylon*, *Betula sect. Nanae*, fir (*Abies sp.*) and *Betula sect. Albae*, along with a high proportion of marsh herbs and sphagnum moss. As shows the radiocarbon analysis, the age of deposits sampled from the 5.1 m depth is 21.402 ± 453 cal BP (Ki-2166) (figure 3).

**Figure 3.** Spore-pollen diagram of bottom sediments of the Khanka Lake, from borehole 579. For explanation see figure 2. 1 – sand, 2 – gravel, 3 – sandy loam, 4 – plant detritus, 5 – break in sedimentation.
3.2. Early Holocene (MIS 1)

The pollen assemblages in the Sorochevka River floodplain reflected a fast warming of the Early Holocene. These pollen records were obtained from borehole 508 near Chkalovskoye settlement. The sample of blue-gray sandy loam taken from the depth of 4.5 m was dated by radiocarbon at 11,003 ± 186 cal BP (Ki-2171); the pollen assemblage obtained from the layer is noted for a dominance of tree pollen – *Betula* sect. *Nanae*, *Betula* sp. and *Duschekia*. In the accompanying group there are willow (*Salix* sp.), *Alnus*, *Betula* sect. *Albae* and *Betula* sect. *Costatae*. Coniferous group includes pollen of Korean pine (*Pinus koraiensis*), *Picea*, *Larix* sp. and *Abies*. Among broadleaf species there are Mongolian oak (*Quercus mongolica*), hazel (*Corylus* sp.) and elm (*Ulmus* sp.). Typical is a high proportion of *Sphagnum* and *Lycopodium* genus (figure 4).

![Figure 4](image-url)

**Figure 4.** Spore-pollen diagram of floodplain of the Sorochevka River near Chkalovskoye settlement, from borehole 508. For explanation see figure 2; 3.

4. Discussion

Obtained palynological data backed up by the data of the radiocarbon analysis allow us to reconstruct the evolution of the vegetation of the eastern part of the Khanka Plain at the transition from the Late Pleistocene to the Holocene.

According to the results of previous studies, the Khanka lowland appeared to be a wide alluvial plain in the Late Pleistocene [12]. In the cold epoch of the Late Pleistocene at around 22,200 cal BP, the wetlands with shrub birch, shrub alder, and larch with a great number of marsh grass, ferns, club-moss, and mosses were widespread on the plain. The slopes of Sinyi Ridge were covered with sparse dark coniferous forests with domination of spruce and larch. More open, light areas were covered with *Pinus* subgenus *Haploxylon*.

It is quite possible that pollen grains of *Pinus* subgenus *Haploxylon* extracted from the cold Pleistocene epoch sediments are attributable to *Pinus pumila* (Japanese stone pine) [13] which is similar to *Pinus koraiensis* in the pollen grain morphology. That is evidenced by the taxonomic composition of pollen spectra testifying to distribution of light larch and spruce forests with shrubs of birch and alder. Japanese stone pine is light-demanding and poorly competitive species; it can hardly compete with other trees and shrubs and does not form compact communities under a close canopy of trees [14; 15].

Similar changes in vegetation have been recorded in the north of Primorsky Krai (Maritime Territory) in the lower reaches of the Bikin River (46°29’ N, 134°29’ E), about 21,700 cal BP [4].

It should be noted that in the present time the plant formations of that kind were typical of the modern vegetation of the southern part of the Chukchi Peninsula. This is proved by subfossil pollen assemblages with domination of pollen *Betula* sect. *Nanae*, *Duschekia* and *Alnus*. In the NAP group the family Asteraceae pollen prevails together with *Sphagnum* sp. spores [16; 17].

During climate warming in cryochron MIS 2 spruce role increased in vegetation of the Pre-Khanka Plain. Closed forests were formed in the spurs of Sinyi Ridge. South-boreal dark coniferous taiga
formations with domination of *Picea, Abies, Betula* sect. *Albae, Betula* sect. *Nanae, Betula* sp. and *Duschekia* were widespread. It is quite possible that pollen grains of *Pinus* subgenus *Haploxylon* recovered from interstadial sediments in the Pre-Khanka Plain are attributable to *Pinus koraiensis*.

During climate warming in cryochron about 21.200 cal BP in vegetation of the Pre-Khanka Plain increased of spruce role. In the spur of the Sinyi Ridge formed of closed forests. A wide were distribution of south-boreal dark coniferous taiga formations with predominant *Picea, Abies, Betula* sect. *Albae, Betula* sect. *Nanae, Betula* sp. and *Duschekia*. It is quite possible that pollen grains of *Pinus* subgenus *Haploxylon* recovered from interstadial sediments in the Pre-Khanka Plain are attributable to *Pinus koraiensis*. That is suggested by the taxonomic composition of pollen spectra indicative of a wide occurrence of dark coniferous (spruce and fir) forests highly diversified in structure. That is evidenced by taxonomic composition of pollen spectra indicative of wide distribution of dark coniferous (spruce and fir) forests highly diversified in the structure.

Carpological remains earlier extracted from the same depth (5.1 m) in borehole 579 also indicate that taiga formations with *Picea jezoensis*, larch, and shrub birch dominated in the east of the Khanka Plain.

Swampy parts of the plains were occupied with sphagnum mires [5].

Similar pollen assemblages were recovered from the layer of bottom sediments of Lake Karasye (depth interval is 1.7-1.65 m) (42°39'28" N, 130°58'30" E) that was accumulated about 20.600 cal BP [18].

Climatic fluctuations causing the changes in vegetation during warming at the end of the Late Pleistocene cryochron were also recorded in the river basins adjacent to the Pre-Khanka Plain. They have been described in the north of Primorsky Krai (a Maritime Territory), in the lower reaches of the Bikin River, about 14.500 and 13.200 cal BP, where the share of dark coniferous plants, i.e. *Abies* and *Picea*, increased and oak and elm also grew [4]. In Siberia the growing importance of the role of dark coniferous plants in pollen assemblages is also indicative of warming [19]. Taiga on Cape Ochiishi, the Nemuro Peninsula, Eastern Hokkaido between 13.000 and 14.000 cal BP was presented mainly by *Larix gmelinii* with *Picea jezoensis* and/or *Picea glehni* with participation of *Abies sachalinensis* and *Pinus pumila* [20].

Global warming which occurred at the beginning of the Holocene led to significant changes in vegetation. That time in the foothills of Sinyi Ridge the forests with Korean pine (*Pinus koraiensis*), Mongolian oak (*Quercus mongolica*), hazel (*Corylus* sp.), and elm (*Ulmus* sp.) were widespread. However, communities of shrub birch and alder shrub still remained on the swampy floodplains of rivers and mires of plains.

Similar vegetation was also documented in the valley ecosystems of the lower reaches of the Bikin River, where *Ulmus* began to grow along with other broadleaf plants about 10.400 cal BP. Sphagnum mires with scrub birch and scrub alder, dark coniferous forests, probably, with larch still remained [4]. The share of *Picea, Pinus koraiensis* and broadleaf trees increased notably in vegetation of the upper reaches of the Khor River valley (48°53'55" N, 137°16'21" E) about 9.600 cal BP [21]. The forests with *Picea* and Korean pine with broadleaf plants were also wide spread at the Vinogradnaya River mouth (42°43'57" N, 130°57'15" E) in the south of Primorsky Krai at around 8.800 cal BP [22].

The changes in vegetation resulting from the Early Holocene warming also occurred in the adjacent regions of Siberia and the Far East. In the interval between 7.800-10.500 cal. BP in the Baikal region the areas of forests with domination of pine (*Pinus sibirica*) and *Abies* increased [23]. On Sakhalin Island distribution of spruce forest was reduced at around 8.580 cal BP. Spruce forests were replaced by forest vegetation with domination of *Larix, Duschekia, Betula, Alnus*, with participation of *Quercus, Ulmus*, and *Juglans* sp. [24]. In West Siberia expansion of Scots pine (*Pinus silvestris*) occurred at around 9.100 cal BP [25].

5. Conclusions

Palynological studies of different genesis sediments made it possible to reconstruct the evolution of vegetation of the eastern part of the Khanka Plain at the transition from the Late Pleistocene to the Holocene.
It is determined that the last cold epoch of the Late Pleistocene in MIS 2 was marked by extensive development of vegetation, typical of the north of the boreal zone. The palynological data substantiated by the radiocarbon dates show convincingly that during the Late Pleistocene cryochron (MIS 2) the plains were dominated by large mires with shrubs birches and scrub alder, and larch. Sparse spruce forests with larch, birch, and alder grew on Sinyi Ridge.

The last cold epoch of the Late Pleistocene in MIS 2 was marked by extensive development of vegetation, typical of the north of the boreal zone. The palynological data substantiated by the radiocarbon dates show convincingly that during the Late Pleistocene cryochron (MIS 2) the plains were dominated by vast mires with shrubs birches and alder, and larch. Open spruce forests with Japanese stone pine, larch, birch and shrub alder grew on the mountain slopes.

Slight warming led to wide spread of south-boreal dark coniferous taiga with participation of *Pinus koraiensis* at around 21,400 cal BP. Spruce, trees and shrub birches, trees and shrub alder dominated in the forests.

The Early Holocene is characterized by a significant rise of mean annual temperatures, and probably, by the similarity of the climate conditions in of the Pre-Khanka Plain with interglacial MIS 3. In the transition from cryochron MIS 2 to thermochron rapid expansion of deciduous forests occurred. That time the elements of the contemporary Manchurian flora such as oak, elm and others appeared on the Khanka Plain ecosystems, which are the main components of natural complexes at present.

The range of the Korean pine also expanded northwards and reached the Pre-Khanka Plain in the Early Holocene [13]. The formation of the broad-leaved forests with domination of oak, elm, and Korean pine happened on the slopes of Sinyi Ridge. However, Sphagnum mires with shrub birch still remained on the plains and swampy flood plains of the rivers.

In the south of the Russian Far East the continental ecosystems of the Pacific landscape zone began to acquire their modern outlook and the Korean pine became their principal component [13]. Thus, the interval of transition from the Late Pleistocene to the Holocene corresponds to the time of coniferous-broadleaved forest recovery after the cold epoch had come to its end. Obtained paleogeographic information contributes to our understanding of the evolution of natural systems in one of largest catchments of the Amur River basin, i.e. the Ussuri River valley, during the transition from the Late Pleistocene cryochron to the Early Holocene. Hence, these studies make it possible not only to detail the stages of development of the natural environment in the past, but also to present the probable scenarios of its evolution in the future.

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