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CLIMATE AND HUMAN IMPACT ON VEGETATION IN THE UPPER PART OF THE USSURI RIVER BASIN IN LATE HOLOCENE, RUSSIAN FAR EAST

ABSTRACT. Changes in vegetation in the southern Sikhote-Alin Mountains, which are in the upper reaches of the Ussuri R., are shown respond to minor climatic fluctuations over the past 5.4 ka. The largest mountain, Muta mire, chosen for paleoenvironmental reconstructions, is located within the main regional watershed. The studies include diatoms and pollen analyses. Chronology is based on radiocarbon dating and position of B-Tm tephra of the Millennium eruption of Baitoushan volcano. The cooling and warming reconstructed from the regional data correlate with global paleoclimatic events. The regional humidity changes notably along with the temperature fluctuations. Fire chronology was established and its significance for vegetation was estimated. Periods of frequent forest fires coincided with reduced moisture supply during cooling events. The analysis performed revealed a considerable human impact on the vegetation in the 20th century.

KEY WORDS: vegetation, climate changes, anthropogenic factor, forest fires, late Holocene, Sikhote-Alin

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INTRODUCTION

Short-term climate fluctuations are among the leading factors that controlled the landscape evolution in the late Holocene. In Primorye, human contribution to landscape changes started at the end of the 19th century when the first settlers started land cultivation. These processes

included deforestation, forest fires, housebuilding, agricultural land use, and mining. Secondary forests and shrub communities increased in importance (Kurentsova 1973). Geoarcheological data provided evidence of the human impact on the environments having longer history than formerly recognized (Vostretsov 2009). The earlier settlement of the region

since the late Neolithic led to environment transformation but, the scale of the changes was incomparable with modern impact.

The present paper is intended to display the response of mountain and river valley landscapes with late Holocene climate changes, and to find relative significance of natural and anthropogenic factors in the vegetation evolution.

The upper reaches of the Ussuri R., in the «Zov Tigra» National Park, have been chosen as the site of paleoenvironmental reconstructions (Fig. 1). The studies were concentrated on the Muta mire, the most extensive swamp (10×3 km) in the Sikhote-Alin mountains. The mire occupies a flat watershed separating the Ussuri River from the Milogradovka River basin, flowing into the Sea of Japan. The flattened, divide surface resulted from the river causing regressive erosion during a previous Pleistocene cold phase (Korotky 2010).

The reconstructions are based on a section in the northwest area of the mire. The biostratigraphic studies included diatom and pollen analysis. The methods and results were described in detail (Razjigaeva et al. 2018). Small charcoals and burnt cells of plants have been counted. The age determinations were based on radiocarbon dates obtained at St. Petersburg State University and on tephrostratigraphy. The radiocarbon dates were calibrated by

OxCal 4.2 and IntCal13 curve (<https://c14.arch.ox.ac.uk>). The tephra was identified with microprobe analysis of volcanic glass studied in V.G. Khlopin Radium Institute, St.-Petersburg.

REGIONAL SETTING

The upper Ussuri River flows across an intermountain depression. The ridges surrounding the mire display a distinct altitudinal zonation: 1) Korean pine (*Pinus koraiensis*)–broadleaf forests: 530–800 m; 2) Korean pine–spruce–fir forests: 800–1100 m; 3) spruce–fir forests: 1000–1550 m; 4) woodland of Erman's birch and shrub pine: 1550–1700 m; 5) 'goltsy' and alpine tundra: above 1700 m (Kiselev and Kudryavtseva 1992). The mire is confined to 550–600 m a.s.l. The largest part of the mire is covered with open relict larch forest (*Larix olgensis*, Fig. 2), which is one of the largest (5000 hectares) in the Sikhote-Alin (Shishkin 1933).

The forests in the Ussuri valley have been disturbed by repeated fires (1924, 1929, the mid-1980s) (National... 2014). Traces of fire in the late 18th century, 1936, 1941, and 1948 were found on the Oblachnaya Mt. (Kiselev and Kudryavtseva 1992). The oldest fire could be climate-controlled; fires in the 20th century occurred due to human activities.

Ussuri River valley colonization began late in the 19th century. Settlements persisted until the mid-20th century and have been replaced by forb meadow. In the

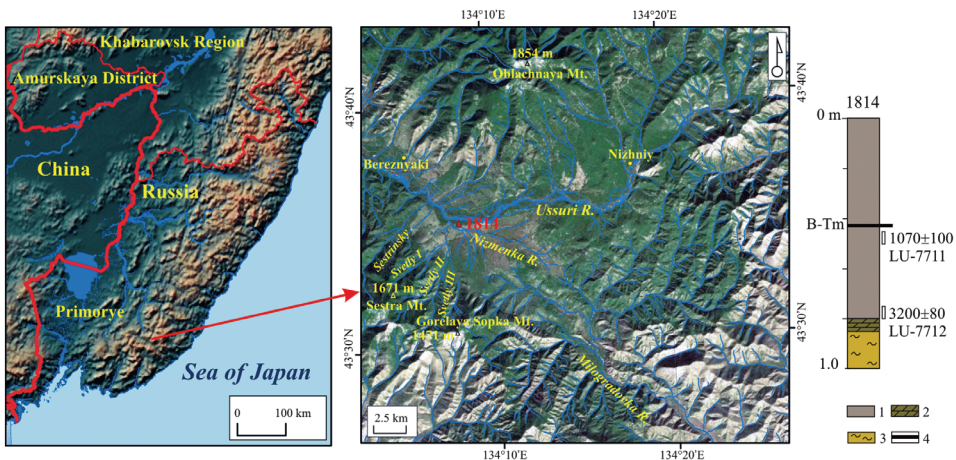


Fig. 1. Study area with position and construction of peatbog section

1950s-1970s, the region was explored for the geological surveys. The territory south of the mire was not subjected to human impact. Forest cutting continued from the 1970s until 2008 (National... 2014). The secondary forests are noted for a wide occurrence of *Betula platyphylla*.

The regional climate is continental with some monsoon features. The mean annual temperature is +0.4°C, the coldest month is January (-21.3°C) the warmest month is July (+18.1°C). The frost-free period is no more than 100 days. Mean annual precipitation is 760 mm, 80% of total falling during the warm period. The snow cover (from 5 to 67 cm) persists for 152 days. Northwest winds are dominant in winter (70%) compared to south-eastern in summer (39%). Foggy days are up to 52 per year (National... 2014).

RESULTS

Vegetation of the studied area

This area is larch forest with *Betula platyphylla*. The forest age may be estimated ~300-350 years. The understory includes *Betula ovalifolia*, *Alnus hirsuta* and *Ledum palustre*. The *Vaccinium uliginosum*, *Lonicera caerulea*, *Rubus arcticus* and *Rhodococcum vitis-idaea* occupy small hummocks. The grass is poorly developed (*Maianthemum bifolium*, *Galium boreale*; *Carex disperma*, *C. globularis*, *C. loliacea*, *C. minuta*). The moss layer is dominated by *Sphagnum squarrosum* with *S. girgensohnii*, *S. angustifolium* and *Alaucomnium palustre*. *Oxycoccus microcarpus* is common on the mosses.

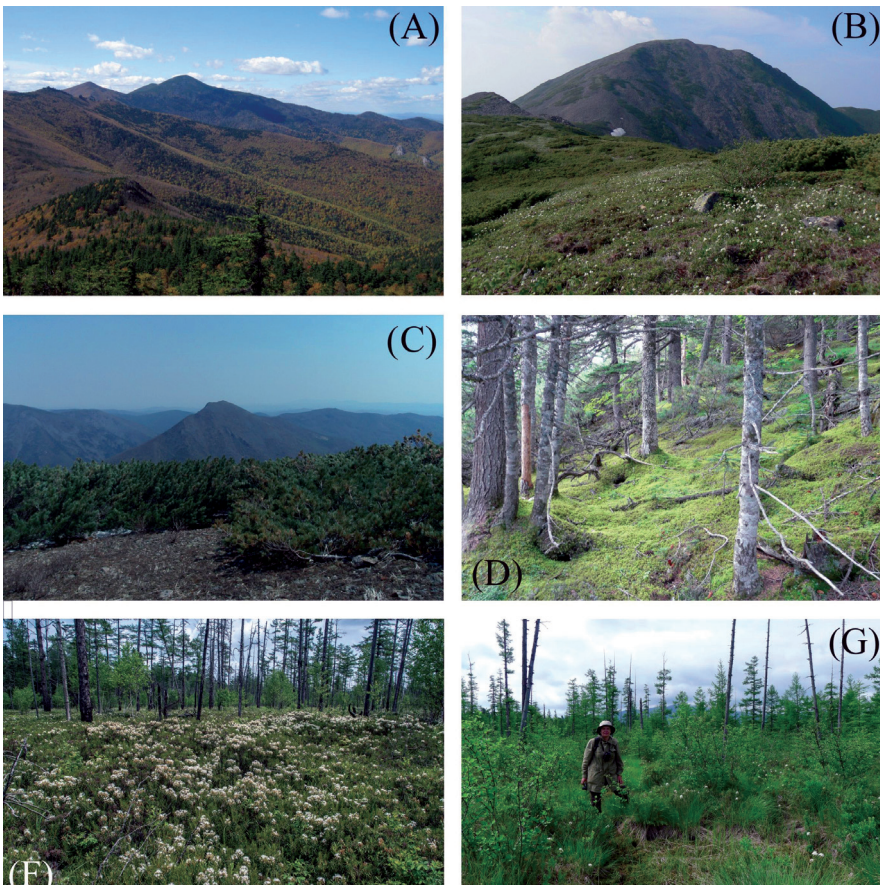


Fig. 2. Landscapes of Sikhote Alin: A – Ridge between Gorelaya Sopka and Sestra Mts., B – shrub pine and alpine tundra, Oblachnaya Mt., C – shrub pine near Snezhnaya Mt., D – fir-spruce forest, Oblachnaya Mt. (Photos of Yu. I. Bersenev); F, G – Muta mire

The age and accumulation rate of the peat

The lower part of the peat (0.35–0.80 m) is dark brown, compact, fairly decomposed, with herb remains. The upper part consists of yellowish-brown loose sphagnum peat (0.10–0.35 m) and moss mat (0–0.10 m). The base of the peat was dated at 3200±80 yr BP (3430±100 cal yr BP), LU-7712. A tephra horizon is correlatable with B-Tm tephra of the caldera-forming eruption of Baitoushan volcano in 946/947 AD (Chen et al. 2016). The tephra age is supported by ¹⁴C date 1070±100 yr BP (1000±120 cal yr BP), LU-7711 obtained from the underlying peat. At the beginning the peat accumulation rate was 0.14 mm/yr; during the last millennium the rate rose to 0.35 mm/yr.

Changes in humidity

The diatom distribution permits distinguishing 9 stages in mire evolution which were controlled by the changes in atmospheric precipitation (Fig. 3, 4).

3780–3430 yr BP. Beginning of surface waterlogging and development of a shallow oligotrophic-dystrophic pond. Cosmopolitan *Eunotia praerupta* typical of northern bogs and mountain shallow lakes prevail, its optimal pH is 7.05.

3430–3080 yr BP. Moisture decreased. Benthic species most common. The dominant are benthic *Pinnularia crucifera*, and epiphyte *Eunotia glacialis*, typical of shallow ponds in the northern latitudes and in mountains. Planktonic and epiphytes – inhabitants of current water were brought by floods.

3080–2735 yr BP. Moisture supply reduced. Increasing proportion of *Pinnularia borealis* and *Hantzschia amphioxys* suggests occasional drought periods. Species brought by floods are decreased.

2735–2040 yr BP. The aridity is growing, as suggested by a low proportion of diatoms.

2040–1000 yr BP. The swamp gains water supply. The number of species indicating the overgrowth of the moss bog is increasing. The pH value most favorable for the dominant species is 5.6-6.5. Planktonic diatoms, presumably brought by strong floods, are more numerous.

1000–715 yr BP. The dominants inhabit hygrophilic mosses. On sphagnum bogs *Eunotia paludosa* prefers relatively dryer habitats (Nováková and Pouličková 2004). The peat bog rose above the ground water table and the role of atmospheric moisture

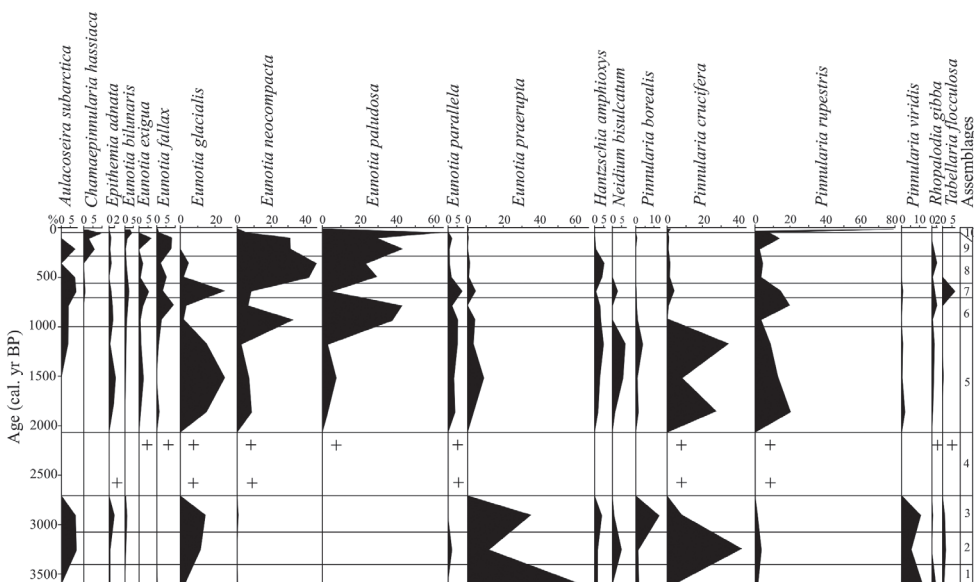


Fig. 3. Diatom percentage diagram of Muta peatbog plotted against the chronology

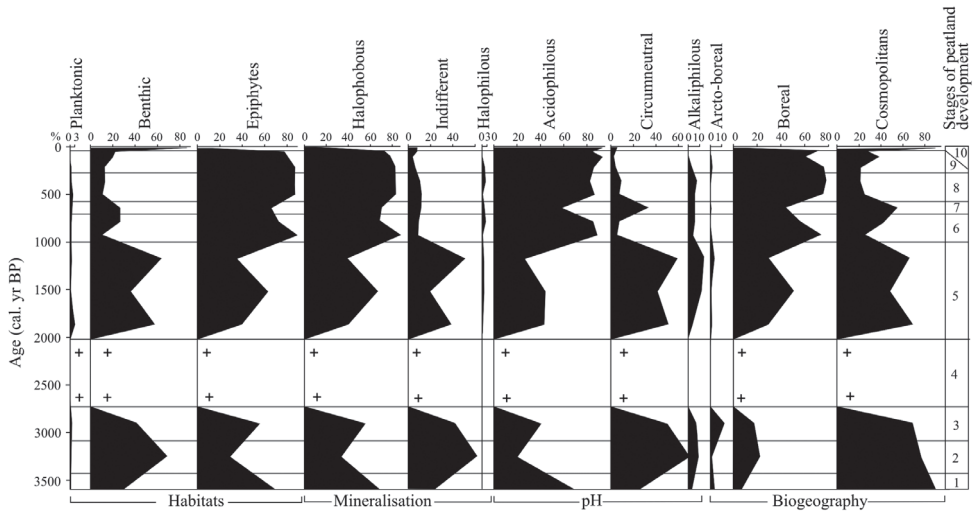


Fig. 4. Distribution of ecological groups of diatoms plotted against the chronology

supply increased. 715–570 yr BP. The environment became wetter and colder, open water patches rose in number and area. Hydrophilic diatoms increase in proportion, particularly those typical for oligotrophic ponds in the north and on mountains.

570–290 yr BP. Values of pH decreased to ~5.6. Planktonic *Aulacoseira granulata*, *A. italica*, *A. subarctica* were possibly brought to the mire during floods.

270 yr BP – the mid-20th century. The moisture supply is somewhat reduced. The species characteristic of flowing water disappeared. The usual inhabitants of moss bogs occur.

The late 20th – early 21st centuries. The moisture supply to the swamp increased.

Proportions of *Eunotia bilunaris*, the species choosing wet sphagnum areas with pH 3.5, increase. *Pinnularia rupestris* increased rapidly. Usually this species becomes dominant in wetter places on sphagnum bogs (Nováková and Pouličková 2004).

Phases in the vegetation development

were reconstructed accordingly the pollen zones identified in the section (Fig. 5).

5410-4120 yr BP. The lower boundary of the coniferous forests was lower than modern ranges, possibly due to cooler climate than present. A wide occurrence of ferns may be attributed to forest fires. There was a short episode identified when fir pollen was proportion higher. At present, forests dominated by *Abies nephrolepis* occur in

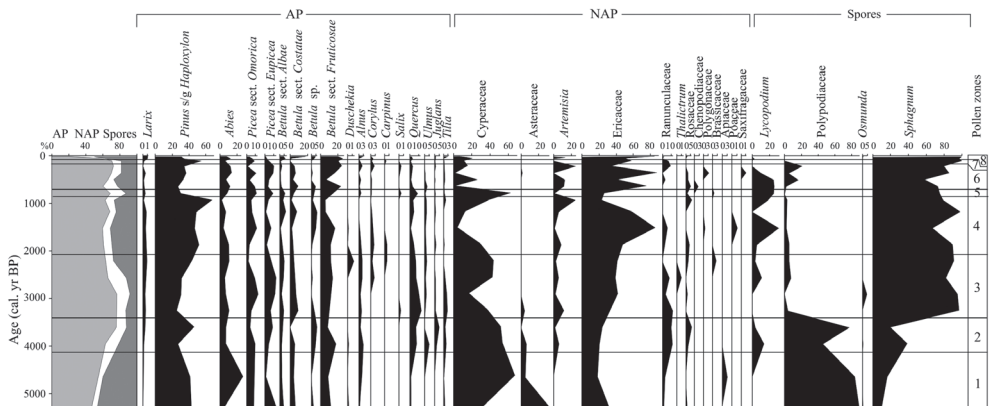


Fig. 5. Pollen percentage diagram of Muta peatbog plotted against the chronology

the upper forest zone only (Kiselev and Kudryavtseva 1992). It is possible that, those forests became widespread at the swamp periphery. Pollen data indicates a development of sedge marsh with *Betula ovalifolia*. Wet meadows occurred in small patches.

4120–3430 yr BP. The swamp was encircled with forests of Korean pine and broadleaf trees, with fern cover. Valley forests had an abundance of walnut, elm, and alder. Spruce began to dominate in the dark coniferous forests. The second half of the interval was marked by increasing expansion of larch over the swamp. Sedge communities with Rosaceae and Ranunculaceae were dominant. The pollen of Rosaceae could have been partly transported from surrounding slopes. In the ground cover of coniferous-broadleaf forests Ranunculaceae was widely presented.

3430–2040 yr BP. The vegetation evolved further under conditions of decreasing temperature and moisture. *Picea koraiensis* increased in river valleys forests. Proportion of dark coniferous increased ~3025–2215 yr BP. Birch became more important in the forests, while the floodplain was actively overgrowing with willow. Hazel acquired a greater importance in the undergrowth. *Artemisia* was rising notably, which is a the plant usually found in dry forests of Korean pine with oak, and predominantly oak forests. Pollen of *Artemisia lagocephala* could be brought from stone taluses in the upper slopes. Brassicaceae pollen makes its appearance on the river banks. A cooling period accompanied with drying was recorded ~2620–2215 yr BP and was marked by *Betula ovalifolia* and Ericaceae increasing. The swamp began to be overgrown with larch and *Sphagnum*. *Duschekia* pollen indicates that the area of shrub alder (and possibly, of shrub pine) expanded at that time. The presence of *Carpinus* pollen suggests increasing intensity of southern winds at the beginning of summer. At present, the northern limit of *Carpinus cordata* is 40–50 km to the south.

2040–860 yr BP. Forests of Korean pine with broadleaf trees were dominant at elevations

of ~500–600 m a.s.l. Sedges and sagebrush could also grow in the dry forests. The river terraces appear to be occupied by moist forests of Korean pine with elm, linden, and walnut. The lower boundary of spruce and fir forests was shifted upwards. In the swamp, the sedge presence was drastically reduced, while heather became more common; proportion of Ranunculaceae decreased, sagebrush expands on taluses.

860–715 yr BP. The environments became more favorable for broadleaf (primarily, oak) and white birch forests, which possibly replaced those of broadleaf trees and Korean pine. A reduced population of Korean pine could be the result of forest fires during the previous dryer interval. The subsequent increase in humidity favored an enlargement of fir-spruce. Alder forests and willow thickets developed in the valley. An increased humidity is suggested by a sharp increase in sedge content.

715–140 yr BP. Coniferous forests became dominant. The upper limit of the broadleaf–Korean pine forests went down below 500 m a.s.l. Oak apparently disappeared from the slopes surrounding the swamp. Willow and alder were still common in valley forests, and *Betula ovalifolia* and heather shrubs grew in the swamp. Presence of Saxifragaceae pollen suggests a wide occurrence of golets and stone streams on the mountain slopes. The source of pollen could be *Chrysosplenium* sp. which is typical of wet habitats near rivers. A high proportion of *Artemisia* pollen may be due to a wide occurrence of stone rivers spread over the territory until now. Slope processes were typically activated during coolings in the Holocene (Korotky et al. 1997). Chenopodiaceae pollen could be brought from either sandy banks or dry slopes.

The late 19th – early 20th centuries. Before an active cultivation of the Ussuri valley, the Korean pine forests were widespread in the region. The presence of *Carpinus* pollen agrees with prevalence of southern winds in early summer.

Since the 1950s the process of secondary forest development in places of tree cutting and fires is recorded in pollen assemblages

by lower AP content and a steep rise of the *Betula* pollen proportion. A reduced content of Korean pine and dark coniferous pollen seems to exhibit the timber cutter preferences with Korean pine, spruce and fir being cut first. Less spruce pollen could be partly attributed to the trees drying up (National... 2014). The broadleaf pollen content increases (up to 6%), though it is less than during the earlier warm phases. The oak pollen was most likely brought by wind from the Milogradovka basin, where *Quercus mongolica* is widely distributed up to 650 m a.s.l.

DISCUSSION

Climatic control of vegetation development

Small-magnitude Holocene climatic changes are receiving much attention (Borisova 2014; Mayewski et al. 2004; Wanner et al. 2008; 2011), as they present the most probable analogies to environmental changes that can be expected in the future under conditions of differing climatic trends. The warm intervals may be considered possible scenarios of the environmental evolution under conditions of global warming (Climates... 2010), while the latter seems to be the principal modern trend in the climatic regime of the Far East (Lobanov et al. 2014). The data obtained from regional responses to global events deserve special attention, as well as important information on the mountain landscape changes in response to minor climatic fluctuations.

The multi-proxy studies of peat revealed a considerable sensitivity of the upper Ussuri environments to the climate changes. This can be attributable to the altitudinal position of the mire and also to the swamp hydrological regime related to its position on a vast and flat watershed. The swamp was fed mostly by atmospheric precipitation, with groundwater being of secondary importance.

The wetlands became widely distributed since ~ 4120 yr BP. The swamp development due to warm and wet climate was recorded on the plateaus of the southern Sikhote-Alin,

on large landslides surfaces, in river valleys, and on the coasts of the Sea of Japan (Korotky et al. 1997; Razzhigaeva et al. 2016a; 2017). It is possible that, the peat accumulation began earlier in the central part of the Muta mire where the peat layer is 1.5 m thick (Zhudova 1967). Sizeable portions of watershed could be eroded in the middle Holocene, when the river discharge was greater (Korotky et al. 1997).

There were several episodes of cooling and warming recorded in the peat and underlying loam during the late Holocene, which influenced the dynamics of wetland and mountain plant communities.

One of most important paleoclimatic event was global cooling ~5410–5170 yr BP occurrence (Borisova 2014), which was distinctly pronounced on the southern Far East (Korotky et al. 1997). As with other regions of East Asia (Wanner et al. 2011), it was marked by a decrease in the mean annual precipitation (by 100 mm below the present value); mean annual temperatures on the sea coast were 1–1.5°C below those of today (Korotky et al. 1997). The lower boundary of the coniferous forests near the Muta area was at least 100–150 m below its position at present.

The cooling correlate with the global cold event of ~2800–2600 yr BP was associated with low solar activity (Borisova 2014; Mayewski et al. 2004; Wanner et al. 2008, 2011) and did not result in considerable changes within the Korean pine – broadleaf forest belt at elevations of ~500 m a.s.l., apart from reduced proportion of broadleaf species in the forests. An increase in dark conifer pollen suggests a lowering of the fir-spruce forest boundary. As in studies of peatlands on the Shkotovskoe plateau, expansion of dark coniferous forests occurred then at ~700–750 m a.s.l. (Razzhigaeva et al. 2016a). The interval of ~3080–2735 yr BP was marked by drying, with forest fires becoming common in the region. The pyrogenic factor could partly account for a wide distribution of the shrub birch on the swamp (~2735–2390 yr BP) and birch and hazel on the mountain slopes. The maximum aridity on the swamp during

~2735–2040 yr BP was typical of the Far East south (Korotky et al. 1997; Razzhigaeva et al. 2016a, 2016b, 2017). Taking into consideration the ecological optimum of *Larix olgensis* (hygro-mesophytic plant, more thermophile than other larches of the Far East (Urusov et al. 2007), it may be supposed that the sum of temperatures $\geq 10^{\circ}\text{C}$ was no less than 1600°C , and the annual rainfall was at least 600 mm/year. A decrease of rainfall was particularly characteristic of Eastern Asia monsoon during that cooling period (Wanner et al. 2008, 2011).

The global cooling during ~1750–1350 yr BP was noted for abrupt and negative anomalies of temperature (Wanner et al. 2011). It was one of longest-lasting cold intervals in the late Holocene. In the Upper Ussuri R. basin, the role of Korean pine increased, and Korean pine-broadleaf forests were dominant at elevations of ~500–600 m a.s.l. It is quite possible that a part of the pollen identified as *Pinus* s/g *Haploxylon* could belong to the shrub pine that became more common above the tree line. The swamp became wetter and mosses were actively overgrowing it. Occasional findings of planktonic diatoms suggest episodes of floods. Two extreme floods have been dated at $\sim 1640 \pm 70$ yr BP and 1430 ± 70 yr BP on the marine coast (Razzhigaeva et al. 2016b).

The Little Ice Age was noted for considerable changes in the forests in the Upper Ussuri basin when the dark coniferous forest zone expanded, along with open spaces on the mountain slopes. Broadleaf species reduced drastically and in all probability, oak disappeared completely from that part of the basin. Slope processes seem to become more active while stone streams and screes were widespread. Sphagnum mosses were widely distributed on the mire. As concluded from the diatom composition, the beginning of the Little Ice Age (715–570 yr BP) was the coldest period, which agrees with the data on the Sikhote-Alin (Razzhigaeva et al. 2016b; 2017). Strong floods happened in the upper reaches of the Ussuri ~715–430 yr BP.

Pronounced warming occurred in the region during the Subboreal optimum – a global climatic event (Borisova 2014). In the Primorye its magnitude was close to the Holocene optimum, though it was shorter. The mean annual temperature was $2.5\text{--}3^{\circ}\text{C}$ above that of today (Korotky et al. 1997). In the Sea of Japan region the period was distinct for highly active summer monsoons (Yi 2011; van Soelen et al. 2016) and intensified cyclonic activity, including typhoons with heavy rains.

About 4120 yr BP the upper boundary of broadleaf forests with Korean pine was approximately 100–150 m above present-day position. Oak was common in the forests. Walnut, elm, and alder were widely spread in valley forests. On Shkotovskoe Plateau polydominant broadleaf forests with Korean pine and Korean pine–broadleaf forests occurred at $\geq 700\text{--}750$ m a.s.l. (Razzhigaeva et al. 2016a). In the upper reaches of the Ussuri R. such vegetation persisted up to 3430 yr BP, in spite of lowered temperature (Korotky et al. 1997); although it is worthy of note that the time was close to the beginning of the global cooling ~3300–2500 yr BP (Wanner et al. 2011).

A short-term warm phase at the beginning of the Subatlantic has not been recognized in the upper reaches of the Ussuri R., though it is easily identifiable on the Shkotovskoe Plateau and on the coasts of Primorye (Razzhigaeva et al. 2016a, 2016b; Mikishin et al. 2008).

At the Medieval Warm Period, forests of Korean pine were widespread in mountains. A growing population of that species was recorded in other regions of the Primorye (Razzhigaeva et al. 2016a). A higher proportion of broadleaf trees in the forests has been recorded by the end of the Little Holocene Optimum. Mountain slopes around the swamp were overgrown with forests of oak and white birch. Increased presence of broadleaved trees, first of all oak, was noted in the south Primorye coasts at the end of the warm phase (950–790 yr BP). The Medieval optimum in the Ussuri upper reaches was noted for intensive floods, as witnessed by bogs diatom data.

Chronology of paleofires

An irregular distribution of charcoal fragments and burnt cells of plants over the peat section suggests a few periods with high frequency of forest fires. These were intervals ~3780–3430, 3080–2735, 2390–2040, and 1690–1000 yr BP. The intervals marked by fires correlate with regional chronology of pyrogenic events, which are confined to periods of droughts (mostly also to coolings). As to the neighboring regions of the Sikhote-Alin, the intervals of frequent fires were as follows: on the Sergeevskoe Plateau ~3670–3310 yr BP, 2620–2210 yr BP, 2130–1920 yr BP, 1600–1180 yr BP, 980–390 yr BP; on the Kit Bay coasts ~3800–3660 yr BP, 3380–3240, and 1430 yr BP (Razhigaeva et al. 2016a; 2017).

Unlike other regions, no traces of forest fires datable to the Middle Ages have been found on Muta mire. It is possible that the swamp was inundated at that time. The anthropogenic factor was minor, as the environments in the intermountain depression were not favorable for human settlement during the Little Ice Age. Traces of fire activity in the upper part of the section are most probably attributable to the 1924 fire. A vast burnt area on the swamp with *Betula platyphylla* and *Alnus hirsuta* was studied in 1946 (Zhudova 1967). Fire in the mid-1980s destroyed forested area between Sestrinsky and Svetly creeks (National... 2014), though hardly damaged the Muta mire.

Significance of the human impact

A peat layer dated to ~1690–1350 yr BP appeared to contain *Ambrosia* pollen, which may be considered as a sign ancient human presence and its effect on the vegetation. The *Ambrosia* pollen presence in the Holocene sequences in Primorye is usually associated with the early man appearance and considered to be a sign of practiced agriculture (Kudryavtseva et al. 2018). Archeological sites of the paleo-metal epoch have been found in the Milogradovka R. upper reaches (National... 2014). At that time, the inner regions of Primorye were brought under cultivation by the

Krownovskaya culture – bearers practicing agriculture (Vostretsov 2009).

The birch forests in the upper reaches of the Ussuri R. are young formations that existed as a result of area cultivation in the second half of the 20th century. Among the causes of their appearance were man-induced fires and forest felling; the primary objects of felling were Korean pine and dark conifers.

CONCLUSIONS

1. The wetland vegetation, as well as valley and mountain landscapes in the upper Ussuri basin, underwent considerable transformations through the last 5.4 ka with their dynamics being mostly controlled by climate.
2. This data allowed identification of cooling and warming periods that exerted primary control over the vegetation evolution. Both the temperature and the moisture supply were subject to noticeable changes. The flat surface was waterlogged at the beginning of the late Holocene, under conditions of higher temperature and humidity as compared with the present. The identified intervals of utter aridity coincided mostly with coolings.
3. Fires were one of the factors of change in biotic components. As shown from the data on the age of fires, the periods of increased frequency mostly coincided with reduced moisture supply during cooler periods.
4. The man-induced transformation of environments in the upper Ussuri reaches occurred in the 20th century. All the earlier changes in landscapes may be attributed to natural causes.

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