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ABSTRACT
The present-day ranges of broadleaved tree species in Europe reach the Ural Mountains in the east, and those in the Far East reach the eastern slopes of the Bolshoi Khingan Ridge in the west. After the last glacial period the first appearance of broadleaved species, *Quercus mongolica* Fisch. ex Ledeb., *Ulmus pumila* L. and, probably, *U. lacinata* (Trautv.) Mayr, in the Russian part of Amur River Basin revealed as early as 10 ka BP (the early Holocene). The temperate broadleaved species reached their maximum distribution in the Mid-Holocene (6–8 ka BP). The mixed coniferous-broadleaved forests reached as far north as the Amur River mouth. In the intracontinental regions of the Amur River basin *Quercus mongolica*, *Ulmus pumila* and, probably, *U. macrocarpa* Hance appeared in the Mid-Holocene (5 to 4 ka years BP). The centers of the species dispersal were refuges in river valleys and locally on slopes noted for relatively favorable microclimatic conditions. They were mostly confined to the southern part of the Transbaikalia and reached as far east as the southeastern foothills of the Yablonovy Range. During the Holocene the European and Far Eastern ranges of the broadleaved species never joined each other. That fact may be attributed to bio-ecological characteristics of oak and elm, as well as to the absence of their refugia, complexity of orographic systems and dryer climatic conditions in the southern part of the Baikal Lake Region.

Keywords

Spreading of Broadleaved Species in Amur River Basin in the Holocene

Valentina B. Bazarova

INTRODUCTION
The present-day spatial distribution of vegetation over the Amur River basin is primarily controlled by an intricate interaction between global and regional circulating of atmosphere systems and the mostly mountainous relief of the region. Dramatic changes of climate occurring frequently through the Holocene resulted in a complete restructuring of the landscape systems in the Amur drainage basin. There are but a few works including high-resolution reconstructions of paleolandsapes and vegetation dynamics in the Amur basin. The best studied is the part of the basin positioned closely to the Pacific (hereafter denoted as maritime). The wide occurrence of peatlands all over the Lower Amur drainage basin made possible reconstructing climatic changes during the Late Pleistocene and Holocene (Bazarova et al. 2008, 2011 b); eight regional biomes were
identified and compared with the present-day vegetation (Mokhova et al. 2009). The problems of vegetation evolution and the relationship between forest and steppe in the Holocene were discussed in earlier works with reference to the interior part of the Amur basin (Vipper 1968, Vipper et al. 1976, Vipper & Golubeva 1976). Reconstructions of vegetation dynamics and climate changes during middle-late Holocene have been performed for the middle reaches of the Amur (Klimenko et al. 2000). Climate humidity changes for the last 1900 years (Pitsin et al. 2010), as well as climate and environment changes through the Holocene (Bazarova et al. 2011 a) have been reconstructed for the south-eastern part of the Transbaikalian region. Nevertheless, the above mentioned studies have not given comprehensive answers to many questions related to the Amur basin paleogeography. They revealed some debatable problems including one related to specific features of floristic changes during the Holocene. An analysis of published papers (Vipper 1968, Vipper et al. 1976, Vipper & Golubeva 1976, Tarasov et al. 2002, 2007, Bezrukova et al. 2002, 2005, Reshetova et al. 2008) permitted to identify one of such problems, namely, the broadleaved species development and expansion during the Holocene both within the Amur River basin and on the adjacent areas. The following steps are suggested as the way to solving this problem: (a) to study specific features of the broadleaved species distribution in the Amur basin; (b) to identify regions of their refuges; (c) to determine the time of their disappearance; and (d) to find if there was a connection between the western and eastern ranges of the broadleaved flora during the Holocene. To answer the above listed questions we analyzed original palynological data and compared them with the data on the adjacent territories.

**Regional Settings**

The Amur drainage basin is a large geosystem about 2 million km² in size (that is the tenth largest river drainage basin of the world). The river is subdivided into three segments, namely the Upper Amur, Middle Amur, and Lower Amur. Our studies were performed in the Russian part of the area, at two opposite parts of its drainage basin; by convention those are termed hereafter as intracontinental and maritime (Fig. 1). During the last century the mean annual air temperature in the Amur drainage basin rose by 1.3°C. The minimum warming (by 0.6°C) was recorded in the east of the drainage basin; landwards it increases gradually (up to 1.7°C) (Novorotsky 2007). Four natural zones are represented within the Amur drainage basin; those are: forest zone (with subzones of mixed coniferous-broadleaved forests, middle taiga and southern taiga), forest-steppe, steppe and semidesert (including subzones of northern semidesert and dry steppe). The present-day European range of broadleaved species is bounded by the Ural Mountains. The Far Eastern range of the broadleaved species reaches as far west as the eastern slopes of the Bolsboy Khingan Ridge in China and the southern Amur-Zeya interfluve area in Russia (~125°E). There is also a relict Budyumkan oak grove in the lower reaches of the Argun River in Transbaikalia (see Fig. 1) (Klyuchikhina 1998, Mikheev et al. 2010). As to the presence of *Quercus mongolica* on the western slopes of the Bolsboy Khingan Ridge (Dobrynin 2000), it is still to be confirmed. It follows from the above that broadleaved vegetation is practically missing from present-day Siberia, except for a few small linden groves in south of the city of Tobolsk (Volkova & Belova 1980) and in the Altay-Sayan foothills (Mountain Shoria area) (Blyakharchuk 2010), relict elm forests and the above-mentioned Budyumkan oak grove in SE Transbaikalia. The named places form a kind of modern refugium for broadleaved species in Siberia.

**Intracontinental part of the basin**

**Topography.** Typically, the Transbaikalian region displays alternating ridges and basins (depressions) extended approximately from NE to SW. Principal features of the modern relief are primarily controlled by Mesozoic and Cenozoic geological structures complicated by later faulting and fracturing. The northern Transbaikalia is noted for high mountain ranges (up to 2500–3000 m a.s.l.) and large deep basins of the Baikalian type. Farther east they are replaced by ridges of medium to low altitudes (1800 to 800 m) and plateaus, the basins are not so large and deep and belong to so called Transbaikalian type. In the southwest of...
the Transbaikalia there is a heavily dissected highland up to 2500 m high, in the southeast – Uldza-Torey Plain 500 to 800 m a.s.l. (Sochava et al. 1967).

Climate. The intracontinental part of the Amur drainage basin lies in the Asian interior far from oceans and seas; along with considerable elevations, that accounts for its continental and extremely continental climate. Mean annual temperature varies between -2.7°C and -0.5°C. Annual precipitation amounts to 250–400 mm.

Vegetation. According to the geobotanical subdivision, the intracontinental part of the Amur basin belongs to steppe and mountain forest-steppe of Dauria distinguished for a gradual transition southward from forest-steppe to steppe plains (Dulepova 1993). The forest constituents of the mountain forest-steppe are dominated by larch–birch, pine and birch woods. Dark coniferous forests of Siberian pine, spruce and, less common, fir are found occasionally as small groves under conditions of well wetted high floodplains. Specific for the forest component of the forest-steppe are forests with Betula dahurica Pall. that occur on the Shilka-Argun interfluve. There passes a floristic boundary marked by the Tertiary species appearance in the forest-steppe river valleys (Dulepova 1993). Among the species, Ulmus pumila, U. macrocarpa and U. japonica (Rehd.) Sarg. are found; they are mostly confined to the best insulated aprons of the south-facing slopes with sandy soils or to the lower parts of high terrace scarps. The species of the genus Ulmus are Tertiary relics, remains of the Turgai flora which survived and got adapted to the severe climate due to specific features of their biology (Butina 2009). The above mentioned relict Budyumkan oak grove (in the lower reaches of the Argun River) marks the farthest northwest above mentioned relict Budyumkan oak grove (in the lower part of the Argun River) marks the farthest northwest above mentioned relict Budyumkan oak grove (in the lower part of the Argun River) marks the Far East, with three subzones clearly distinguished. In the subzone of mixed coniferous and broadleaved forests a number of dark coniferous species (Pinus jezoensis Siebold et Zucc.) Carr., Abies nephrolepis (Trautv.) Maxim., Picea koraiensis Siebold et Zucc.) are found along with broadleaved ones, such as Quercus mongolica, Ulmus laitaiata, U. japonica, Tilia amurenensis Rupr., Acer mono Maxim., shrubs Carya mandshurica Maxim., Eleutherococcus senticosus (Rupr. et Maxim.) Maxim., Euonymus mauropterus Rupr, and lianas Actinidia kolomikta (Maxim.) Maxim., Schisandra chinensis (Turcz.) Baill. Less common is Taxus cuspidata Siebold et Zucc. ex Endl. There are also some small-leaved species of Betula middendorfii Trautv. et Mey., B. fruticosa Pall., Abies birsuta (Spach.) Turcz. et Rupr. The southern taiga subzone is noted for dominance of dark coniferous species (Picea jezoensis, P. obovata Ledeb., Abies nephrolepis), while light coniferous ones (Larix gmelinii (Rupr.) Rupr. and Pinus sylvestris L.) prevail in the middle taiga (Mar’ko & Rozenberg 1967, Kolesnikov 1969, Voroshilov 1982).

**MATERIAL AND METHODS**

This study is based on original published pollen data and radiocarbon dates (Bazara et al. 2008, 2011 b). Some materials on sections from the adjacent territories including pollen and ¹⁴C data were also considered (Vipper & Golubeva 1976, Bezrukova et al. 1996, 2002, Dorofeyuk & Tarasov 1998, Reshetova et al. 2008, Tarasov et al. 2002, 2007). Newly obtained pollen and radiocarbon data are represented by the Chlya section (Fig. 2) in maritime part of the basin and by the Aga section (Fig. 3) in intracontinental part of the basin.

Pollen analysis. Pollen was extracted following routine procedures (Sladkov 1967), and 300–400 grains were counted. The percentage of palynomorphs of three groups represented by arboreal pollen (AP), non-arboreal pollen (NAP) and spores was estimated for each sample, assuming that total amount of pollen of the main genera was counted as a percentage within each group, and the total amount in each group was 100%.

Chronology. The radiocarbon dates were obtained in the V.S. Sobolev Institute of Geology and Mineralogy SB RAS, Novosibirsk (Lab. index is SOAN). Samples were treated by acid/alkali/acid, and the humid fraction was extracted. The ¹⁴C activity was measured by liquid scintillation counting. The conventional ages were converted to calibrated ages by the radiocarbon age calibration program CALPAL-A (Weninger et al. 2002) (Table 1).

**RESULTS AND DISCUSSION**

About 12 to 11 ka BP the maritime part of the drainage basin, near the Amur mouth (Tyapka section 53°42’N, 140°07’E, Chlya section 53°32’N, 140°13’E and Dudi section 53°32’N, 140°13’E) was covered by broadleaved species in Amur River basin in Holocene
52°01’N, 140°08’E) was dominated by shrub birch and open forests of birch and Alnus. Farther south, on the Middle Amur Lowland (Gur section 50°00’N, 137°03’E and Kiya section 47°50’N, 135°10’E), there were forests of alder and birch, with some dwarf birch, dwarf pine and an insignificant presence of spruce and fir (Bazarova et al. 2011b). Cryo-xerophytic steppe communities were dominant in the intracontinental regions of the Amur drainage basin, in the southeastern Siberia (Bazarova et al. 2011a). The permafrost decay in the region began at about 9.5–10 ka BP, and since that time forest expansion began all over the area. Mixed forests of small-leaved and coniferous trees were widely spread in the lower reaches of the Amur; until 9–9.5 ka BP, they featured a minor proportion of Quercus mongolica and Ulmus laciniata, the species having disappeared about that time. The broadleaved species reached their maximum expansion in the optimum of the Holocene (8–6 ka BP). At that time, the mixed coniferous-broadleaved forests expanded as far north as the Amur River mouth. There the forest formations included Quercus mongolica and Ulmus laciniata, occasionally Juglans mandshurica Maxim. and Corylus mandshurica Maxim. The proportion of Quercus mongolica and Ulmus laciniata increased towards the middle reaches of the Amur River, along with increasing species diversity of the broadleaved constituents. That interval was marked by the appearance of Tilia amurensis Rupr., Phellodendron amurense Rupr., Corylus mandshurica, Juglans mandshurica and Syringa amurensis Rupr. (Fig. 4). Modern northern boundary of mixed coniferous and broadleaved forests reaches 51°N along Amur valley (Man’ko & Rozenberg 1967).

During the next period 5 to 6 ka BP the boundary of mixed coniferous and broadleaved forests shifted south by

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**Figure 2** Pollen diagram of the Chlya section. 1 – wood peat, 2 – grass peat, 3 – sphagnum peat, 4 – green moss, 5 – 14C date.

**Figure 3** Pollen diagram of the Aga section. 1 – light yellow fine sand; 2 – light brown fine sand; 3 – light gray silty sand; 4 – pebble; 5 – plant roots; 6 – 14C date.
Broadleaved species in Amur River basin in Holocene


a few hundreds of kilometers. Quercus mongolica and Ulmus lacinia disappeared from the area near the Amur River mouth, and most of broadleaved species were absent at that time from the southern part of the region. The broadleaved flora proportion increased again about 3.5 to 5 ka BP, mainly at the expense of Quercus mongolica and Ulmus lacinia. About 2.5–3 ka BP those species become completely absent from the vicinities of the Amur lowest reaches and reduced in abundance farther south (Fig. 4).

As to the Holocene environments in the middle reaches of the Amur River, the one report is available. The Egoryevskii peat bog located in the southern part of the Amur–Zeya interfluv (51°N, 128°E) is 14C-dated at 6729±128 cal yr BP that is middle Holocene. A few broadleaved species – Quercus mongolica, Populus amurensis Kom.,

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CONCLUSIONS

After the last glacial period, in the maritime part of the Amur River drainage basin the first appearance of temperate broadleaved flora elements (Quercus mongolica, Ulmus pumila, and U. macrocarpa) as constituents of mixed boreal broadleaved and coniferous forests is dated to 9.5–10 ka BP.

The climate of the middle Holocene was favorable for the full flourish of broadleaved flora in the Amur River drainage basin. The maritime region displays not only increase in abundance of the species, but also in species diversity. Their range extended as far as the Amur River mouth. In the intracontinental regions Quercus mongolica, Ulmus pumila and U. macrocarpa did not appeared until the middle Holocene. Forest formations with insignificant presence of oak and elm reached as far west as the southeastern foothills of Yablonovy Range. The European range of the temperate broadleaved species extended as far east as southern part of the Lena-Angarskoe Plateau. Pollen grains of broadleaved

Figure 4 Time of appearance and presence duration of broadleaved species in forest formations of the Amur River drainage basin
species (*Quercus* spp., *Tilia sibirica* Bayer.) were found in the deposits dated by 6500–5500 yrs BP (Belov & Belova 1984). The pollen grains of *Quercus mongolica* and *Ulmus pumila* also were found in the Irkut River higher flood deposits dated by 5500 yrs BP (Volkova & Belova 1980). Therefore, as a specific feature of the temperate broadleaved flora distribution we can note the fact that in the middle Holocene broadleaved elements penetrated into southern part of Siberia both from east and from west. But the Far Eastern and European ranges of broadleaved species never joined each other. The absence of broadleaved species pollen in Holocene deposits of southwestern and southeastern coastal zones of Baikal Lake is evidence of this conclusion (Fig. 5). As possible reasons for that, one may suggest: (a) the absence of broadleaved species refuges at the southern, southwestern and southeastern coasts of Baikal Lake; (b) specific features of those species dispersal; (c) dryer climatic conditions; and (d) mountain ranges around Baikal forming a topographic barrier.

The calculations of the maximum migration rate of arboreal plants performed by a number of specialists for some regions in the Eurasian temperate zone provided support for the opinion that the broadleaved flora in the Amur drainage basin is essentially a Tertiary relict (Dobrynin 2000, Udra 1982, 1988, Dulepova 1993). The fact that *Quercus mongolica*, *Ulmus pumila* and, probably, *U. laevigata* appeared in small quantities in the south of the maritime part of the Amur drainage basin in early-middle Holocene, as well as their appearance in the intracontinental part of the basin in the middle Holocene corroborate the above stated opinion on the existence of broadleaved species refuges in the region throughout the Holocene. In the maritime part of the basin the refuges likely were evenly distributed along the Amur valley. In the intracontinental regions they were mostly confined to some places in valleys and south-facing slopes with relatively mild microclimate.

The occurrence of elm parklands in the forest-steppe zone of Eastern Transbaikalia and extremely rare findings of *U. macrocarpa* and *U. pumila* pollen grains in the studied Holocene deposits brought to light another floristic problem, that is the problem of *U. macrocarpa* and *U. pumila* expansion during the Holocene. To deal with the problem some new natural objects should be found and studied, along with the palynological analysis of recent sediments.

**ACKNOWLEDGMENTS**

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**Figure 5** Orographic map of the southern part of the Transbaikal area and locations of the pollen records:


III – Budyumkan oak grove.

**LITERATURE CITED**


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Bazarova


MEETINGS RELATED TO BOTANY AND VEGETATION SCIENCE FOR 2015
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58th Annual Symposium of the International Association for Vegetation Science "Understanding Broad-Scale Vegetation Patterns"

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BOOK

This book presents the first generalization of the chromosome number data on vascular flora of the Primorskii Krai, for the period of time of chromosome studies (from 1966 up to now). Since 1966, chromosome numbers in 1318 vascular plant species from 604 genera and 128 families were revealed in Primorskii Krai. The chromosome number were the most extensively studied in families Asteraceae – 207 species of 91 genera and in Poaceae – 166 species of 60 genera. Adventive (alien) species in the flora of the Primorskii Krai were marked. References and brief information on the origin of specimens studied were given. The analysis of chromosome number data as a source of information on the flora was given on examples of caryotaxonomic situation in some families and genera. Caryological studies on vascular plants permit to consider these data in the context of special features of the forming of the flora in the south of the Russian Far East, including human impact.

The book is available from the author:
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