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RESEARCH PAPER

Spreading of Broadleaved Species in Amur River Basin in the Holocene

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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
broadleaved species, *Quercus, Ulmus*, refugium, Holocene, Amur River basin.

РЕЗЮМЕ

Базарова В.Б. Распространение широколистных видов в бассейне Амура в голоцене

Современное распространение европейских широколистных видов деревьев на восток ограничивается Уральскими горами; западная граница дальневосточных широколиственных видов достигает восточных склонов Большого Хинганского хребта. Впервые *Quercus mongolica, Ulmus pumila* и, возможно, *U. lacinata*, в российской части бассейна Амура появились в раннем голоцене. Наибольший расцвет широколиственная флора достигла в среднем голоцене. В этот период в бассейне Амура граница смешанных хвойно-широколиственных лесов перемещалась до устьевой зоны Амура. Во внутриконтинентальной части бассейна в составе лесных формаций в небольших количествах появлялись *Quercus mongolica*, *Ulmus pumila* и, возможно, *U. macrocarpa* (5–4 тыс. л.н.). Их распространение происходило из небольших рефугиумов, сохранившихся в долинах рек и на южных склонах некоторых хребтов, где сохранялись локальные благоприятные микроклиматические условия. В этот период граница распространения *Quercus mongolica* достигала подножий восточных макросклонов Яблоневого хребта. В течение голоцена западный и восточный ареалы широколиственных видов деревьев не смыкались. Основными причинами могли быть биоэкологические особенности данных пород, отсутствие рефугиумов, более аридные условия и сложная орографическая система в прибрежной зоне оз. Байкал.

Ключевые слова
широколиственное дерево, *Quercus, Ulmus,* рефугиум, голоцен, бассейн реки Амур

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 paleolandscapes 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 (Ptitsin 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 km^2 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 Bolshoi 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 Bolshoy 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

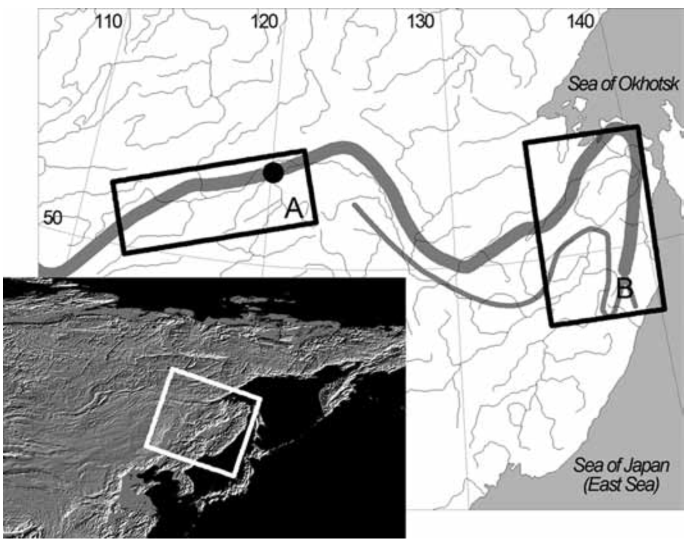

Figure 1 Map of the Amur River drainage basin.
A – intracontinental study area, B – maritime study area.
Dot is the Budyumkan oak grove; thin gray line is the modern northern boundary of mixed coniferous broadleaved forests (Kolesnikov 1969); thick gray line is the northern boundary of mixed coniferous-broadleaved forests in Mid-Holocene

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 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 insolated 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 relicts, 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 northwestern part of the *Quercus mongolica* range (Klyuchikhina 1998, Mikheev et al. 2010). That species is thermophilic, so near the northern limits of its occurrence it is mostly confined to the best insolated south facing slopes. It is not uncommon that it grows in the immediate vicinity of seasonally frozen ground with the mean annual temperature as low as -5°C. Under such conditions *Quercus mongolica* hardly bears fruits and persists due to its ability to produce abundant sprouts. In continental environments *Quercus mongolica* can be attributed to the northern climatic ecotype (Udra 1988).

Maritime part of the basin

Topography. Morphotectonically, the part of the Amur drainage basin adjoining the Pacific Ocean belongs to the Mesozoic fold belt noted for large positive morphostructures of NE trending and Cenozoic depressions. Principal topographic features are controlled by the geological structures. The mountain part of the Lower Amur drainage basin includes middle and low mountains of the northern Sikhote-Alin, similar ridges on the left side of the river, as well as lower foothills. Along the main river and its tributaries there are vast lacustrine-alluvial lowlands with small isolated uplands (Gerasimov 1969).

Climate. Most part of the Lower Amur drainage basin has distinctive features of the monsoon climate. Mean annual temperature varies between -2.7°C and -0.5°C in the inner part of the region and between -2.2°C and 1.6°C in the maritime part. Mean annual precipitation ranges from 570 mm on plains to 750 mm in mountains, with 67–80% of the total falling during the warm season (May to October) (Petrov et al. 2000).

Vegetation. The considered part of the Amur drainage basin lies within the limits of the forest zone of the Far East, with three subzones clearly distinguished. In the subzone of mixed coniferous and broadleaved forests a number of dark coniferous species (*Picea jezoensis* (Siebold et Zucc.) Carr., *Abies nephrolepis* (Trautv.) Maxim., *Pinus koraiensis* Siebold et Zucc.) are found along with broadleaved ones, such as *Quercus mongolica*, *Ulmus laciniata, U. japonica, Tilia amurensis* Rupr., *Acer mono* Maxim., shrubs *Corylus manshurica* Maxim., *Eleutherococcus senticosus* (Rupr. et Maxim.) Maxim., *Euonymus macroptera* 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., *Alnus hirsuta* (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 silvestris* L.) prevail in the middle taiga (Man'ko & Rozenberg 1967, Kolesnikov 1969, Voroshilov 1982).

MATERIAL AND METHODS

This study is based on original published pollen data and radiocarbon dates (Bazarova et al. 2008, 2011 b). Some materials on sections from the adjacent territories including pollen and ^{14}C 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 ^{14}C 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

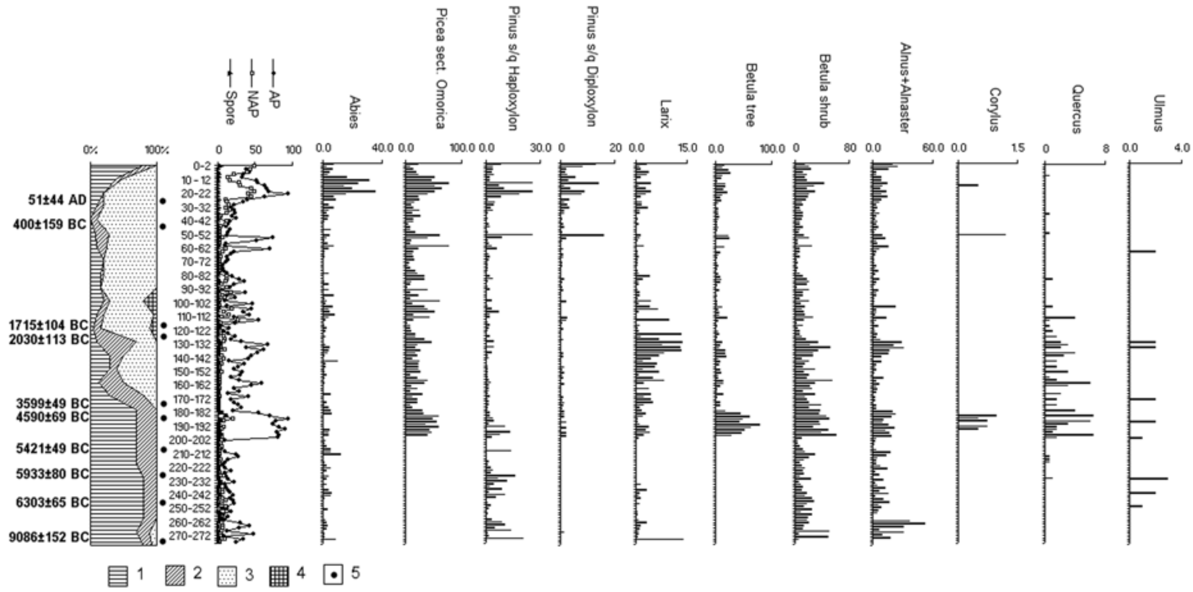

Figure 2 Pollen diagram of the Chlya section. 1 – wood peat, 2 – grass peat, 3 – sphagnum peat, 4 – green moss, 5 – ^{14}C date

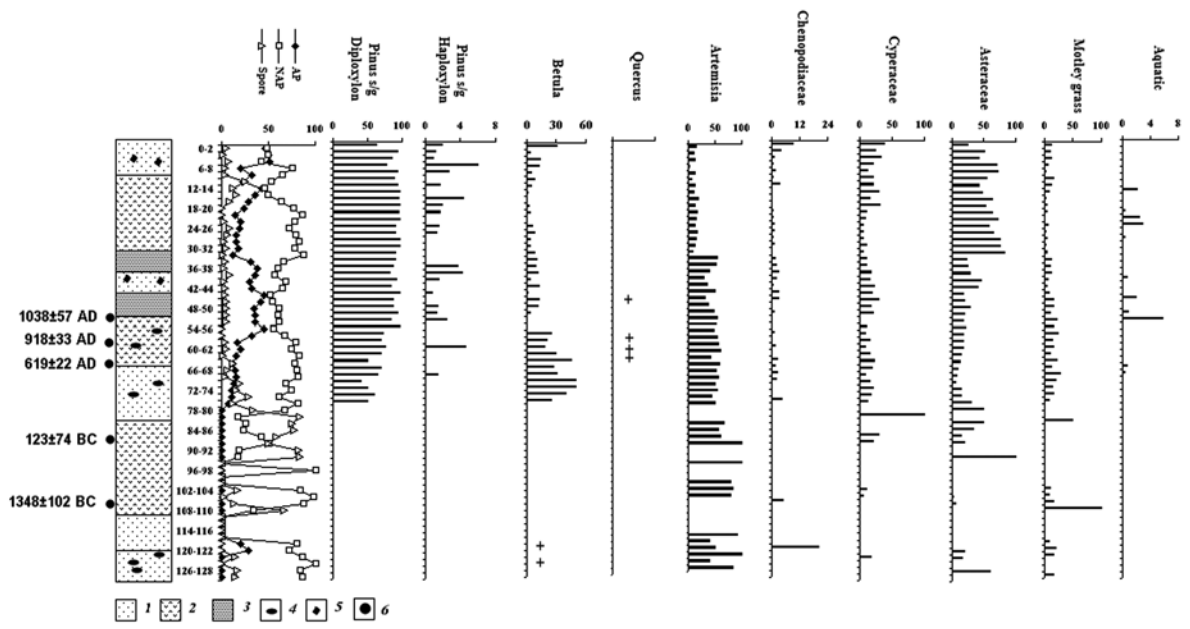

Figure 3 Pollen diagram of the Aga section. 1 – light yellow fine sand; 2 – light brown fine sand; 3 – light gray silty sand; 4 – pebble; 5 – plant roots; 6 – ^{14}C date

52°01'N, 140°08'E) was dominated by shrub birch and open forests of birch and *Alnaster*. 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 amurensis* 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

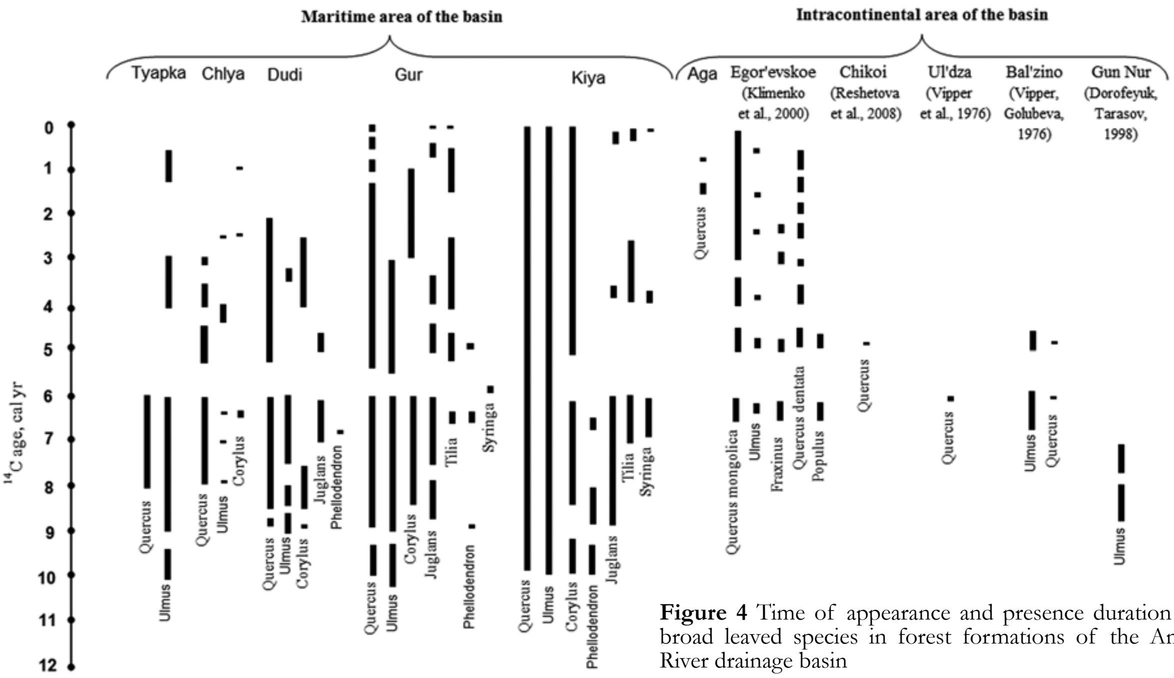

Figure 4 Time of appearance and presence duration of broad leaved species in forest formations of the Amur River drainage basin

Table 1. Radiocarbon dates

Laboratory number	Depth, cm	Dating material	^{14}C age BP	Calendric age BC
Chlya section				
SOAN-4719	270-275	peat	9700±80	9086±152
SOAN-4720	240-245	peat	7630±75	6503±65
SOAN-4721	220-225	peat	7065±85	5933±80
SOAN-5061	205-210	peat	6455±55	5421±49
SOAN-4722	183-188	peat	5730±50	4590±69
SOAN-4723	170-175	peat	4825±35	3599±49
SOAN-4457	125-130	peat	3645±85	2030±113
SOAN-4458	115-120	peat	3400±75	1715±104
SOAN-4727	45-50	peat	2400±30	476±52
SOAN-4759	40-45	peat	2305±100	400±159
SOAN-4728	20-25	peat	1945±40	51±44 AD
Aga section				
SOAN-7963	104-108	sand, humified	3100±85	1038±57 AD
SOAN-7962	84-88	sand, humified	2090±60	918±33 AD
SOAN-7961	62-66	sand, humified	1420±35	619±22 AD
SOAN-7960	54-58	sand, humified	1135±25	123±74
SOAN-7959	52-54	sand, humified	1015±45	1348±102

a few hundreds of kilometers. *Quercus mongolica* and *Ulmus laciniata* 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 laciniata*. 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 interfluve (51°N, 128°E) is ^{14}C-dated at 6729±128 cal yr BP that is middle Holocene. A few broadleaved species – *Quercus mongolica*, *Populus amurensis* Kom., *Fraxinus mandshurica* Rupr. – are present there as early as 6.5 ka BP, while *Quercus dentata* Thunb. appeared about 5 ka BP (Klimenko et al. 2000).

The early Holocene decay of permafrost in the Upper Amur drainage basin resulted in a considerable restructuring of landscapes. The vegetation of cold and dry steppes was replaced with community's characteristic of temperate zone. Pine appeared on fluvial terraces; its presence became more conspicuous during warmer and wetter periods and reduced at intervals of colder and drier climate (Bazarova et al. 2011 a).

The section of the Aga River terrace (51°05'N, 114° 32'E, 674 m a.s.l.) has been studied in the steppe zone of southeastern Transbaikalia. A sample from the base of the section was dated by ^{14}C at 3298±102 cal yr BP (Table 1). The overlying deposits accumulated 1.4–2 and ~1 ka BP yielded single grains of *Quercus mongolica* pollen (Fig. 3).

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. laciniata*) 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 Leno-Angarskoe Plateau. Pollen grains of broadleaved 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. laciniata* 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.

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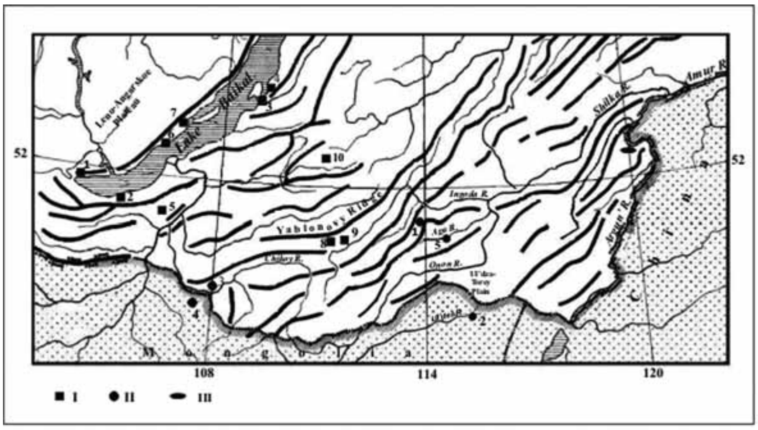

Figure 5 Orographic map of the southern part of the Transbaikalian area and locations of the pollen records:

I – locations of pollen records without temperate broadleaved species pollen: 1 – Pan'kovka River, 2 – Dulikha (Bezrukova et al. 1996), 3 – Arangatuy, 4 – Chivyrkuy (Bezrukova et al. 2002), 5 – Chernoe Lake (Tarasov et al. 2002), 6 – Buguldeika (Tarasov et al. 2007), 7 – Kuchelga (Bezrukova et al. 2007), 8 – Arei Lake (Vipper & Golubeva 1976), 9 – Tanga Lake (Vipper & Golubeva 1976), 10 – Eravnoe Lake (Tarasov et al. 2002)

II – locations of pollen records with temperate broadleaved species pollen: 1 – Bal'zino Lake (Vipper & Golubeva 1976), 2 – Ul'dza River (Vipper et al. 1976), 3 – Chikoi River (Reshetova et al. 2010), 4 – Gun-Nur Lake (Dorofeyuk & Tarasov 1998), 5 – Aga River

III – Budyumkan oak grove

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The book is available from the author:

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