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The boreal forests of north-eastern Eurasia *

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Key words: Boreal forests, Forest vegetation pattern, Monsoon Asia, Vegetation dynamics, Zonation of vegetation

Abstract

The distribution, diversity and structure of boreal forests of monsoon Asia are reviewed. The boreal zone is circumscribed by the isotherms of 15 °C and 45 °C of Kira's Warmth Index (WI) and includes the territory of the Amur basin, the seashores of the Sea of Okhotsk, Kamchatka, Sakhalin and the Kuril islands. Boreal forests also occur on the mountains of Hokkaido, Honshu, Korea and NE China. The oceanic sectors of the boreal zone are composed mainly of birch forests, the marine sectors of spruce-fir forests and the continental sectors of larch and pine forests. The upper limit of the boreal forests ascends from the lowest level in the North to *ca.* 1500 m a.s.l. in the South of the zone, and reaches above 2500 m in the mountains of the temperate zone. In the boreal zone the secondary forests are common. They form after fires and cutting. Volcanism is an essential factor in the forest dynamics in the oceanic part of the region. It is suggested that as a result of global warming one may expect a strong alteration in vegetation pattern, especially in the northern and mountain areas.

Nomenclature: Mainly Vorobiev (1968), Wild trees and scrubs of the (Russian) Far East, Nauka, Leningrad (in Russian)

Introduction

The extratropical forests of the Northern Hemisphere are divided traditionally into boreal (northern) and nemoral (temperate) forests. The border between these in East Asia was established clearly in a number of publications by Russian authors (e.g. Sochava 1969, Figure 1). The northern coniferous forests (taiga) are usually designated as boreal. They are subdivided into the dark-coniferous (composed of *Picea* Dietr. and *Abies* Mill.) and light-coniferous (made up of *Larix* Mill. and *Pinus* L.) forests. In the Western Pacific island arc (Kamchatka, Kurils and the northern Japanese islands) there occur also *Betula ermanii* Cham. forests. Some geographers consider these as boreal, though transitional to the subarctic type (Sochava 1980; Isachenko 1985). These forests occur only at the western and eastern borders of Eurasia and do not seem to be regarded as typically boreal, as they are not coniferous. However, geographically these are the northernmost forests and therefore may be included into the boreal zone. Thus, the boreal forests of East Asia are composed mainly of coniferous and birch forests. They are distributed from the Amur basin to the Kolyma basin at their continental part, and in the coastal zone they occur on Sakhalin, Kamchatka, Shantar, Kuril and partially on the Japanese islands, i.e. mainly on Russian territory, and also in China, Korea and Japan.

The numerous publications devoted forest vegetation of north-western Pacific, including important ones (Kolesnikov 1955; Sochava 1956, 1980; Tatewaki 1958; Ageenko 1969; Numata 1974), were summarized in a few bibliographies (Rosenberg 1970; Gorovoi 1973; Manko 1994 and others).

The aim of the paper is to elucidate the diversity of natural conditions and forest vegetation in this vast region for purposes of TEMA Project. Therefore this paper is mainly the short review of vegetation in con-

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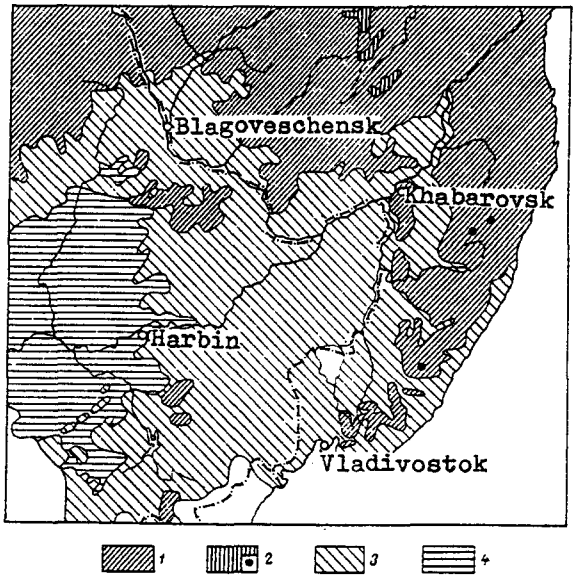

Fig. 1. Vegetation types in the eastern part of the Amur basin (from Sochava 1969): 1 - taiga, including subtaiga, 2 - alpine tundra (the dots indicate small areas), 3 - nemoral, 4 - steppe.

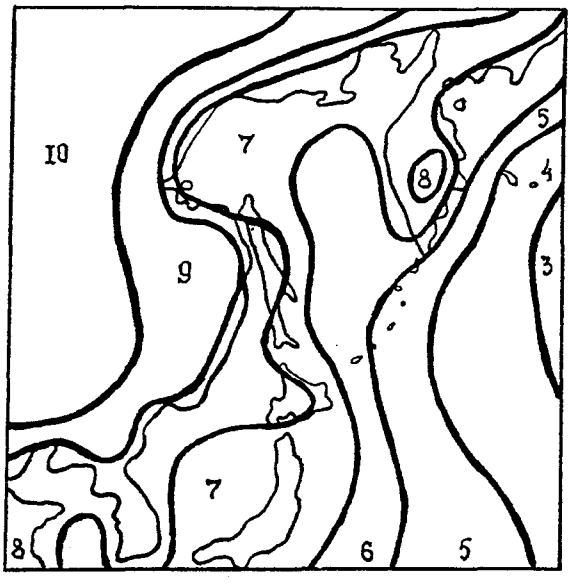

Fig. 2. The belts of continentality in the Far East (from Ivanov 1959): 3 - moderately oceanic, 4 - marine, 5 - slightly marine, 6 - slightly continental, 7 - moderately continental, 8 - continental, 9 - strongly continental, 10 - extremely continental.

text of its main features: distribution, pattern, including zonal differentiation and some aspects of dynamics.

Study area

The territory under consideration is situated in the transitional zone from North Asia to the Pacific Ocean. Mountains prevail in this zone. These are mesozoic structures that became more active during the Neogene-Quarternary (Sikhote-Alin Mts., northern part of Japanese islands); these are also recent, young structures of a modern geosynclinal area, including those of volcanic origin (Kamchatka, Kuril islands, Sakhalin). Kamchatka presently has about 100 volcanoes including 29 active ones, 78 occur on the Kurils, and more than 200 on the Japanese islands (Aprodov 1982). Northeastern China and Korea have Mt. Changbai, which is an active volcano too. The highest elevation of the region is the young Holocene giant Kluchevskoy volcano (4750 m) in Kamchatka. Permafrost is essentially a legacy of the Quarternary glaciation. The present southern boundary of the permafrost almost precisely agrees with that of the boreal forests. Recent glaciation may be found in the high mountains of the northern part of the boreal zone. Thus, some glaciers descend from the Kamchatka mountains to 500 m a.s.l.

The region described here should be restricted to the territory in which the influence of the Pacific is obvious. This can be done by using climatic parameters and the pattern of the vegetation. Sochava (1980) addressed this problem and distinguished the Neopacific, Subpacific and Paleopacific regions. The first and second regions are situated within the sphere of influence of the modern ocean. The limit of this sphere of influence may be defined as the line separating the vast area of East Asia with an extremely continental climate from the less continental zone, in which the continentality strikingly decreases towards the ocean (Figure 2).

Tree species dominate the boreal forests of the western Pacific reflecting the influence of the ocean: most of species (*Picea ajanensis* Fisch., *Larix dahurica* Turcz., *Abies nephrolepis* Maxim., *A. sahalinensis* Mast., *Betula ermanii*) have the Okhotian type of distribution area (Figure 3, Table 1).

The distribution area of the boreal forests agrees well with the July isotherms +12 °C and +18 °C. The Kira WI varies in this area from +15 to +45 °C, and the total sum of active (> 10 °C) temperatures varies

Table 1. The dominants of the boreal forests of the Western Pacific (lower altitudinal belt, 0–500 m a.s.l.)

Subzones	Continental	Marine	Oceanic
Subarctic	*Larix dahurica* (as a component of the forest-tundra ecotone)	*Pinus pumila* krummholz	*Alnus kamtschatica* and *Pinus pumila* krummholz
Northern boreal	*Larix dahurica*	*Larix dahurica* *Picea ajanensis*	*Betula ermanii*
Middle boreal	*Larix dahurica* *Pinus sibirica*	*Larix dahurica* *Picea ajanensis*	*Betula ermanii*
Southern boreal	*Larix dahurica* *Pinus sibirica*	*Picea ajanensis* *Abies* spp.	*Picea ajanensis* *Abies* spp.
Subboreal	*Pinus sibirica* *Larix dahurica* *Quercus mongolica*	*Pinus koraiensis* *Quercus mongolica*	*Abies sahalinensis* *Quercus mongolica*

Table 2. Mean temperature data from some climatic stations in the study area (from Reference book on a climate of the USSR 1966–1971). Abbreviations: *c* - continental, *m* - marine, *o* - oceanic sector.

Station	Latitude	Longitude	Station altitude (m)	Mean temperature			Sum of active temperature			
				Annual	Warmest month	Coldest month	> 0	> 5	> 10	WI Kira
Subarctic										
c Anadyr	64.7° N	177.5° E	64	−7.4	10.4	−21.9	no data	799	393	10.0
m Apuka	60.5° N	169.6° E	5	−2.3	10.6	−13.0	1068	950	476	13.3
o Nikolskoie	55.2° N	166.0° E	19	2.1	10.5	−4.0	1228	1025	366	13.0
Northern boreal										
c Arka	60.1° N	142.3° E	198	−7.0	13.6	−28.5	1376	1298	984	21.9
m Bolshoy Shantar	54.8° N	137.5° E	8	−3.5	12.2	−20.9	1262	1122	715	17.4
o Semlychiki	54.1° N	160.4° E	26	1.7	12.9	−7.5	1527	1372	895	21.8
Middle boreal										
c Nelkan	57.7° N	136.1° E	326	−7.5	17.1	−37.3	1745	1664	1392	31.7
m Kozyrevsk	56.0° N	159.8° E	45	−1.8	15.1	−19.2	1674	1578	1245	28.2
o Petropavlovsk-Kamchatsky	53.1° N	158.7° E	28	1.7	13.7	−8.6	1645	1492	1081	25.2
Southern boreal										
c Nora	52.3° N	129.9° E	254	−5.4	18.0	−33.5	2028	1961	1591	39.0
m Mariinsk	51.7° N	140.2° E	26	−1.0	17.1	−23.3	2177	1998	1715	39.0
o Yuzhno-Kurilsk	44.0° N	145.8° E	44	4.7	16.6	−6.7	2094	1593	765	38.2
Subboreal										
c Kumara	51.6° N	126.7° E	173	−2.1	19.9	−27.4	2367	2294	1987	48.4
m Olga	43.7° N	135.3° E	*ca.* 20	3.6	18.9	−12.4	2366	2265	1946	47.2

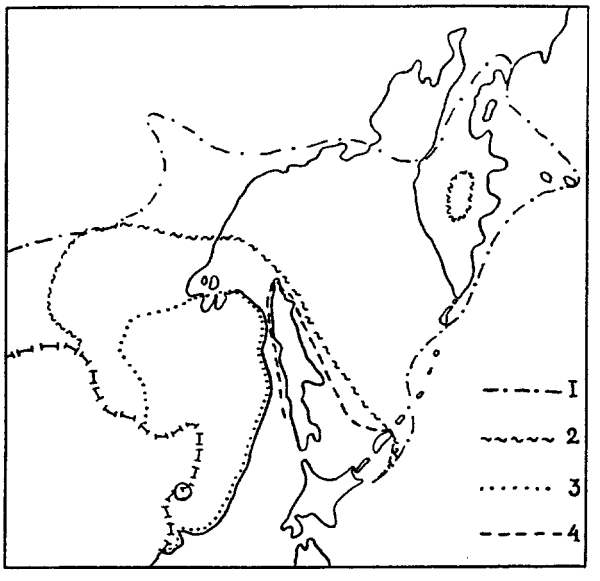

Fig. 3. The distribution of the dominants of the boreal forests in the basin of the Sea of Okhotsk (from Grubov 1977): 1 - *Betula ermanii* s.l., 2 - *Picea ajanensis* (= *P. yezoensis*) s.l., 3 - *Abies nephrolepis*, 4 - *Abies sahalinensis*.

from ca. 800 to 1800 °C (Table 2). The precipitation varies from 200 to 1400 (1800) mm. The minimum (200–400 mm) falls in the north of the continental part, where larch forests dominate completely. The mean amount of precipitation (400–800 mm) occurs in the region of the Amur basin, where spruce, larch and fir-spruce forests dominate. The maximum (> 800 mm) falls in the oceanic and high-mountain areas, where birch and spruce-fir forest are prevalent. The climate in the region varies from extremely continental to slightly marine (Ivanov 1959), with a predominance of moderate-continental and continental climate types even at the seaside (Kamchatka, Sakhalin, Hokkaido).

The monsoon circulation in the atmosphere is more prevalent in the southern part of the region. Apart from that the climate in the vast territory, stretching about 2,000 km from North to South, is influenced by the prevailing mountain relief and the sea currents.

Differentiation of the boreal zone

The forest vegetation in this vast area is very heterogeneous. There is considerable variability in vegetation along gradients of latitude, altitude and longitude. The forest vegetation of the boreal zone may be differentiated following three main criteria: 1. the structure of the climax (zonal) vegetation, 2. the structure of the altitudinal belts of vegetation and the altitudinal position of the climatical upper forest line, 3. a complex of climatic indices which correspond to vegetation boundaries.

Attempts towards a zonal differentiation of the vegetation of north-eastern Asia were undertaken mainly on the basis of vegetation only, even though the vegetation is not sufficiently investigated. For example, Kolesnikov (1955) includes the middle and northern Kuril islands in the middle subzone of the coniferous zone, while Hämet-Ahti *et al.* (1974) propose that the middle and part of the northern Kuril islands belong to the southern subzone of the boreal zone. Meanwhile, it is known well, that forest vegetation is entirely absent in the northern half of the Kuril islands. This is due to severe climatic conditions, fully corresponding to a subarctic climate. Therefore, it may be more promising to differentiate the zonal vegetation on the basis of formal, objective climatic criteria such as the warmth index of Kira. Kira (1977, and preceding publications) has shown that isolines based on his index closely correspond to the distribution limits of forest types. For example, the distribution of *Betula ermanii* zonal forests in our region is, according to preliminary data, limited by the 15 °C and 35 °C isotherms of Kira's Warmth Index, that of *Picea ajanensis* forests by the 15 °C and 45 °C, and that of *Larix dahurica* forests by 15 °C and 50 °C. Warmth indices, such as the Kira's, are the sum of the positive mean daily or monthly air temperatures. These are indirect functions of geographical latitude, i.e. they are in fact zonal. Thus, if we use the temperature limits of 15 and 45 °C of Kira's Warmth Index for the borders of the boreal zone, we may subdivide this space into three traditionally distinguished subzones (Figure 4, Table 3). On the same basis we can determine the adjacent subzones: the subarctic (between the arctic and boreal zones) and the subboreal (between the boreal and temperate or nemoral zones).

On the basis of this subdivision, one can qualify the zonal status of the forest vegetation in any territory using the climatic data and one can determine the correlation between the expected altitudinal position of vegetation belts in mountains, as calculated on the basis of the local climate and their actual position.

It is interesting to note that the boundaries of subzones established in this way agree with the well-known phytogeographical "lines" of the North-western

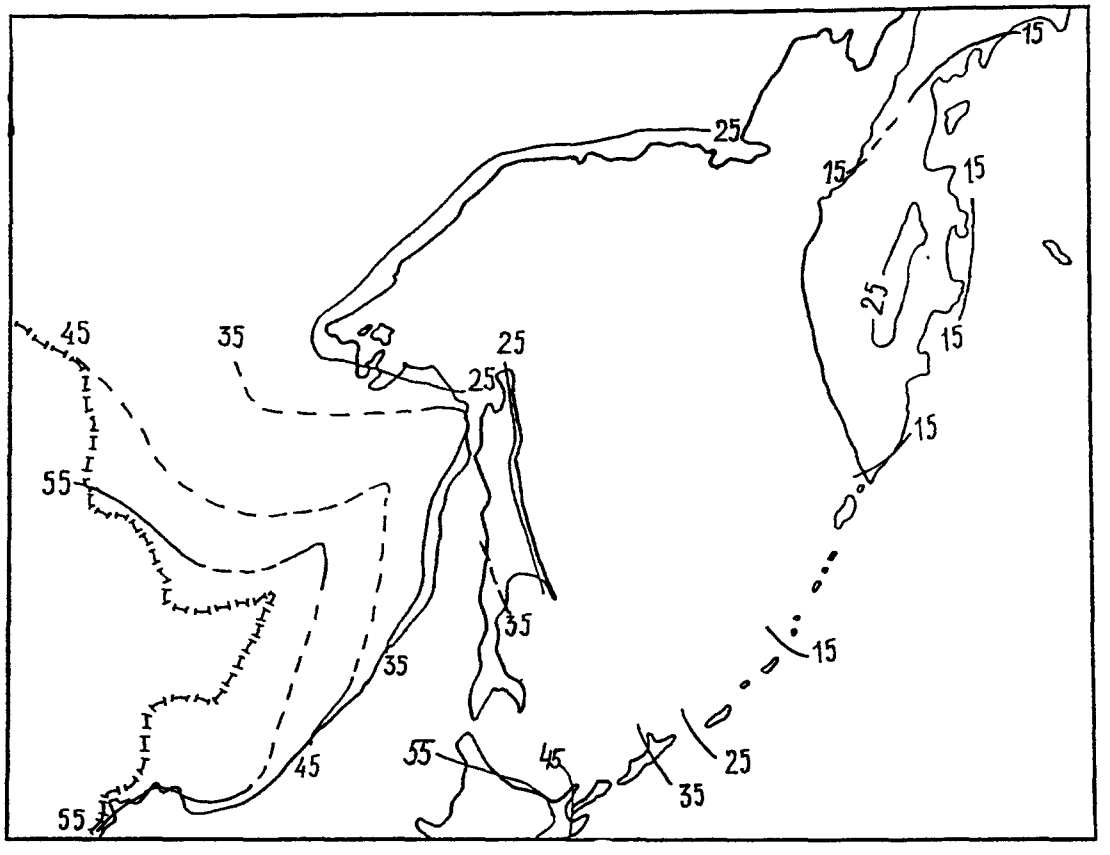

Fig. 4. The isopleths of Kira's Warmth Index in the boreal zone of the Western Pacific. Interrupted lines pass through mountain areas. The scheme based on calculated data of more than 300 stations of Russian Far East (Reference book on a climate of the USSR 1966–1971). The data for Hokkaido is shown according to Kira (redrawn from Hämet-Ahti *et al.* 1974).

Table 3. Some features of the boreal zone of the Western Pacific

Subzones	Warmth index Kira	Mean temperature of the warmest month	Net primary productivity (t ha^{-1} $year^{-1}$, from Buks 1976)	Number of tree species (estimation on the basis of Vorobiev 1968)	Position of the climatic tree line, m a.s.l.
Subarctic	5–15	9.8–12.0	< 2	5	–
Northern boreal	15–25	12.0–14.2	2–4	10	0–500
Middle boreal	25–35	14.2–16.4	4–8	20	500–1000
Southern boreal	35–45	16.4–18.6	6–10	40	1000–1500
Subboreal	45–55	18.6–20.8	> 8–10	100	1500–2000

Pacific (Tatewaki 1963). Thus, the boundary between the northern boreal (Kamchatka) and subarctic (Kommander Isl.) subzones agrees with Hulten's line; the boundary between the middle and northern subzones on the Kuril islands agrees with Miyabe's line, and the boundary between the southern and middle subzones on Sakhalin corresponds with the Schmidt's line. Moreover, other climatic zonal boundaries coincide

rather precisely with important vegetational boundaries. For example, the isotherm of 15 °C separates most of Kamchatka, which is situated in the northern boreal subzone, from the extreme southern and northern parts of the peninsula with their subarctic conditions. The 25 °C isotherm circumscribes the coniferous "island" in the central part of Kamchatka. The 15 °C isotherm, across the middle of the Kuril Islands arc separates there the northern boreal subzone from the treeless subarctic one. The 35 °C isotherm separating the southern and middle subzones, coincides with the northern limit of coniferous forests on the Kuril Islands.

A more complex group of factors (contrasting air temperatures, humidity, permafrost and others) varies along the longitudinal gradient. Three longitudinal sectors are traditionally distinguished: the oceanic, marine and continental sectors. The first is an area with dominance of *Betula ermanii* forests, the second is distinguished by the dominance of dark-coniferous forests (*Picea ajanensis*, *Abies* spp.) and the third is characterized by the prevalence of light-coniferous forests (*Larix dahurica*, *Pinus sylvestris* L.).

Thus, this "network" made of three latitudinal strips, crossed by three longitudinal ones, gives a first approximation to differentiate the diversity of hydrotermic conditions and, correspondingly, the boreal forests. This differentiation agrees in its main features with the previously established ones (Lavrenko 1947; Lavrenko & Sochava 1954; Kolesnikov 1955; Sochava 1969, 1980; Hämet-Ahti *et al.* 1974; Hämet-Ahti 1976; Buks 1976).

The forest vegetation pattern

Between the northern boundary of relatively closed boreal forests and the treeless arctic tundra there is a zonal forest-tundra ecotone or a subarctic subzone. The position and structure of this ecotone strongly depends on the orography and on the balance between marine and continental influences. Northwards the monsoon climate influence on the boreal forests of the Northern Far East seems to be restricted to the basin of the Sea of Okhotsk (about 60–62° N). Larch forests occur farther to the north than Okhotsk and Magadan, approximately to 70° N, but there they occur under the extremely continental climate of north-eastern Siberia.

Characteristically the subarctic forest-tundra ecotone consist of a combination of a few types of vegetation. The forest vegetation is represented by deciduous flood plain communities of *Chosenia arbutifolia* (Pall.) A.Skvorts., *Populus suaveolens* Fisch., *Salix* spp. L., and open woodlands of larch in the lowlands. Subalpine krummholz is widely distributed in the lower parts of mountain slopes: *Pinus pumila* (Pall.) Rgl. in the northern part of the basin of the Sea of Okhotsk, and *Alnus kamtschatica* (Call.) Kom. in the Bering Sea basin. The open woodlands and krummholz are usually distributed below 500 m a.s.l. Vast areas are covered with tundra and bog vegetation.

The boreal forests of the northern subzone occupies the lower altitudinal belt, below 500 m a.s.l., in areas with a cold vegetation period. It is composed of species-poor and simple communities of *Betula ermanii* on Kamchatka and the Middle Kurils, and of *Larix dahurica* along the seashore of the continental part of the Sea of Okhotsk, including north-eastern Sakhalin. Spruce and larch forests are distributed in the Shantar Islands (Figure 5). The tree layer of these communities is characterized by open crowns, suppressed, small stature and low productivity. The prevalent types of larch forest have a cover of dwarf shrubs, mosses and lichens, locally combined with bogs. *Betula ermanii* forms a park-like forest with tall or subalpine herbs in the lower layer, or with subalpine krummholz (*Pinus pumila*, *Alnus kamtschatica*) in the understory.

The forests of the middle boreal subzone may be considered as the typical boreal forests. They grow under the conditions of a moderately warm vegetation season. They are distinguished by moderate productivity and are distributed from sea level to 1000 m a.s.l. The climatic timberline is located above 500 m. The forests are dominated on central Kamchatka by larch, spruce and birch (*Betula platyphylla* Sukacs. and *B. ermanii*) (Figure 6). On the Kuril islands these forests, formed by the stone birch, occur only at the northern part of Etorof Island. In the southern and western continental parts of the region of the Sea of Okhotsk, on the northern half of Sakhalin, in the lower part of the Amur basin and in the Amgun basin larch and spruce forests with a share of the stone birch in the upper part of the vertical forest belt occur widely distributed. In the more continental basins of the Zeya and Maya rivers (western part of the region) pine forests (*Pinus sylvestris*) are common. However, stone birch and spruce (*Picea ajanensis*, *P. obovata* Ledeb.) forests occur there only in the mountains. The fir (*Abies nephrolepis*) is confined to the spruce forests of the southern and eastern parts of this subzone.

The distinct feature of the plant cover of this subzone is the widely distributed mires and moorlands,

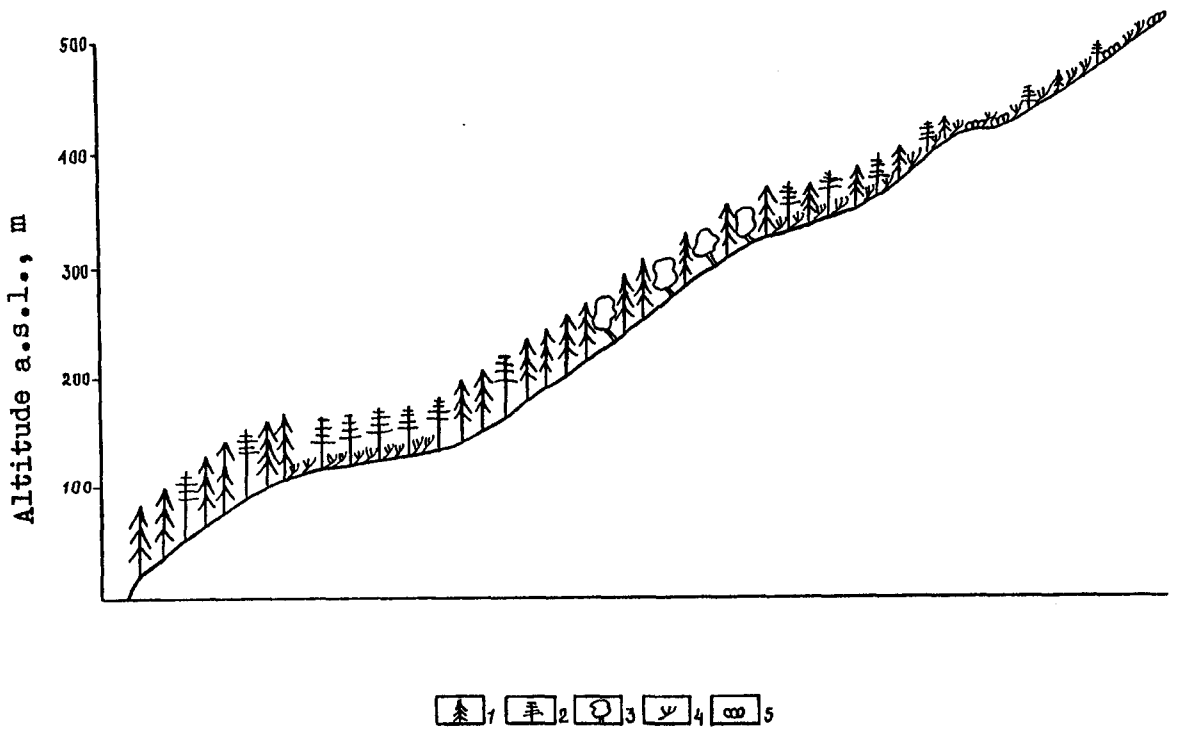

Fig. 5. Vertical profile of the vegetation in the Shantar Islands (from Andreev *et al.* 1984, simplified): 1 - *Picea ajanensis* forest, 2 - *Larix dahurica* forest, 3 - *Betula ermanii* forest, 4 - *Pinus pumila* krummholz, 5 - alpine tundra.

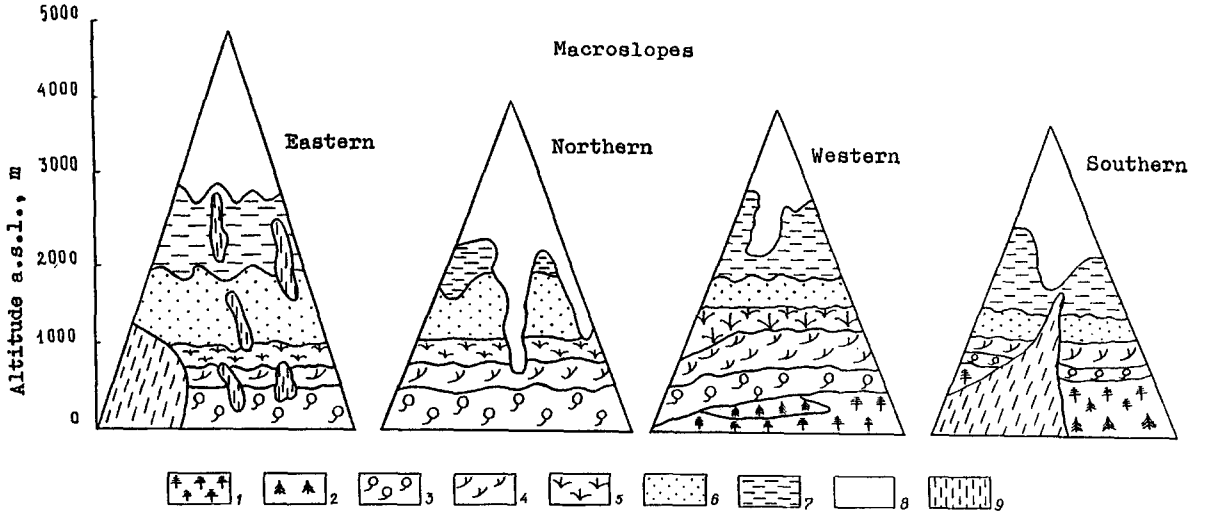

Fig. 6. Altitudinal zonation of the mountain vegetation in the Kluchevskoy volcano group (from Grishin 1993): 1 - *Larix dahurica* forest, 2 - *Picea ajanensis* forest, 3 - *Betula ermanii* forest, 4 - *Alnus kamtschatica* and *Pinus pumila* krummholz, 5 - subalpine meadows, 6 - alpine tundra, 7 - cold rock desert, 8 - glaciers, 9 - areas of volcanic deposits.

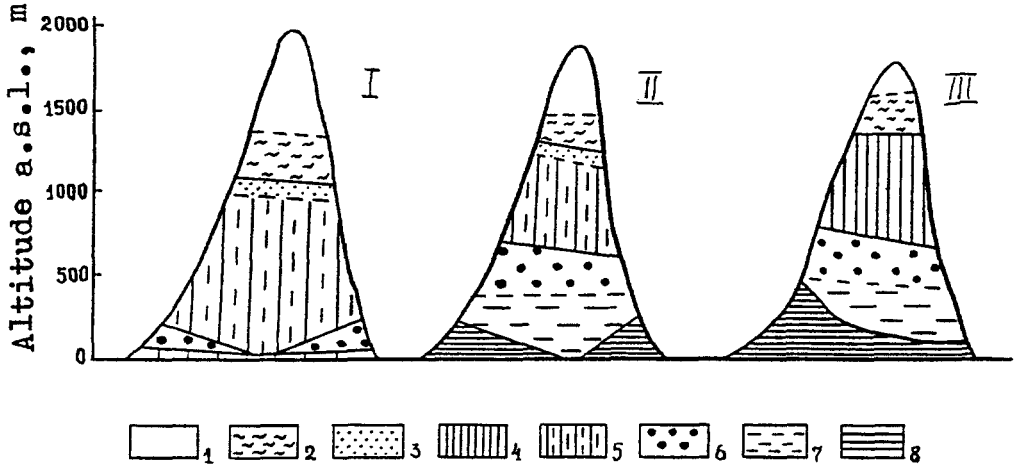

Fig. 7. Altitudinal zonation in the Sikhote-Alin Mountains (simplified from Kolesnikov 1955): I - Northern Sikhote-Alin (southern boreal subzone), II and III - Central and Southern Sikhote-Alin (subboreal subzone). 1 - alpine tundra, 2 - subalpine krummholz (*Pinus pumila*), 3 - *Betula ermanii* forest, 4 - spruce-fir forest, 4 - spruce-fir and larch forest, 6 - spruce-broadleaved forest, 7 - Korean pine-broadleaved forest, 8 - nemoral, mainly oak forest, with inclusion of steppe vegetation.

covered by open woodlands and forests of larch swamp with a *Ledum* spp. L. or *Sphagnum* spp. cover.

The forests of the southern boreal subzone enjoy a warm vegetational period and are commonly of high productivity. They are distributed on a southern half of Sakhalin, occur on the southern Kurils, in the middle part of the Amur basin and in the northern half of the Sikhote-Alin Mountains.

The characteristic feature of this subzone is that the boreal forests may cover the whole altitudinal interval of 0–1500 m a.s.l. (0–500 m - southern boreal forests; 500–1000 m - mountain forests, like the middle boreal forests; 1000–1500 m - high-mountain forests, like the northern boreal forests). Fir-spruce and larch forests dominate in lowest and middle altitudinal belts, spruce and stone birch in the upper belt. Another feature of the southern boreal subzone is that the forests are enriched with nemoral floristic elements. Thus, in some places *Quercus mongolica* Fisch. ex Turcz., *Pinus koraiensis* Siebold et Zucc., etc. become rather important intermixed species (Figure 7).

Most common types spruce forests have a fern cover in the river valleys and on gentle slopes, and a moss cover on steep slopes. Climax larch forests occur only in marshy valleys and in the high-mountain belt.

In the western, continental part of the subzone, spruce, fir and stone birch are very rare. There larch forests and secondary forests of *Betula platyphylla* predominate as well as azonal pine forests on sand deposits and steep southern slopes (with admixtures of larch, birch and, in some places, oak trees). The Siberian spruce (*Picea obovata*) occurs in river valleys.

The southern boreal subzone is replaced by the subboreal one towards the south. The latter is composed of broad-leaved forests, formed mainly by *Quercus mongolica*, admixed with species of *Acer* L., *Ulmus* L., *Tilia* L., *Fraxinus* L. and others, and enriched with some coniferous tree species, first *Pinus koraiensis*, and then *Picea koraiensis* Nakai, *P. glehnii* Mast., *Abies mayriana* Miyabe et Kudo, *A. holophylla*, *Taxus cuspidata* Siebold et Zucc. and others as well. In the western part of the region (upper Amur basin) larch-pine and pine (*Pinus sylvestris*) forests with oak and birch (*Betula dahurica* Pall., *B. platyphylla*) are predominant. They have a cover of herbs and dwarf shrubs. The forest vegetation forms a complex with steppe vegetation in the south of the western part.

The subboreal forests grow under conditions of a very warm growth season and are characterized by high productivity and a complex structure. The climatical upper forest line in this subzone is situated at the altitude 1500–2000 m a.s.l. In the lower altitudinal belt of the mountains (0–500 m) there occurs a nemoral forest, and above it fir-spruce, larch and stone birch forests predominate, similar to those which form the major forests in the boreal zone toward the north. Howev-

er, the mountain, high-mountain and subalpine forests differ from boreal forests, due to the zonal position of the subboreal subzone.

Subboreal forests are distributed in the middle Amur valley, the Ussuri basin and the northern part of Hokkaido.

Farther to the south, as the temperature increases, the altitudinal analogues of boreal forests ascend higher on the mountains of the nemoral zone. Thus, in the northern nemoral subzone, on Mt. Changbai, situated at 42° N, the forests, composed of *Picea ajanensis*, *P. koraiensis*, *Abies nephrolepis* and *Betula ermanii*, are distributed in the altitudal interval of 1100–2100 m a.s.l. (Xu & Lin 1981). On Mt. Fuji (35° N), situated in the warm temperate zone, the timberline advances to more than 2500 m (Ohsawa *et al.* 1971).

Apart from zonal forests there are also flood plain forests within the limits of the boreal zone. Their composition,structure and productivity depends on their zonal position. Thus, the flood plain forests of the northern boreal subzone consist exclusively of *Populus suaveolens*, *Chosenia arbutifolia* and a few species of *Salix*. In the forests of the middle subzone the communities contain *Picea obovata*, *P. ajanensis*, *Abies nephrolepis* and they are part of some successional stages. Flood plain forests of the southern subzone are enriched with broad-leaved species of the nemoral flora (*Fraxinus mandschurica* Rupr., *Phellodendron amurense* Rupr., *Juglans manshurica* Maxim., *Ulmus propinqua* Koidz. etc.).

Secondary forests widely occur in the boreal zone (Figure 8). They result from clear-cutting and fires. These forests are composed mainly of *Betula platyphylla* on the North, and of larch and the same birch species in the middle and partly in the southern subzones.

The essential and not clear until now is a phenomenon of natural drying of the fir-spruce forests in the southern subzone (Sikhote-Alin Mts.).

The important factor in forest vegetation dynamics is volcanism, distributed in great territory (Figure 9). The vegetation pattern depends on volcanic events that happened between a few hundred years and a few thousand years ago. Different volcanic activities have different effects in the various zones and belts. For example, succession on lava flows of Sakurajima volcano in the nemoral zone of Japan continues for 500–700 years (Tagawa 1964), and the same is for the subalpine belt of Central Kamchatka for about 2000 yrs (Grishin 1992).

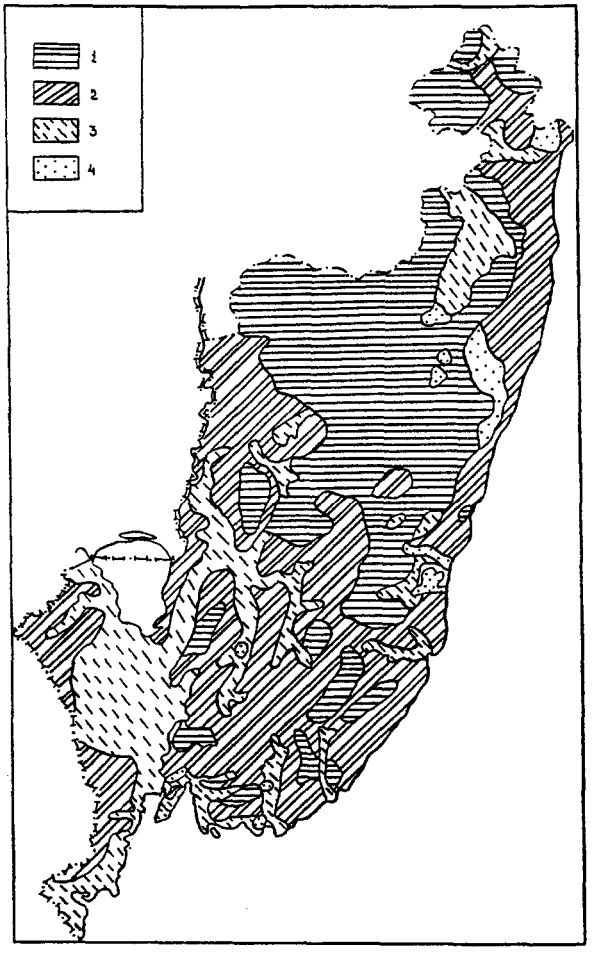

Fig. 8. The state of natural vegetational cover of Primorsky Kray (southern part of the Russian Far East). The climax vegetation covers: 1. 51–80%, 2. 26–50%, 3. 11–25%, 4. 0–10% (from Yelykov 1993).

Concluding remarks

Concluding this short review on the boreal forests of monsoonal Asia, it should be pointed out that the climax forests are mainly coniferous, composed of a few species of *Picea*, *Abies*, *Larix*, and partly deciduous, composed of some species of *Betula*. These forests are spread over a vast geographical area: the basis of the zone is limited with the 50 and 60° N latitudes, while fragments of boreal forests as compact patches or as widely dispersed open woodlands penetrate to the North almost as far as the polar circle. Toward the south, at approximately 50° N, the altitudinal analogs

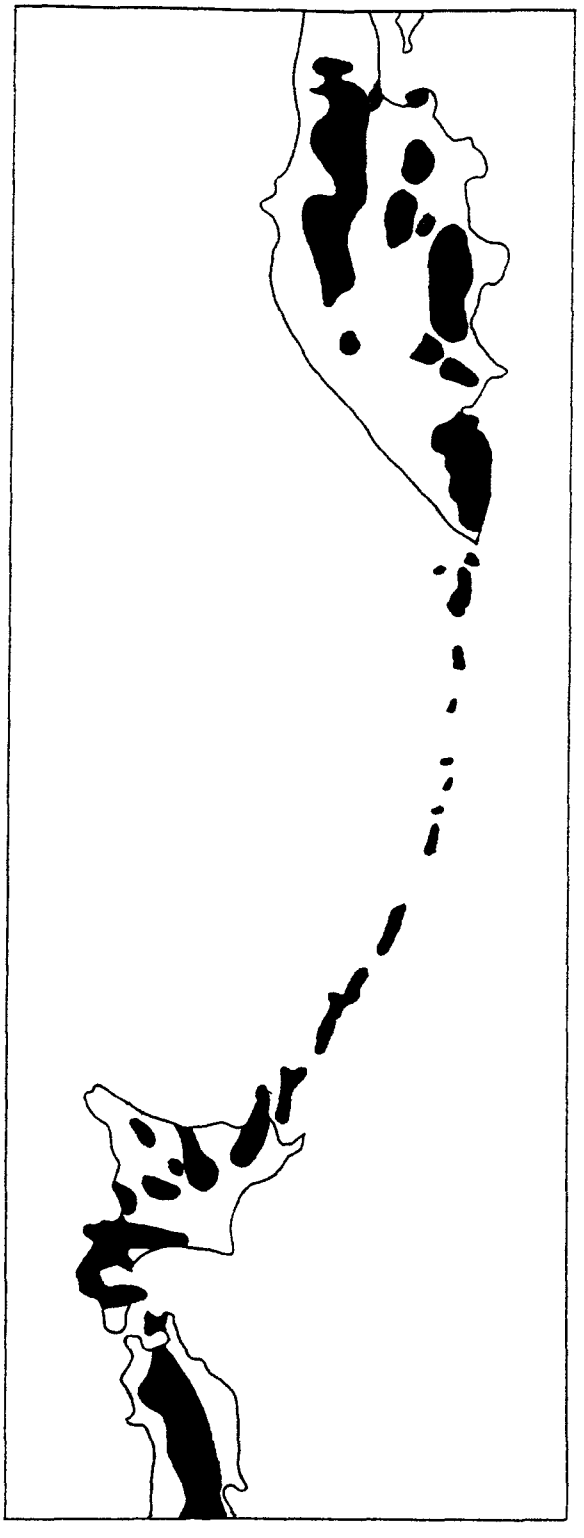

Fig. 9. The areas of newest effusives in the region (from Aprodov 1982).

of the boreal forests ascend on the mountains, and they reach their highest occurrence at more than 2500 m at 35° N.

The zonal pattern of climatic factors, such as the radiation balance of the earth's surface, complicated by reflection resulting from differences in relief and from circulation of the atmosphere, leads to a complex pattern in hydrothermic space. The latter largely determines the composition and structure of the forest vegetation. As a result of this complex pattern there is a high diversity and remarkable contrast in the forest cover of this oceanic arc.

In the area under a monsoonal climate, that ranges from the continental parts of eastern Siberia and Manchuria to the oceanic islands in the west Pacific, the structure of the boreal forests and their composition of tree dominants change in accordance with the gradual changes in the effects of the monsoonal climate.

As far as the problem of global warming is concerned (Budyko 1980) it is likely that, with respect to these forests, an increase in the mean yearly air temperature of 2 and 4 °C will result in an increase of Kira's Warmth Index by ca. 15 and 30 °C, respectively, over the entire area. The last value corresponds to the difference in WI at the northern and southern boundaries of the boreal zone (15–45 °C). With such a warming of the area one may expect a strong alteration in vegetation pattern. This is to be expected especially in the mountains of the northern boreal subzone and the subarctic forest-tundra ecotone (the continental seashore of the Sea of Okhotsk, Kamchatka, southern Chukotka). In the middle and southern boreal subzones vegetation changes may be expected to be more limited due to resistant species interaction in the forest communities of the continental area and the isolated islands of the Kuril, Shantar and Kommander groups. In the southwestern sector of the region the decrease in area of the light-coniferous forests may be apparent from an expansion of the steppe vegetation. The changes in the altitudinal distribution of vegetation belts on the mountains of the middle boreal-subboreal subzones may be rather spectacular: the altitudinal belts will ascend on the mountains, but the upper timberline will probably stay at almost the same level because it depends strongly on other factors (wind stress, edaphic problems and so on).

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References

Ageenko A.S. (ed.) 1969. The forests of the (Russian) Far East, Moscow (in Russian).

Andreev S.A., Butovets G.N., Gladkova G.A., Grishin S.Yu., Ilyina T.M., Levus A.P., Lykova S.D., Manko Yu.I., Sidelnikov A.N., Shafranovsky V.A. 1984. The spruce forests of Shantar Islands. Vladivostok (in Russian).

Aprodov V.A. 1982. The volcanoes. Mysl, Moscow (in Russian).

Budyko M.I. 1980. Climate in the past and future. Gidrometeoizdat, Leningrad (in Russian).

Buks I.I. 1976. Techniques of compiling and analysis of correlational eco-phytocoenological map of Asian Russia, scale 1:7 500 000. In: Sochava V.B. & Isachenko T.I. (eds) Geobotanical mapping, pp. 44–51. Nauka, Leningrad (in Russian).

Gorovoi P.G., (ed.) 1973. Flora, vegetation and plant resources of the (Russian) Far East. Bibliography (1928–1969), Far East Science Center of USSR Academy of Sciences, Vladivostok (in Russian).

Grishin S.Yu. 1992. Successions of the subalpine vegetation on lava flows of the Tolbachik area. Botanicheskiy Zhurnal 77: 92–100 (in Russian).

Grishin S.Yu. 1993. The features of altitudinal zonation of vegetation at Kluchevskoy volcano group. In: Pavlova N.S. (ed.) Komarovskie chtenia, XXXVIII, pp. 95–117. Dalnauka, Vladivostok (in Russian).

Grubov V.I. (ed.) 1977. Areographia arborum fruticumque URSS. I. Nauka, Leningrad.

Hämet-Ahti L. (1976) The biotic subdivisions of the boreal zone. In: Sochava V.B. & Isachenko T.I. (eds) Geobotanical mapping pp. 51–58, Nauka, Leningrad (in Russian).

Hämet-Ahti L., Ahti T., Koponen T. 1974. A scheme of vegetation zones for Japan and adjacent regions. Ann. Bot. Fennici 11: 59–88.

Isachenko A.G. 1985. The landscapes of USSR. Leningrad University Press, Leningrad (in Russian).

Ivanov N.N. 1959. Belts of continentality on the Globe. Izvestia vsesoyuznogo geographicheskogo obshchestva 91: 410–423 (in Russian).

Kira T. 1977. A climatological interpretation of Japanese vegetation zones. In: Miyawaki A. & Tuxen R. (eds) Vegetation science and environmental protection pp. 21–30. Maruzen Co., Ltd., Tokyo.

Kolesnikov B.P. 1955. A sketch of vegetation of the (Russian) Far East. Khabarovsk (in Russian).

Lavrenko E.M. (ed.) 1947. Geobotanical subdividing of the USSR. USSR Academy of Sciences Press, Moscow-Leningrad (in Russian).

Lavrenko E.M. & Sochava V.B. (eds) 1954. Geobotanical map of USSR, scale 1:4 000 000. Leningrad (in Russian).

Manko Yu.I. (ed.) 1994. The forest and forestry in the (Russian) Far East (bibliography of publications 1968–1992). Vladivostok (in Russian). In press.

Numata M., (ed.) 1974. The flora and vegetation of Japan. Kodansha Ltd., Tokyo.

Ohsawa M., Suzuki M., Watanabe R., Irikura S., Abe Y. 1971. Altitudinal zonation of vegetation on Mt. Fuji. In: Tsuya H., Yamamoto S., Huzimura I., Numata M., Kuroda N. (eds) Fuji-san. Results of the cooperative scientific survey of Mt. Fuji. pp. 413–421. Fuji Kyuko Co., Ltd. Tokyo.

Reference book on a climate of the USSR (Series of volumes, 1966–1971). Gidrometeoizdat, Leningrad (in Russian).

Rosenberg V.A. (ed.) 1970. The forest and forestry at the (Russian) Far East (bibliography of Russian publications, 1755–1967). Far East Branch of USSR Academy of Sciences, Vladivostok (in Russian).

Sochava V.B., (ed.) 1956. Vegetation cover of the USSR. I. USSR Academy of Sciences Press, Moscow-Leningrad (in Russian).

Sochava V.B. 1969. Botanical and geographical relations in the Amur-river basin. In: Yunatov, A.A. (ed.) Amur taiga, pp. 5–15. Nauka, Leningrad (in Russian).

Sochava V.B. 1980. Geographical aspects of Siberian taiga. Nauka, Novosibirsk (in Russian).

Tagawa H. 1964. A study of the volcanic vegetation in Sakurajima, South-West Japan. I. Dynamics of vegetation. Mem. Fac. Sci. Kyushu Univ. Ser. E (Bot.) 3: 165–228.

Tatewaki M. 1958. Forest ecology of the islands of the North Pacific Ocean. J. Fac. Agric. Hokkaido Univ. 50: 371–486 + 30 plates.

Vorobiev D.P. 1968. Wild trees and scrubs of the (Russian) Far East. Nauka, Leningrad (in Russian).

Yelykov G.B., (ed.) 1993. Long-term programme of nature protection and rational utilization of natural resources of Primorsky Kray until 2005 yr. Parts 1, 2. Dalnauka, Vladivostok (in Russian).

Xu W.-D. & Lin C.-Q. 1981. Preliminary study of relations between vertical distribution of vegetation and thermal climate in Changbai Mountain. In: Research of forest ecosystems. Changbai Mountain Res. Station, Academia Sinica. 2: 88-95 (in Chinese with English summary).