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REGIONAL FEATURES OF THE ALTITUDINAL GRADIENTS IN NORTHERN TRANSBAIKALIA VEGETATION COVER

ABSTRACT. According to the the biome concept, the idea of the orobiome and its significance in the evaluation of the biodiversity for mountain territories are disclosed. Altitudinal gradients of vegetation with certain altitudinal limits of development are the basis for analysing the floristic and coenotic diversity of the orobiome and the ecological and geographical patterns of its spatial organization at the regional level. Based on the example from Kodar-Kalar orobiome, an altitudinal composition of the vegetation of the Northern Transbaikalia has been identified using thematic maps. The statistical evaluation of the altitudinal distribution of 4 vegetation belts (the upper tundra belt, the tundra belt, the sub-tundra belt and the mountain taiga belt) has been made. The regional features of the altitude position of the basic vegetation types forming the belts have been determined for the orobiome. They are reflected in three geographical variants. Orographic conditions and the history of the territory development have been discussed in the analysis of regional features of altitudinal spectra difference.

KEY WORDS: orobiome, altitudinal structure of vegetation cover, vegetation belts, the Stanovoy highland.

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INTRODUCTION

According to the altitudinal gradient of bioclimatic conditions in the mountains, an altitudinal structure of vegetation cover forms. It is associated with regular changes in species richness (Sang 2009; Wiesmair et al. 2017), coenotic diversity (Hemp 2006; Molozhnikov 1986) and spatial structure (Nakashizuka et al. 2016). These particularities have regional features that determine the separation of the altitudinal spectra of vegetation, which is reflected in the typology of altitudinal zonation, with the identification of its groups and classes (Ogureeva 1991). The geography of the botanical diversity of mountains is revealed on the basis of the biome concept (Walter and Breckle 1999). The idea of biomes is based on the concept of geographic dimensions of geosystems at the global, regional, and local levels. The biome is considered to be a combination of ecosystems of different levels, including the biota that most effectively uses the abiotic components of the environment as a result of a specific, historically conditioned adaptation to them.

The biome concept was used as a strong basis for creating the map «The Biomes of Russia» (2018). The map legend was based on the classification of terrestrial ecosystems-biomes, which includes three major categories, namely the zonobiome, the orobiome (altitudinal vegetation belts spectra in the mountains) and the pedobiome, where there are large edaphic variants in the zonal types of ecosystems. For each orobiome, the regional specificity of mountain biota was shown. Its role in the belt structure of the vegetation cover as the basic component of structure and diversity in mountain ecosystems was determined (Ogureeva and Bocharnikov 2017).

The botanical diversity of orobiomes is revealed through the altitudinal structure of the vegetation cover and includes floristic and coenotic components. Taxonomic and coenotic diversity is considered by taking into account the basic vegetation formations that have certain altitudinal limits.

So, in the regional evaluation of the botanical diversity of orobiomes, one of the key problems is the identification of the altitudinal spectra of vegetation and the altitudinal limits of the distribution of their divisions. This allows for a comparative geographic evaluation of diversity and the identification of key factors that determine the differentiation of biota at the regional level. This analysis becomes especially valuable for infrequently studied mountain areas, one of which is the Northern Transbaikalia.

The main objective of this investigation was the identification of the belts structure and biodiversity of the Kodar-Kalar orobiome and its geographic variants, developing in the conditions of the mountain systems of the Northern Transbaikalia. The characterization of the typological diversity in the structure of altitudinal zonation vegetation at high hierarchical levels, the statistical evaluation of the altitudinal limits of vegetation belts and an analysis of altitudinal zonation within the different geographic variants of the Kodar-Kalar orobiome were the main tasks of this work. The Kodar-Kalar orobiome and its three geographic variants (the North Baikal, the Patom and the Kodar-Kalar) developed in the vast mountainous territory of the Northern Transbaikalia within the North Baikal, Stanovoy and Patom highlands (Fig. 1). The largest ridges are 2500-3000 m above sea level and have a sub-latitudinal strike (Upper Angarsk, North and South Muisky, Kodar). The vast surfaces of the intermountain depressions (Upper Angara, Muya-Kuanda, Chara) are confined to the Baikal rift zone (Fig. 2).

MATERIALS AND METHODS

The Kodar-Kalar orobiome refers to the Transbaikalian group of orobiomes. It is characterized by the meanings of the bioclimatic characteristics (average annual air temperature, sum of active temperatures and the average annual rainfall), number of species of the main groups of terrestrial organisms (vascular plants, bryophytes and lichens; mammals, birds, reptiles and amphibians). The floristic diversity of the Kodar-Kalar orobiome is represented by more than 800 species of vascular plants and more than 300 species of bryophytes in each geographic variant (map «The Biomes of Russia» 2018). With a similar character of the altitudinal zonality of vegetation, their differences should be sought in the altitudinal limits of the belts and their biodiversity.

Investigations of the spatial structure and biodiversity of mountain vegetation were carried out on the basis of concepts of the types of altitudinal zonation and their classification (Ogureeva 1991) and the biome ecosystem concept (Olson et al. 2001; Walter and Breckle 1991). The vegetation cover of orobiomes was considered through the ecological-dynamic connections of plant communities

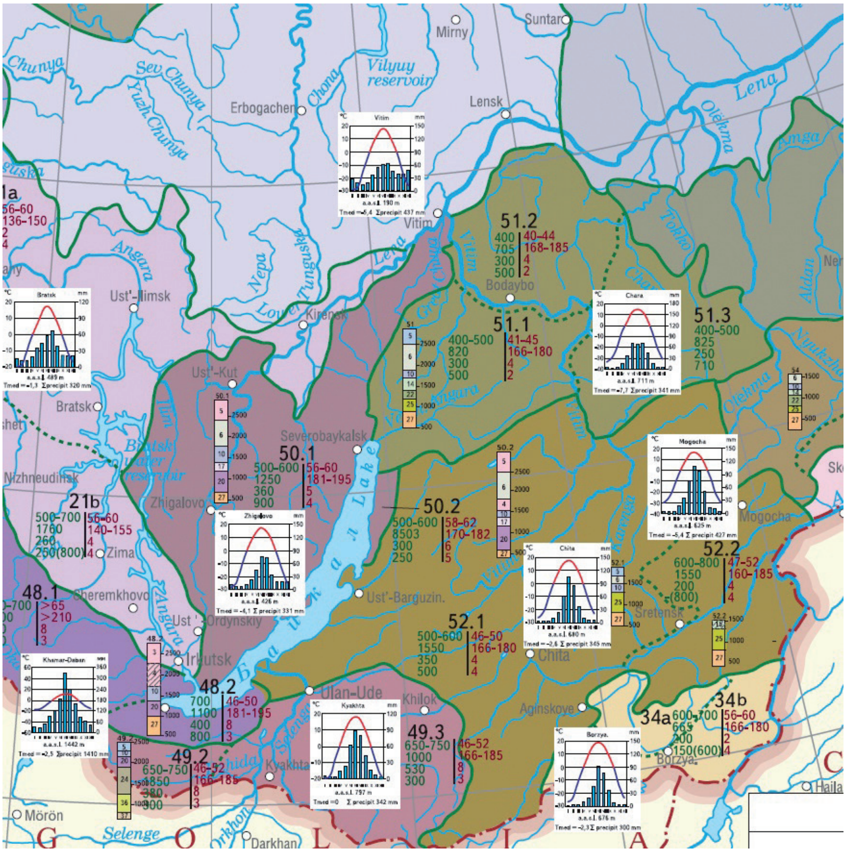

Fig. 1. Fragment of the map «The Biomes of Russia» (scale 1: 7 500 000) (2018). 51.1, 51.2, 51.3 – geographic variants of the Kodar-Kalar orobiome

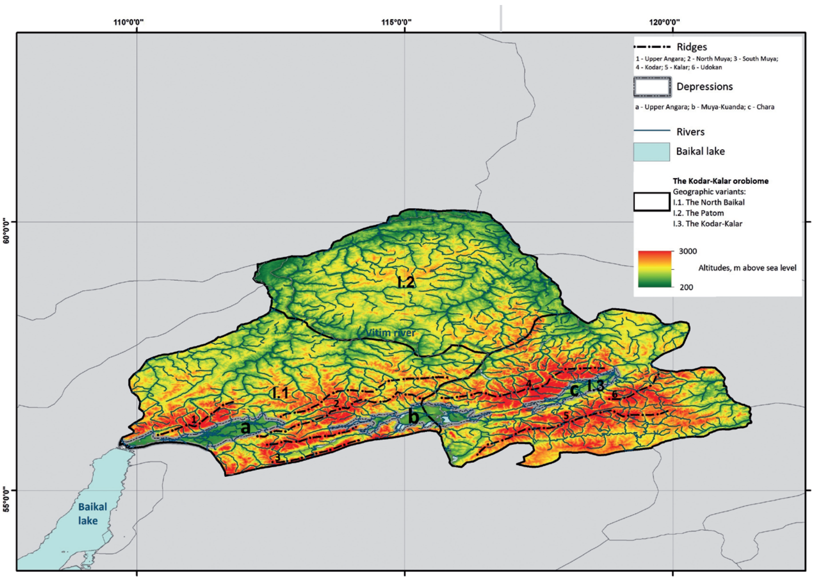

Fig. 2. The Kodar-Kalar orobiome and its geographic variants (I.1 – the North Baikal; I.2 – the Patom; I.3 – the Kodar-Kalar)

within each belt and on the whole for the entire altitudinal spectrum. The regional analysis of the botanical diversity of orobiomes allowed us to understand the uniqueness of orobiomes and the features of their geographical variants.

The investigation was based on the analysis of cartographic works and remote sensing data which can be used to determine the vegetation structure (Litinsky 2017). As the initial map data, at the first stage a digital map of Russia's vegetation cover, based on the processing of MODIS images with a spatial resolution of 230 m (Bartalev et al. 2011) was used. At the second stage a small-scale map of vegetation in the south of Eastern Siberia (scale 1: 1 500 000), executed at the Institute of Geography of the SB RAS (Belov 1973), was used. The legend of this map was based on a geographic-genetic basis, taking into account the dynamic trends in the vegetation cover (for a number of root types of communities, their derivative variants are given). This map was digitized and used as a shp-file.

A statistical analysis of the connection between the basic subdivisions of the vegetation cover and the absolute height of the terrain was carried out. Basic plant communities in the mountains are determined by the position on the indigenous slopes in different exposition and steepness. They have a phytocoenotic optimum at a certain altitudinal levels on which the construction of the altitude spectrum is based (Ogureeva 1991).

The absolute altitude values were derived from the digital elevation model used to create the WorldClim bioclimatic layers (Hijmans et al. 2005). It was represented by a raster surface with a spatial resolution of 0.0087°. This resolution was used as the basis for assessing the connection of vegetation cover with altitude (meters above sea level), which is optimal for a small-scale survey.

For the statistical analysis, the raster layer of absolute heights was trimmed by the mask of the surface layer of the Kodar-Kalar orobiome (Spatial Analyst module, Extract by Mask tool). Geographical reference of the vegetation map of the southern part of Eastern Siberia was carried out on the basis of reference points using a 6th degree polynomial model (WGS-84 coordinate system).

The statistical estimation of the altitudinal distribution of vegetation was carried out by means of the conjugate analysis of vector layers of vegetation units using a raster model of the relief on the basis of its spatial resolution. The main statistical indicators of absolute heights were used: mean, median, standard deviation, maximum and minimum values, and coefficient of variation (Zonal Statistics tool). Along with the descriptive statistics, regression analysis techniques were used to estimate the change in the frequency of occurrence of vegetation units throughout the entire range of absolute heights. The changes were determined by the trend line constructed by the linear filtration method with a smoothing of 50 points. The mean and standard deviation of the basic vegetation for the belts served as the basis for the identification of optimal conditions for the development of vegetation units for each belt. The boundaries between belts and sub-belts were determined on the basis of the weighted average of absolute altitudes, within which basic plant communities are common for vegetation belts. The significance of the absolute heights for vegetation belts was determined by Student's t-test.

All operations with cartographic materials were conducted in the ArcGis 10.0 program. The statistical analysis was performed using the thematic tools of ArcCatalog, as well as SPSS 11.5.

RESULTS AND DISCUSSION

The botanical diversity of the Kodar-Kalar orobiome is formed under conditions of pronounced altitudinal-belt differentiation by a significant gradient of absolute heights (from 200 to 3000 m). The general orographic features of the territory are presented by the development of predominantly sub-latitudinal mountain ridges, having a block type of structure, intermountain depressions, and modern mountain-valley glaciation (Florensov 1968). The continental cold climate with pronounced altitudinal differentiation of the heat and moisture content parameters determines the key bioclimatic conditions for the formation of the altitudinal vegetation spectrum.

Three geographical variants reflect the differences in the structure of the altitudinal zonation of vegetation in the orobiome. They are associated with the regional morphostructural features of the territory, which are reflected in the vegetation cover. The relief of the Stanovoy highland, which is associated with the development of the North Baikal and the Kodar-Kalar variants, is determined by the conditions of the Pliocene-Holocene orogenesis (Florensov and Olyunin 1965). The modern relief was influenced by the ancient glaciation, which is associated with the alpine type of relief of the highlands. In the conditions of the continental climate (Kodar, Udokan, South Muya ridges), the high-mountain (tundra) type of highland, dominated by the continental regions of the boreal zone with development of cryogenic processes, is formed (Korner 2013; Tolmachev 1948). The intermountain depressions are confined to the rift zone. The vast surfaces of depressions are composed of thick layers of loose lake and alluvial sand deposits (Zorin 1971). The Patom highland, developed on a folded base with well-defined areas of ancient equalization surfaces, has a prevailing height of 1200-1300 m (up to 1771 m). The Patom highland is rather poorly transformed by the latest tectonic movements. The erosion-denudation middle-mountain relief with narrow, deeply incised valleys predominates.

The Kodar-Kalar orobiome belongs to the group of Transbaikalian boreal (taiga) orobiomes (map «The Biomes of Russia» 2018). It is characterized by a generality in the structure of the biota and vegetation cover. The main features of the vegetation cover are described (Garashchenko 1993; Ivanova and Chepurnov 1983; Ogureeva 1991; Osipov 1985; Peshkova 1985). The vegetation cover is characterized by the predominance of the communities of the Angarida (East Siberian) geographic and genetic complex (Sochava 1980). Larch forests predominate here (*Larix gmelinii* (Rupr.) Rupr.), forming a mountain taiga belt at altitudes up to 1000-1200 m. The vegetation cover of the highlands refers to the tundra type. It is represented by complex combinations of communities of larch, spruce (*Picea obovata Ledeb.*) and birch *(Betula lanata* (Regel) V.N. Vassil.) sparse forests, *Pinus pumila* (Pall.) Regel communities and high-mountain tundra.

Analysis of the vegetation map of Russia (Bartalev et al. 2011)

At the first stage of revealing the Kodar-Kalar orobiome vegetation structure, an analysis of the digital map «Vegetation cover of Russia» (Bartalev et al. 2011) was carried out. The legend of the map includes 20 typological units within the Kodar-Kalar orobiome. Seven units are interpreted as basic in the composition of the vegetation belts. Using the frequency of occurrence, an altitudinal evaluation of the units was determined (Table 1). Pine and larch forests, cedar pine and shrub tundra are characterized by the unimodal normal distributions of their occurrence in absolute heights (based on the spatial resolution of the digital elevation model) (Fig. 3). These typological units are quite strictly gravitating to a specific altitude level within the orobiome, forming belts of vegetation with a predominance of mountain taiga, *Pinus pumila* communities, and mountain tundra communities. The values of the standard deviations characterize the area of their optimum distribution. The larch forests *(Larix gmelinii)* are confined to heights of 550-1100 m. In general, this is in agreement with the data on the altitudinal distribution of larch forests, which form the mountain taiga belt in the structure of the altitudinal zonation of the Stanovoy highland (Peshkova 1985). Pine *(Pinus sylvestris L.)* forests, confined to the lower part of the mountain taiga belt (500-600 m), have small deviations from the normal distribution at several altitude levels (Fig. 3). This is due to their distribution in the intermountain depressions. In the bottoms of these depressions at altitudes of 600-700 m, they widely predominate on sand deposits.

Table 1. The statistical values of the altitudinal distribution of the typological vegetation units for the Kodar-Kalar orobiome and its geographic variants (according to the vegetation map of Russia).

The orobiome / the geographic variants	The statistical values	The typological units of vegetation						
		1	2	3	4	5	6	7
1	MIN, m	177	174	239	182	291	308	339
	MAX, m	1461	2171	2231	1978	2326	2520	2375
	MEAN, m	614	825	910	1015	1249	1417	1393
	STD, m	196	284	258	237	271	347	314
	MEDIAN, m	577	795	916	1019	1219	1419	1394
	Kvar, %	32	34	28	23	22	25	23
1.1	MIN, m	222	216	354	225	508	414	599
	MAX, m	1461	2171	1774	1978	2204	2371	2309
	MEAN, m	695	862	852	1109	1309	1429	1475
	STD, m	187	262	254	232	240	308	278
	MEDIAN, m	631	848	889	1118	1310	1438	1495
	Kvar, %	27	30	30	21	18	22	19
1.2	MIN, m	176	174	244	185	352	390	369
	MAX, m	1133	1442	1409	1557	1724	1863	1806
	MEAN, m	523	672	886	926	1085	1094	1134
	STD, m	169	198	213	188	186	206	208
	MEDIAN, m	509	675	903	943	1098	1095	1154
	Kvar, %	32	30	24	20	17	19	18
1.3	MIN, m	341	320	330	320	328	351	358
	MAX, m	1345	2398	2041	1992	2257	2430	2455
	MEAN, m	622	982	940	1034	1330	1514	1473
	STD, m	156	328	266	269	278	332	300
	MEDIAN, m	597	953	934	1047	1326	1554	1499
	Kvar, %	25	34	29	26	21	22	20

I – the Kodar-Kalar orobiome. Geographic variants: I.1 – the North Baikal; I.2 – the Patom; I.3 – the Kodar-Kalar. The absolute altitude values: MIN – minimum; MAX – maximum; MEAN – average; STD – standard deviation; MEDIAN – median; Kvar – the coefficient of variation. The typological units of vegetation: 1. Pine (Pinus sylvestris) forests; 2. Larch (Larix gmelinii, L. sibirica) forests; 3. Sparse larch (Larix gmelinii, L. sibirica) forests; 4. The Siberian dwarf pine (Pinus pumila) communities; 5. Shrub (Betula rotundifolia, Rhododendron parvifolium, Salix glauca) tundra; 6. Shrubby (Ledum decumbens, Rhododendron aureum, Cassiope ericoides, Salix berberifolia) tundra; 7. Herb (Festuca ovina, Carex ensifolia, Hierochloe alpina) tundra

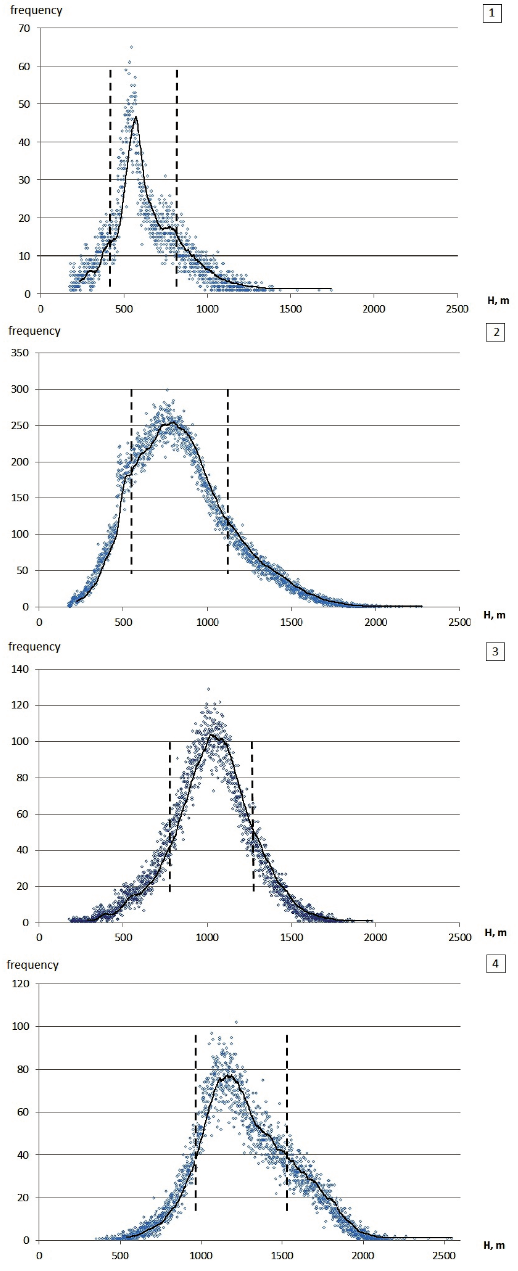

Fig. 3. Distribution of frequency of pine forests (1), larch forests (2), the Siberian pine forests (3) and shrub tundra (4) occurrence in the Kodar-Kalar orobiome by altitudes.
Continuous lines are trends. Dashed lines are standard deviations from the mean altitudes

The bimodal distribution is noted for shrubby and herb tundra. The deviation from the normal distribution can be caused by two reasons. First, vegetation units on the map can be heterogeneous in botanical-geographical and ecological-phytocoenotic terms due to a wide range of environmental conditions at different altitudinal levels. For example, larch sparse forests are involved in the addition of the sub-tundra belt (more than 800 m) and are represented by different types of sparse larch forests over the entire altitude range of the mountain taiga belt

(500-1000 m). Second, the altitudinal structure of vegetation cover is region specific. The regional orobiome combines several altitudinal spectra of vegetation. The development of several peaks on generalized curves may indicate differences in these spectra, which is reflected in the geographic variants of orobiomes. This situation was verified by calculating the altitude distribution of the occurrence of shrubby tundra within geographical variants (Fig. 4). In the altitudinal spectrum of the Patom highland, shrubby tundra grows at lower absolute altitudes (1100-1200 m), significantly differing from the altitude position in the North Baikal highland (1400-1600 m) ($t=88.1$, $p<0.001$). At the same time, in the Kodar-Kalar mountains, the distribution deviates from the normal one. Here, on the highest ridges (Kodar, Kalar, Udokan), shrubby tundra occupies the highest altitudes (1600-1800 m), with a small peak at altitudes of 1200-1300 m. A decrease in the altitudinal position of the high mountain vegetation in the Patom highland compared with the ridges of the Stanovoy highland is associated with a general decrease in its absolute altitudes. Under such conditions, a narrow floristic and coenotic contact between the mountain taiga and high-mountain vegetation is possible, which is reflected in the specific features of the vegetation cover within the orobiome.

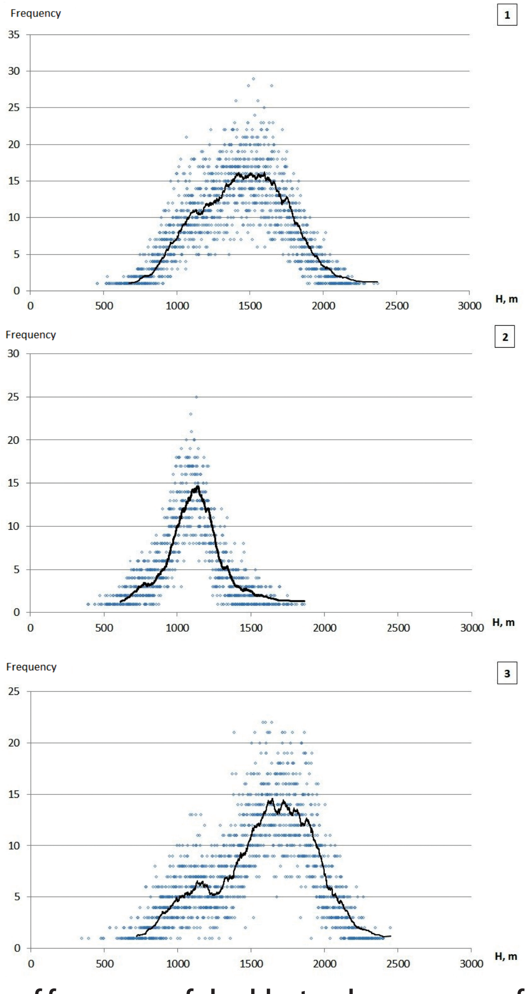

Fig. 4. Distribution of frequency of shrubby tundra occurrence for geographic variants of the Kodar-Kalar orobiome: the North Baikal (1), the Patom (2), the Kodar-Kalar (3). *Continuous lines are trends*

Analysis of the vegetation map of the south of Eastern Siberia

The identification of the generalized spectrum of altitudinal zonation of vegetation and the specification of the altitude limits of the distribution of plant communities within the Kodar-Kalar orobiome and its geographical variants were carried out on the basis of the conjugate analysis of the vegetation map of the south of Eastern Siberia (Belov 1973) using a digital elevation model. The coenotic diversity of the orobiome was determined at the level of 30 typological units, allocated on the basis of a geographic-genetic classification taking into account the dynamic state of vegetation. According to their typological composition, they are classified into 4 belts, including 6 sub-belts (Table 2). In connection with the absolute height, they are characterized by significant differences in the values of the basic descriptive statistics. Significant intersections of vegetation formations that form different belts on an altitudinal gradient are revealed in the analysis of standard deviations from occupied average heights, which is expressed in the active interpenetration of communities of different belts along the altitudinal gradient. The typological units of vegetation cover, ranked at medium height, are characterized by a distribution that is best explained by exponential dependence, with the index R^2 = 0.97, because the Kodar-Kalar geographical variant has the highest value on a linear trend (R^2 = 0.98) (Fig. 5). This type of distribution of vegetation along the altitudinal gradient is associated with a decrease in the coenotic diversity in the mountain taiga belt. There are coenotic poorly herbaceous and shrubby-lichen pine forests developed in the lower part of the mountain taiga belt. They are developed in the Chara intermountain depression and grow here in combination with birches, meadows and grassy marshes (Garashchenko 1993).

Table 2. The statistical values of the altitudinal distribution of the typological vegetation units for the Kodar-Kalar orobiome and its geographic variants (according to the vegetation map of the south of Eastern Siberia)

Altitudinal belts (sub-belts)	The typological units of vegetation	Number of pixels	The statistical values					
			MIN, m	MAX, m	MEAN, m	STD, m	MEDIAN, m	Kvar, %
The tundra belt	1	737	798	2204	1461	313	1477	21
	2	64725	338	2824	1453	363	1452	25
	3	8014	479	2474	1433	345	1441	24
	4	442	988	2231	1666	235	1674	14
	5	291	833	2204	1604	275	1657	17
The sub-tundra belt (the Siberian dwarf pine sub-belt)	30	79315	234	2705	1219	364	1188	30
The sub-tundra belt (the sparse forests sub-belt)	10	9384	330	2146	1077	255	1078	24
	19	54709	244	2342	1030	249	1033	24

The mountain taiga belt (the larch forests sub-belt)	6a	276	332	934	607	130	612	21
	7	2868	309	1864	757	222	729	29
	11	1570	212	1225	619	220	599	36
	11a	3294	173	1399	576	225	533	39
	11b	1662	177	1061	471	184	423	39
	11c	344	212	844	435	137	423	32
	12	1659	247	1458	669	217	650	33
	20	106761	239	2431	995	340	946	34
	21	45908	258	2333	885	326	829	37
	22	3294	199	2293	786	290	743	37
	22a	1903	229	1236	690	224	697	33
	23	23716	185	1549	789	216	808	27
	24	4163	185	1771	589	256	529	44
	25	3852	451	2433	1020	400	961	39
	26	2700	194	1168	631	182	636	29
	27	5866	317	1765	645	209	577	32
	28	3439	459	1680	632	197	555	31
	29	532	733	1646	976	199	952	20
The mountain taiga belt (the larch-pine and fir-pine-spruce forests sub-belt)	8	1694	455	1468	566	116	532	20
	9	1727	460	1575	586	156	532	27
	13	42	292	516	440	68	470	16
	13a	334	197	699	423	127	441	30
	14	283	178	517	371	54	374	15
	15	361	235	524	379	75	393	20
	16	801	230	973	504	138	495	27
	17	3	348	356	351	4	349	1
	18	2857	186	954	435	135	427	31

The typological units of vegetation.

High-mountain tundra vegetation.

Complex of high-mountain tundra vegetation.

South Siberian formations.

1. Shrub *(Betula rotundifolia, Rhododendron parvifolium, Salix glauca)* tundra with moss-lichen tundra.

Baikal-Dzhugdzhur formations.

2. Sparse communities *(Cassiope ericoides, Empetrum nigrum, Salix sphenophylla)* with fragments of lichen and dryad (Dryas punctata) tundra and alpine meadows.

3. Shrubby *(Ledum decumbens, Rhododendron aureum, Cassiope ericoides, Salix saxatilis, S. berberifolia)* – moss-lichen tundra with high-mountain wetlands *(Carex ensifolia)* and the Siberian dwarf pine communities.

4. Meadow tundra *(Festuca ovina, Diphasiastrum alpinum, Hierochloe alpina)* with meadows *(Anemonastrum sibiricum, Vaccinium myrtillus, Oxytropis kusnetzovii)* and birch *(Betula divaricata)* communities.

Altai-Tien-Shan complex of alpine formations.

South Siberian formations.

5. Alpine *(Trollius altaicus, Aquilegia glandu-

losa) and subalpine *(Geranium albiflorum, Saussurea latifolia)* meadows in combination with shrub *(Betula rotundifolia, Duschekia fruticosa, Salix glauca, Pinus pumila)* communities.

Taiga (Boreal) vegetation.

Ural-Siberia complex of formations.
South Siberian formations.
I. Mountain taiga.
I.A. Dark coniferous *(Abies sibirica, Pinus sibirica, Picea obovata)* forests.
6a. Larch-pine dynamic series of fir – Siberian pine shrubby-moss forests.
7. Fir – Siberian pine shrub *(Pinus pumila)* shrubby-moss forests.
II. Low mountain and depression taiga.
II.A. Pine *(Pinus sylvestris)* forests.
8. Pine forests in combination with steppe communities.
9. Pine shrubby-lichen forests.
Middle Siberian formations.
I. Sub-tundra sparse forests.
I.A. Sparse spruce *(Picea obovata)* forests.
10. Sparse spruce moss-lichen forests with Pinus pumila, Rhododendron aureum.
II. Mountain taiga.
II.A. Dark coniferous *(Abies sibirica, Pinus sibirica, Picea obovata)* forests.
11. Spruce – Siberian pine with fir and larch shrubby *(Vaccinium myrtillus, Ledum palustre)* – moss forests.
11a. Larch-pine dynamic series.
11b. Pine-larch *(Larix sibirica)* dynamic series.
11c. Birch dynamic series.
12. Spruce – Siberian pine forests with *Pinus pumila.*
III. South taiga.
III.A. Dark coniferous *(Abies sibirica, Pinus sibirica, Picea obovata)* forests.
13. Siberian pine – spruce moss forests.
13a. Pine-larch *(Larix sibirica)* dynamic series.
III.B. Pine (Pinus sylvestris) and larch *(Larix sibirica)* forests.
14. Larch and pine-larch herb forests.
IV. Middle taiga.
IV.A. Larch *(Larix sibirica)* and pine (Pinus sylvestris) forests.
15. Pine shrubby-lichen forests.
16. Larch-pine with dark coniferous species shrubby-moss forests.
17. Pine and larch pine shrubby *(Vaccinium uliginosum)* – moss forests.

Angara (East Siberian) complex of formations.
Central Siberian formations.
I. North taiga.
I.A. Larch *(Larix gmelinii)* forests.
18. Larch with Siberian pine and spruce shrub *(Duschekia fruticosa)* shrubby-moss forests.
Baikal-Dzhugdzhur formations.
I. Sub-tundra sparse forests.
I.A. Larch *(Larix gmelinii)* forests.
19. Sparse larch shrub *(Pinus pumila, Duschekia fruticosa)* moss-lichen forests.
II. Mountain taiga.
II.A. Larch *(Larix gmelinii)* and pine *(Pinus sylvestris)* forests.
20. Larch shrub *(Pinus pumila)* shrubby-moss forests.
21. Larch shrub *(Betula divaricata, B. exilis)* forests and sparse forests.
22. Larch with spruce shrub *(Duschekia fruticosa, Betula divaricata)* shrubby *(Vaccinium vitis-idaea, Ledum palustre)* – moss forests.
22a. Birch dynamic series.
23. Larch with Siberian pine, fir and spruce shrub *(Pinus pumila, Rhododendron aureum)* herb-moss forests.
24. Larch shrubby *(Vaccinium uliginosum, Ledum palustre)* – moss forests.
25. Larch shrub *(Rhododendron dahuricum)* forests.
26. Larch-pine shrub *(Betula divaricata, B. exilis)* shrubby-moss forests.
III. Low mountain and depression taiga.
III.A. Wetlands, meadows, birch communities.
27. Shrub *(Betula fruticosa)* with larch *(Larix gmelinii)* and birch *(Betula platyphylla)* communities in combination with sedge meadows.
28. Sedge *(Carex pseudocuraica, C. juncella, C. enervis)* and grass *(Calamagrostis langsdorffii)* wet meadows in combination with birch and willow communities.
Amur-Sakhalin formations.
A. Mires.
29. Larch *(Larix gmelinii)* herb and sphagnum mires.

Beringia complex of formations.
Baikal-Dzhugdzhur formations.
I. High-mountain and mountain taiga belts.
30. The Siberian dwarf pine communities in combination with sparse larch *(Larix gmelinii)* forests, shrub *(Betula ermanii)* communities and high-mountain tundra.

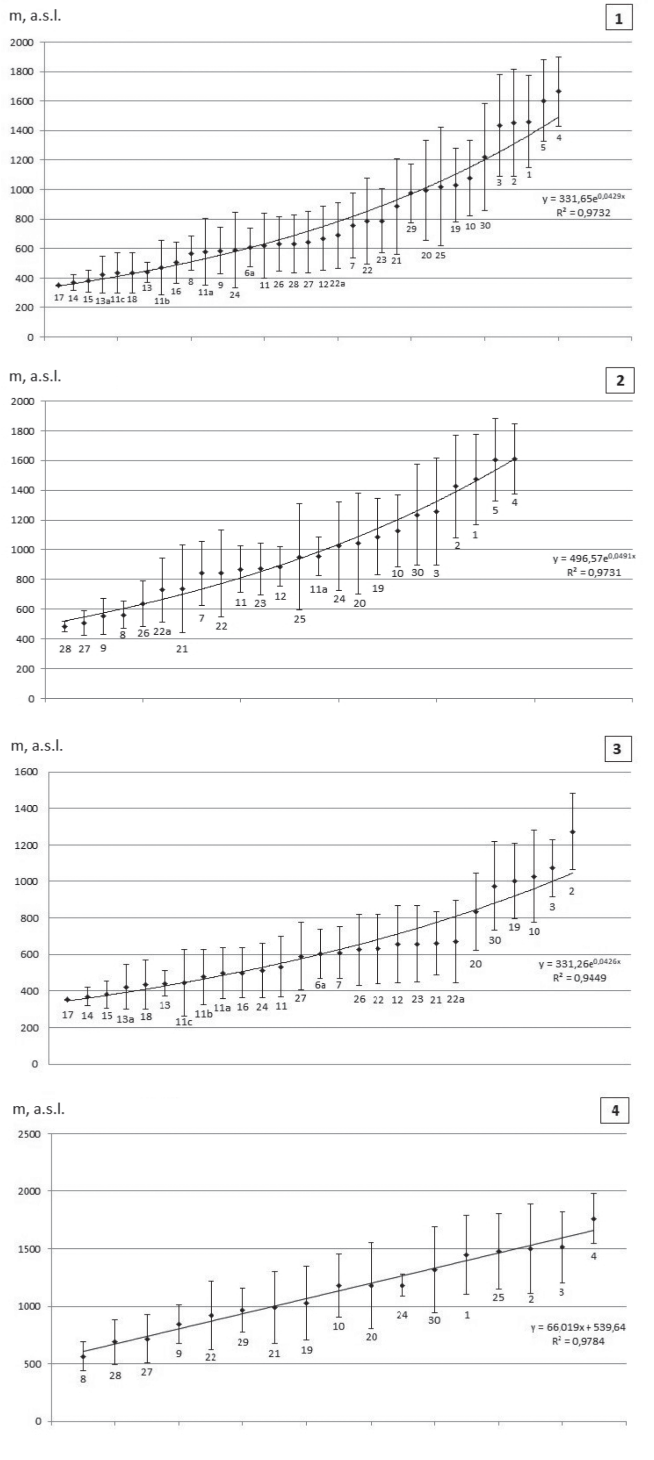

Fig. 5. The distribution of vegetation units (names – see table 2) of the Kodar-Kalar orobiome (1) and its geographic variants: the North Baikal (2), the Patom (3), the Kodar-Kalar (4), ranked by average altitudes, and their standard deviations from the mean values

The altitudinal limits of the belt were determined from the weighted average heights, on which the basic vegetation communities of each belt find optimal development (Table 3). The use of mean values on the interval between the weighted average values of neighbouring belts made it possible to determine the altitude amplitudes of their development, as well as the boundaries between the belts (Table 4). The regional specifics of the spectra within the Kodar-Kalar orobiome were reflected in the altitudinal spectra – generalized models of the altitudinal vegetation organization, showing the general features of its structure (Fig. 6). The dominant larch mountain-taiga belt, the fragmented development of dark coniferous-taiga forests, the formation of the high-mountain vegetation system with the participation of the Siberian dwarf pine communities, mountain tundra and the extremely limited participation of alpine vegetation are the system-forming characteristics of the revealed altitudinal belt structure.

Table 3. The weighted average of absolute altitudes and their standard errors for altitudinal belts and sub-belts of vegetation for the Kodar-Kalar orobiome and its geographic variants (by basic vegetation communities in altitudinal subdivisions) (geographic variants names – see Table 1)

Altitudinal belts	Altitudinal sub-belts	Altitudinal limits of belts, m			
		1	1.1	1.2	1.3
II. The tundra belt		1453±23	1420±27	1257±11	1503±30
III. The sub-tundra belt	III.1. The Siberian dwarf pine sub-belt	1219±1	1235±2	974±2	1316±2
	III.2. The sparse forests sub-belt	1037±3	1096±4	1005±4	1039±12
IV. The mountain taiga belt	IV.1 The larch forests sub-belt	878±21	894±25	725±21	1040±25
	IV.2. The larch-pine and fir-pine-spruce forests sub-belt	496±16	557±4	436±16	620±13

Table 4. The structure of the altitudinal zonality of the vegetation for the Kodar-Kalar orobiome and its geographic variants (by the weighted mean altitudes and their standard errors for the basic vegetation communities of altitudinal belts and sub-belts)

Altitudinal belts	Altitudinal sub-belts	Altitudinal limits of the belts and sub-belts, m			
		1	1.1	1.2	1.3
I. The upper tundra belt		1902-3078	1879-2641	1484-1771	1981-3078
II. The tundra belt		1325-1902	1315-1879	1128-1484	1396-1981
III. The sub-tundra belt	III.1. The Siberian dwarf pine sub-belt	1129-1325	1167-1315	859-989	1183-1396
	III.2. The sparse forests sub-belt	967-1129	1006-1167	989-1128	1046-1183
IV. The mountain taiga belt	IV.1 The larch forests sub-belt	685-967	715-1006	578-859	824-1046
	IV.2. The larch-pine and fir-pine-spruce forests sub-belt	178-685	460-715	178-578	455-824

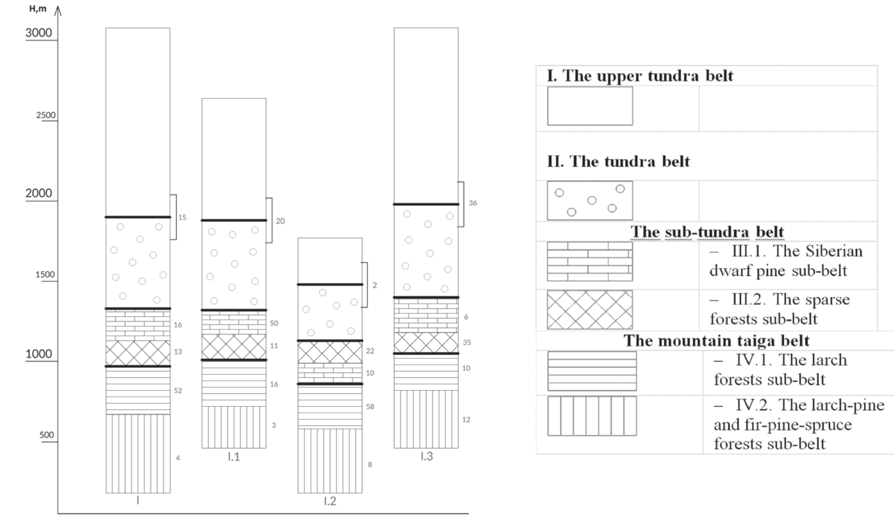

Fig. 6. Altitudinal spectra of vegetation cover of the Kodar-Kalar orobiome (I) and its geographical variants (I.1 – the North Baikal; I.2 – the Patom; I.3 – the Kodar-Kalar). The relative areas (%) of the belts and sub-belts are given

The lower half of the spectrum is occupied by the typologically diverse communities of the mountain-taiga belt. Here, fir-spruce *(Picea obovata, Pinus sibirica, Abies sibirica Ledeb.)* and larch *(Larix sibirica Ledeb.)* herbaceous, shrubby-moss forests of the Ural-Siberian complex of formations predominate in the lower periphery of the orobiome (the Patom variant). They have small values of the standard deviation and minor altitude amplitude, forming the lower sub-belt of the mountain taiga belt (180-580 m). Pine *(Pinus sylvestris)* and larch *(Larix gmelinii)* – pine shrubbery-lichen forests are confined to intermountain depressions and low mountains (450-820 m). Boreal forests of the Eastern Siberian geographic and genetic complex of plant formations participate in the composition of the upper sub-belt, the largest variety of which is found in larch communities. Larch scrub *(Betula divaricata Ledeb., B. exilis Sukaczev)*, rhododendron *(Rhododendron dauricum L.)*, shrubby *(Vaccinium uliginosum L., Ledum palustre L.)* moss forests grow at altitudes of 690-970 m. Highlands are occupied by sub-tundra and tundra vegetation communities. Larch and spruce with Siberian dwarf pine *(Pinus pumila)*, alder (*Duschekia fruticosa* (Rupr.) Pouzar) moss-lichen sparse forests occupy the lower part of the sub-tundra belt at heights of 970-1130 m. Fragments of birch *(Betula lanata)* are developed at altitudes of 1130-1330 m. Shrub, shrubby, moss-lichen tundra form a mountain tundra belt (1330-1900 m). Sparse fragments of the tundra community form the upper tundra belt (1900-3000 m).

The structure of altitudinal spectra of vegetation of geographical variants of the orobiome is associated with the orographic structure of the territory. With an increase in the average altitudes of the ranges, the proportion of the sub-tundra and tundra belts in the vegetation cover increases (the Kodar-Kalar geographic variant). The expansion of the mountain taiga belt and the increase in its coenotic diversity occur in conditions of predominance of middle relief (the Patom geographical variant). The increase in the area of belt development does not always entail an increase in the diversity of communities.

In a generalized form, the structure of the vegetation cover of the Kodar-Kalar orobiome is represented by 4 altitudinal belts and 6 sub-belts of vegetation, which have certain characteristics of distribution and diversity.

I. The upper tundra belt (1900-3000 m). This belt has fragmentary development on the highest ridges with a large altitude amplitude. Fragments of moss-lichen tundra and, in some places, alpine meadows prevail in the rare vegetation cover.

II. The tundra belt (1330-1900 m). This belt is confined to the upper parts of ridge ranges. It can get down to the upper limit of the mountain taiga belt along rocky slopes. The coenotic diversity is represented by shrubby *(Ledum decumbens* (Aiton) Lodd. ex Steud., *Rhododendron aureum* Georgi, *Cassiope ericoides* (Pall.) D. Don, *Empetrum nigrum* L., *Dryas punctata Juz., Salix berberifolia Pall.),* moss-lichen tundra.

III. The sub-tundra belt.

III.1. The Siberian dwarf pine *(Pinus pumila)* sub-belt (1130-1330 m). The basis of the vegetation cover is communities of Siberian dwarf pine. These communities are made up of *Betula divaricata,* B. *exilis, Duschekia fruticosa,* and *Rhododendron aureum.*

III.2. The sparse forests sub-belt (970-1130 m). This sub-belt is formed at small altitude amplitude. Sparse larch *(Larix gmelinii)* and birch *(Betula lanata)* forests predominate in the vegetation cover. In places, sparse forest communities form complex combinations with communities of Siberian dwarf pine.

IV. The mountain taiga belt.

IV.1 The larch *(Larix gmelinii)* forests sub-belt (690-970 m). This sub-belt is the main altitudinal spectrum of the vegetation of the orobiome. It occupies the largest area on the Stanovoy highland. There are scrub *(Pinus pumila, Betula divaricata, B. exilis)*, shrub-moss *(Vaccinium vitis-idaea L., V. uliginosum, Ledum palustre)* and larch forests that predominate in the sub-belt.

IV.2. The larch-pine and fir-pine-spruce forests sub-belt (180-690 m). This sub-belt is common in low parts of the mountains, in the bottoms and on the slopes of intermountain depressions. The sub-belt is characterized by a high level of coenotic diversity. It occupies a small area and has a fragmentary distribution. Pine *(Pinus sylvestris)*, larch-pine and also dark coniferous (*Picea obovata, Pinus sibirica* Du Tour, *Abies sibirica*) forests are developed in the sub-belt.

The modern vegetation cover of the orobiome has developed as a result of a long historical development. A change in the predominance of dark coniferous, light coniferous and small-leaf forests have been from the late Pleistocene to the present according to warming and cooling tendencies in the territory of the Baikal region. At present, the communities of the Ural-Siberian complex are formed in the low part of the ridges and on the most ancient surfaces of the intermountain depressions, are confined to the Baikal rift zone and are not affected by glaciations in the Holocene (Aleksandrova and Preobrazhensky 1964), while in the middle parts of mountains, the larch forests of the East Siberian complex dominate. Bioclimatic conditions contribute to the development of the modern altitudinal structure of vegetation. Regional differences in the diversity of the orobiomes are reflected in geographic variants through the altitudinal limits of the belts and sub-belts. The most significant differences between the Patom and the Kodar-Kalar variants (for the Siberian dwarf pine sub-belt $t=120.1$, $p<0.001$), and between the North Baikal and Kodar-Kalar variants is that they are less pronounced (for the tundra belt $t=2.1$, $p<0.05$).

The peculiarities of diversity for the North Baikal geographic variant are related to the geographical location in contact with the Baikal region, with the specificity of the flora and high level of endemism (Peshkova 1985). The main regional feature of the altitudinal spectrum of vegetation is associated with the fragmented development of alpine and subalpine meadows in combination with birch *(Betula rotundifolia Spach)* communities in the high mountains of the ridges adjacent to Baikal. Sedges (*Carex pseudocuraica* F. Schmidt, C. juncella (Fr.) Th. Fr.) and grass (*Calamagrostis langsdorffii* (Link) Trin., *Alopecurus arundinaceus* Poir.) meadows in combination with communities of B*etula exilis* Sukaczev play a significant role in the structure of the vegetation cover of the larch-pine forest belt in the Upper Angara and Muya-Kuanda intermountain depressions, mostly in its shallow surfaces (Vladimirov et al. 2014). Fragments of steppe vegetation with participation of *Stipa capillata* L., *Agropyron cristatum* (L.) Beauv., *Koeleria cristata* (L.) Pers. have a local distribution in the southern slopes of ranges near Baikal Lake. They characterise relationships in vegetation cover between the Northern Transbaikalia and the Southern Siberia and Mongolia.

In the altitudinal spectrum of the vegetation of the Patom geographical variant, the fir-pine-spruce *(Picea obovata, Pinus sibirica, Abies sibirica)* forests sub-belt in the lower part of the mountain taiga zone is well developed. The greatest diversity is in the northern and north-western parts of the territory of the orobiome in contact with the taiga of the Central Siberian Plateau. In the altitudinal spectrum, the mountain taiga belt is developed up to an altitude of 800-900 m. The specificity of the variant is related to inversion within the sub-tundra belt. The Siberian dwarf pine sub-belt is located bellow the sparse forests sub-belt. This is due to active contact below the tundra and mountain taiga vegetation along the slopes of ridges in the Patom highland.

The Kodar-Kalar geographic variant is characterized by the highest altitude amplitude of the high mountain vegetation due to ridges at great altitudes (BAM peak – 3073 m), active modern glacial activity and the complex orographic structure. The variant has low typological diversity in the larch-pine and fir-pine-spruce forests sub-belts, which are formed in the Chara depression. It is characterized by a complex structure with small fragments of pine with Rhododendron dauricum forests, sedges (*Carex lasiocarpa* Ehrh., C. *vesicata* Meinsh., C. *rostrata* Stokes), and grass (*Poa palustris* L., *Calamagrostis neglecta* (Ehrh.) Gaertn., B. Mey. and Schreb.) meadows with fragments of mires (Garashchenko 1993). The upper boundary of the forest is located at altitudes of 1100-1200 m, and the tundra belt begins from an altitude of 1400 m. The specificity of the Kodar-Kalar variant is associated with the distance from the South Siberian and Baikal regions of the formation of floristic and coenotic diversity.

CONCLUSION

The revealed altitudinal structure of the vegetation cover of the Kodar-Kalar orobiome is the basis for the biodiversity evaluation. The patterns of spatial differentiation of biodiversity within the orobiome are associated with the integrated effect of altitudinal zonality. This is reflected in the formation of the 4 belts of vegetation: the upper tundra belt, the tundra belt, the sub-tundra belt (the Siberian dwarf pine sub-belt, the sparse forests sub-belt) and the mountain taiga belt (the larch forests sub-belt, the larch-pine sub-belt and fir-pine-spruce forests sub-belt). The spatial organization of the vegetation of the Kodar-Kalar orobiome is determined by the regularities at the altitudinal belt level and in connection with regional features that are determined by orographic conditions (the size and orientation of the ridges, the presence of intermountain depressions) and the history of the territory development. Among the key features of the botanical diversity of the orobiome and its spatial structure at the regional level, the following should be noted.

Vegetation communities associated with the Baikal-Dzhugdzhur natural area are more important communities in the vegetation cover of the Kodar-Kalar orobiome. They participate in the formation of the mountain taiga belt (larch forests of the Angara (Eastern Siberian) geographic and genetic complex), the sub-tundra belt (the Siberian dwarf pine communities of the Beringian complex) and the mountain tundra belt. Dark coniferous forests have fragmentary development in river valleys, steppes are locally developed on the southern slopes of ridges.

The dominance of larch forests, the low position of the upper boundary of the forests, and the wide altitude amplitude of the tundra belt determine the key features of the altitudinal zonality of the vegetation cover in the orobiome and its regional specificity. The most important altitudinal features in the vegetation cover fall to 1000 m, at which the sub-tundra belt is changing to the mountain taiga belt, and to 1300 m – the lower boundary of the upper tundra belt.

Geographical variants of the orobiome have the same divisions in the spectrum of altitudinal belts, but they differ in typological diversity and the altitudinal limits of their distributions. Variations of the boundaries of the belts and sub-belts between the variants is more than 300 m for the lower limits of the Siberian pine and mountain taiga belts. This reflects the regional specificity in the structure of the altitudinal zonality of the vegetation cover in the orobiome. The Patom geographical variant is characterized by the most specificity in the altitudinal structure of the vegetation cover. Its diversity is connected with the relatively low altitudes of the highlands and the geographical location on the periphery of the area of active formation of floristic and coenotic diversity.

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