A Model of Vegetation Pattern at the Verkhneussuriysky Biogeocenotic Station

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Abstract—A model of relationships between forest communities and basic parameters of environmental conditions, which is suitable for making prognostic maps of forest types, has been developed and tested on the territory of Verkhneussuriysky Biogeocenotic Station of the Institute of Biology and Soil Science. A comparative analysis of the spatial distribution of forest communities has been performed according to this model and to the large-scale map of recent forest vegetation on the territory of the station.

Key words: vegetation, cover, mapping, prediction, model, environment, factors.

The assessment of present-day biological diversity and its conservation are of major interest in areas with limitations on human activity (nature reserves, wildlife refuges, and other specially protected territories), where active processes of vegetation regeneration take place. In Primorye (the Russian Far East), special attention should also be paid to reference areas of unique Ussuri taiga, which comprise broadleaf–cedar pine, dark conifer–Korean pine, and nemoral fir–spruce forests characteristic of the Southern Sikhote Alin. In particular, such forests occupy the territory of the Verkhneussuriysky Biogeocenotic Station of the Institute of Biology and Soil Sciences. A cartographic approach to the study of such regions appears promising, as it allows detailed characterization of the vegetation, reflects its spatial pattern, and helps to reveal relationships of the plant cover with the environment and to select ecologically different communities for subsequent detailed analysis (Sochava, 1979; Augustin et al., 1996; Austin, 2007; Brzeziecki, 1995; Peterson, 2003; Segurado, 2004).

The purpose of this study was to develop and test a model of relationships between the vegetation and environment on the territory of the Verkhneussuriysky station. The main tasks were as follows: (1) to construct a large-scale geobotanical map of the present-day forest vegetation on this territory; (2) to reveal correlations between types of forest communities and basic parameters of the localities they occupy (to develop a model); (3) using the model, to create a map of the potential forest vegetation; and (4) to compare this prognostic map with the map of the actual vegetation.

STUDY AREA

The Verkhneussuriysky Biogeocenotic Station occupies an area of 4417 ha in the basin of the Pravaya Sokolovka River, a tributary of the Ussuri River, Primorye (Fig. 1). Natural conditions in this area are typical of the middle mountain belt of the Southern Sikhote Alin, and its vegetation may serve as a reference standard of southern taiga with prevalence of broadleaf–cedar pine and nemoral fir–spruce forests. In geomorphological terms, this area lies in the north of the Southern Sikhote Alin, the mountain range with low and medium high ridges (500–800 m a.s.l.) extending mainly in the southwest–northeast direction.

The climate of the study area is formed under the effect of seasonal succession of continental winds and oceanic monsoons. In general, it can be characterized as moist and moderately cold (Gvozdetskii and Mikhailov, 1987).

Forest vegetation dominates in the study area, occupying about 98% of its area. The main landscape-forming role is played by typical broadleaf–cedar pine forests (Kolesnikov, 1969; Komarova and Ashchepkova, 2000) formed by the Korean cedar pine, or Korean cedar (*Pinus koraiensis* Siebold et Zucc.), with an admixture of broadleaf (*Acer mono* Maxim., *Quercus mongolica* Fisch. ex Ledeb., *Tilia taquetii* Rupr.) and other tree species. The dissected topography of the region and consequent diversity of edaphic, hydrological, and thermal conditions account for considerable heterogeneity of site conditions and wide diversity of forest stands.
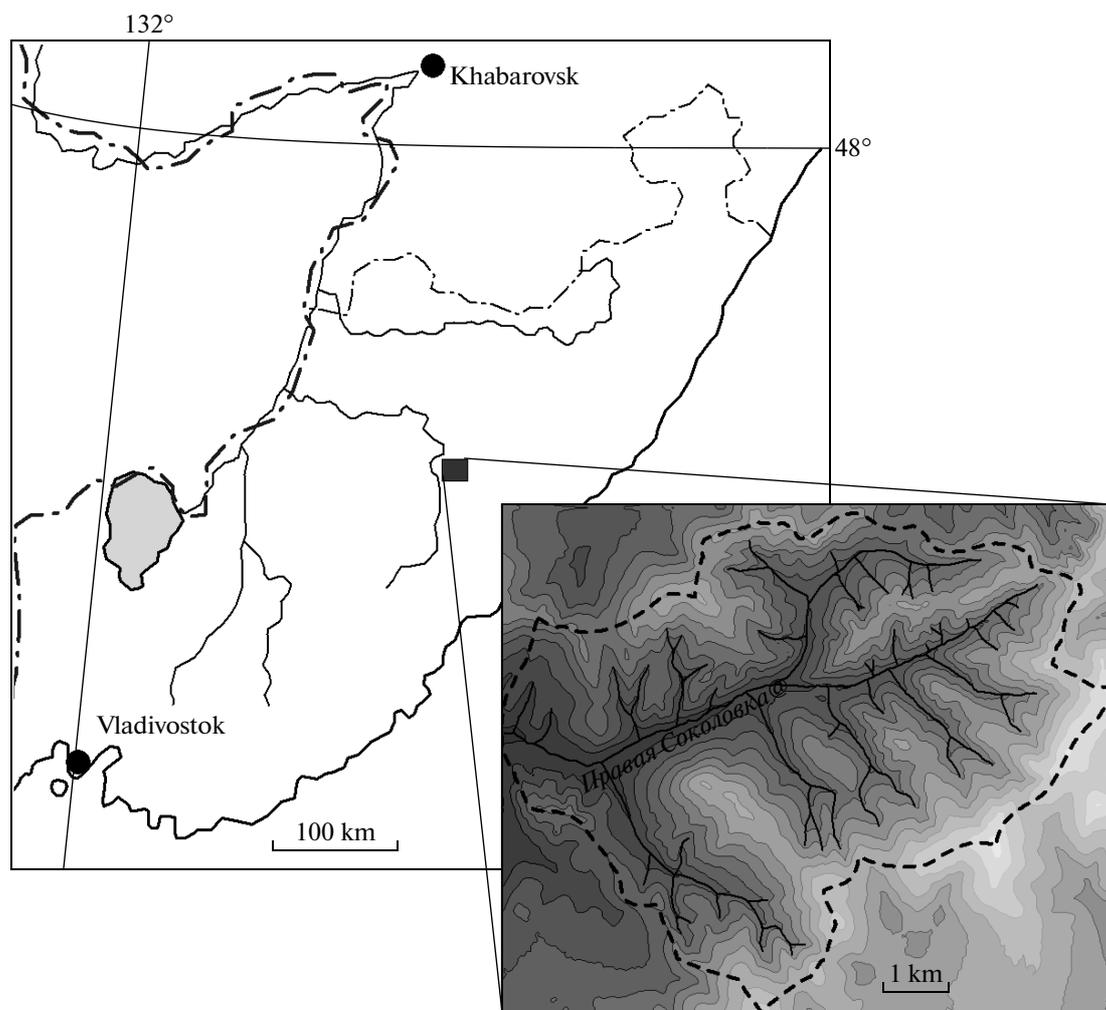
Fig. 1. Schematic map showing location of the Verkhneussuriysky Biogeocenotic Station

MATERIAL AND METHODS

Initial data. Geobotanical releves were made during five field seasons, 1999–2003. Studies were performed by methods of reconnaissance and detailed route surveys with the establishment of approximately 50 geobotanical transects and key plots throughout the study area. On the whole, over 250 detailed descriptions were made, each including a complete list of species and their proportions in the community.

Classification of vegetation. To reveal typological diversity of forest biogeocenoses and specific features in their distribution at the Verkhneussuriysky station, several approaches to this task were used in combination, as in the study by Komarova and Ashchepkova (2000). In particular, use was made of conventional biogeocenological, geobotanical, and sylvicultural methods (*Programma...*, 1974; Sukachev et al., 1957; Sukachev and Zonn, 1961); some techniques of Braun-Blanquet's (1964) ecofloristic classification based on identification of interrelated differential spe-

cies and rankless vegetation units (phytocenotic groups); regional phytocenological scales constructed according to Ramenskii (1938); and principles of Kolesnikov's (1956, 1959) geographic–genetic classification. Following this author (Kolesnikov, 1956), forest type regarded as a certain stage of the forest-forming process was taken as the basic classification unit.

A large-scale geobotanical map of the Verkhneus-suriysky station was constructed and drawn by methods described in basic manuals (Sochava, 1979; Gribova and Isachenko, 1972). Forest vegetation was mapped with regard to the main typological units identified for the mid-mountain belt of the Southern Sikhote Alin (Komarova and Ashchepkova, 2000).

Construction of a prognostic vegetation map. A prediction model of the relationship between site conditions and types of forest communities was created using four major "indirectly acting" parameters (Davis and Goetz, 1990; Brown, 1994; Horsch, 2003):

Parameters of discriminant classification functions (constants and weights of forest-site parameters in classification functions for forest types)

Forest type	Parameter				
	Elevation a.s.l.	Exposure	Slope steepness	Location on the slope	Constant
I	0.22	24.01	1.34	8.77	−125.86
II	0.27	26.54	1.21	7.17	−158.07
III	0.21	24.26	2.02	7.17	−123.81
IV	0.22	20.02	1.66	6.67	−116.76
V.1	0.21	23.97	1.17	9.28	−119.76
V.2	0.22	25.72	1.43	5.00	−107.23
VI	0.21	31.56	1.21	2.94	−98.60
VII	0.22	28.20	1.94	2.74	−115.60
VIII.1	0.22	16.87	0.96	9.53	−120.34
VIII.2	0.21	21.38	1.08	6.97	−107.51
VIII.3	0.20	19.03	1.46	5.27	−93.58
IX	0.23	20.12	1.09	2.01	−93.41
X	0.24	17.86	1.74	2.98	−113.47
XI	0.24	21.27	1.58	3.86	−118.31
XII.1	0.31	17.12	1.40	4.66	−173.99
XII.2	0.29	16.12	1.04	7.77	−170.45
XIII	0.25	16.85	1.06	5.41	−120.86
XIV	0.23	25.59	0.58	−1.80	−84.33
XV.1	0.19	26.37	0.32	−3.29	−60.30
XV.2	0.20	28.93	0.32	−3.74	−69.40

Note: For all forest types, $p \le 0.05$.

elevation above sea level, location within the slope area, slope, and exposure.

To reveal connections between parameters of site conditions and types of forest communities, discriminant analysis was used (Cairins, 2001; Manel et al., 1999). A table was compiled in which the columns contained the numbers of geobotanical releves, the forest community type, and the values of the above four parameters, with verbal characteristics (exposure and location within its area) being converted into numerical values (grades). Grades to slopes of different exposure were assigned with reference to the relative scale of slope insolation (Sheingauz, 1978). To indicate topographic location of forest biogeocenoses, a special seven-grade scale was developed, with its values increasing along an ascending altitudinal gradient.

To make a model map of vegetation at the station, the topographic map of its territory was digitized and converted into a digital elevation model (DEM) with a 50-m cell size (163 × 195 cells). For each cell, the values of four forest site parameters were determined. Thus, four layers were obtained, including the DEM, and each cell was characterized by four parameters (values from different layers). At the last stage, the dis-

criminant classification functions for each cell were used to determine the most probable forest type in the corresponding locality.

RESULTS AND DISCUSSION

Classification of vegetation. In the course of studies, characteristics of certain forest types were specified for the territory of the station, and additional classification units were introduced. With regard to specific features of species composition and structure of communities and regimes of soil moistening and richness determined by ecological scales developed for the study area, 15 forest types and 10 their variants were distinguished.

The names of forest types specify the main forest-forming species (in case of polydominant stands, also the species regularly accompanying the dominant one) and plants that dominate in the underbrush and herbaceous layer or are indicative of site conditions:

(I) Oak−Korean pine forest, rhododendron−cowberry (*Vaccinium vitis-idea*) type.

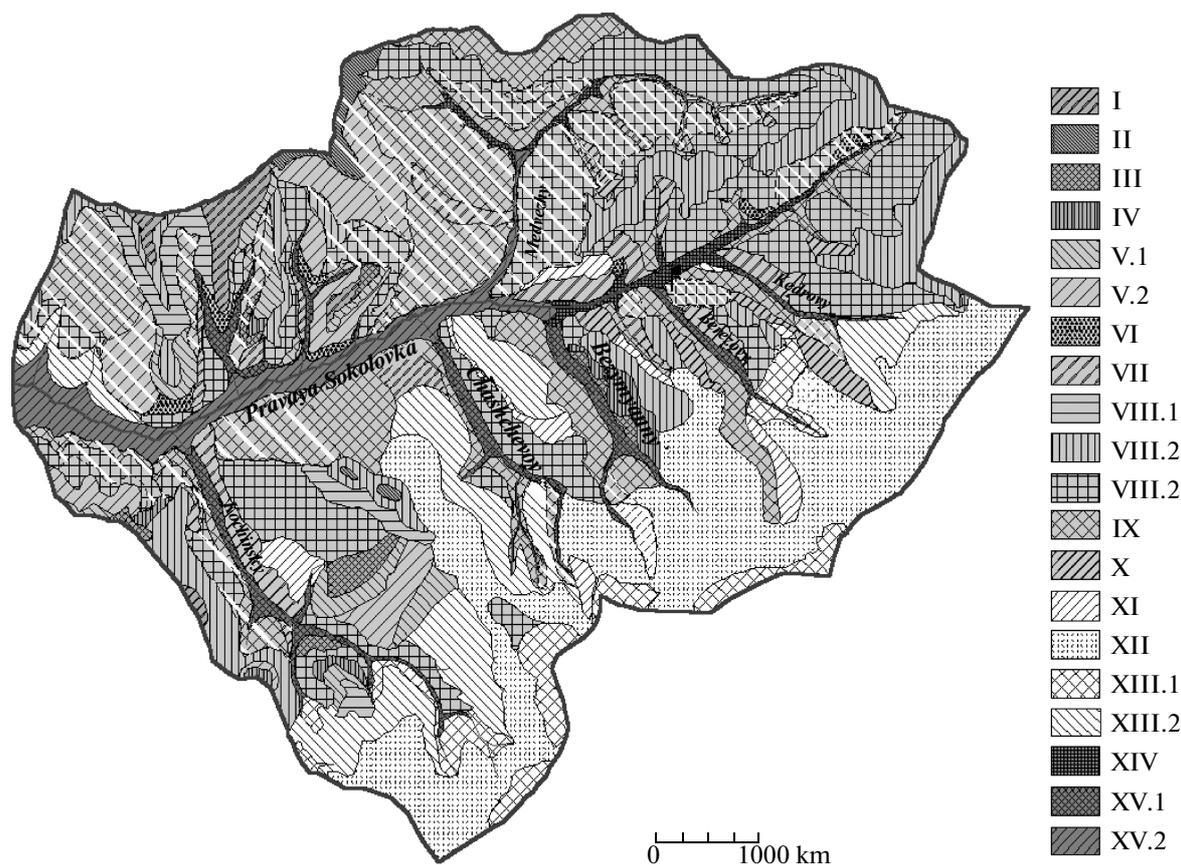(II) Oak−Korean pine forest, rhododendron−iris−small sedge type.

Fig. 2. Map of forest vegetation at the Verkhneussuriysky Biogeocenotic Station (for the names of forest types, see the text).

(III) Oak−Korean pine forest, filbert−rhododen-dron−small sedge type.

(IV) Korean pine forest with Ussuri rose (*Rosa ussuriensis*) and sparse herbaceous layer.

(V) Oak−Korean pine forest, magnolia vine (*Schisandra chinensis*)−filbert, herb−small sedge type:

(V. 1) with a considerable proportion of false Sie-bold's maple (*Acer pseudosieboldianum*);

(V. 2) with a considerable proportion of mono maple (*Acer mono*).

(VI) Broadleaf−Korean pine with Amur linden (*Tilia amurensis*), liana−shrub, sedge−chloranthus (*Chloranthus japonicus*) type.

(VII) Korean pine forest, magnolia vine−filbert, low herb−small sedge type.

(VIII) Broadleaf−dark conifer−Korean pine for-est, liana−shrub, mixed fern type:

(VIII. 1) with a considerable proportion of false Siebold's maple; liana−shrub, mixed herb variant;

(VIII. 2) with a considerable proportion of mono maple; liana−shrub, small sedge−mixed fern−herb variant;

(VIII. 3) liana−shrub, mixed herb−sedge−fern variant.

(IX) Dark conifer−Korean pine forest with red-twig Korean maple (*Acer barbinerve*), actinidia−shrub, herb−sedge−fern type.

(X) Dark conifer−Korean pine forest with creamy bark birch (*Betula costata*), actinidia−mock orange (*Philadelphus tenuifolius*)−golden saxifrage−fern type.

(XI) Korean pine−dark conifer forest with stone birch, liana−low herb−small sedge type.

(XII) Korean pine−dark conifer forest with stone birch (*Betula lanata*), sedge−leptorumohra (*Leptoru-mohra amurensis*) type:

(XII. 1) sedge−leptorumohra variant;

(XII. 2) tall herb−sedge−leptorumohra variant.

(XIII) Korean pine−dark conifer forest, small herb−sedge−leptorumohra type.

(XIV) Dark conifer−elm−ash forest, tall herb−sedge−fern type.

(XV) Ash−elm forest with Siberian alder (*Alnus hirsuta*), sedge−tall herb−fern type:

(XV. 1) sedge−tall herb−large fern variant; (XV. 2) tall herb−sedge−ostrich fern (*Matteuccia struthiopt-eris*) variant.

With regard to species composition and structure of communities and conditions of soil moisture and rich-ness, five ecological complexes of mountain forests

(a)

(b)

Pravaya Sokolovka

A
B
C
D
E

0   1000 km
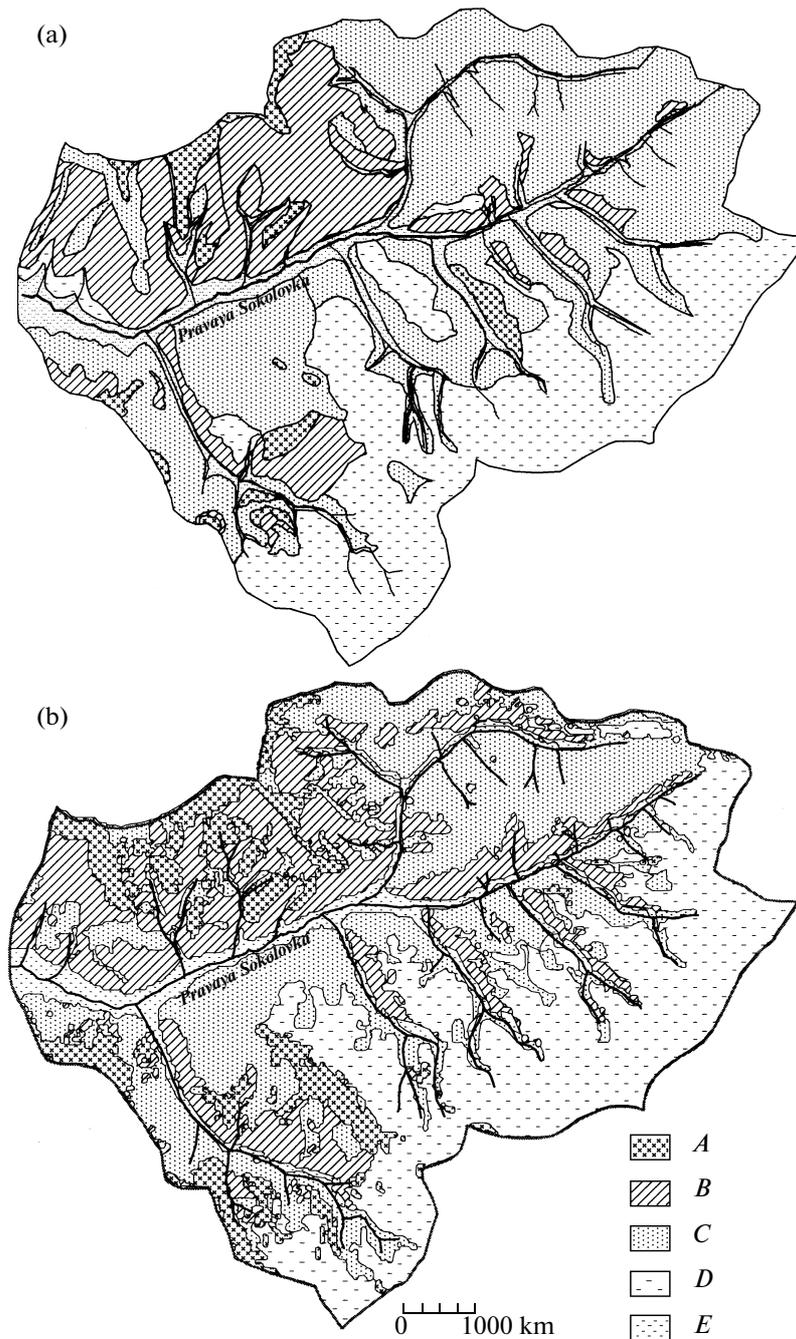
Fig. 3. Distribution of ecological complexes at the Verkhneussuriysky Biogeocenotic Station plotted on the basis of (a) geobotanical and (b) prognostic maps.

were distinguished: (*A*) warm, dry oak−Korean pine forests; (*B*) moderately warm, mesic broadleaf−Korean pine forests; (*C*) cool, mesic−moist dark conifer−Korean pine forest with broadleaf species; (*D*) cool, moist Korean pine−fir−spruce forests with stone birch; and (*E*) moist dark conifer−broadleaf forests and plain broadleaf forests.

Geobotanical map of forest vegetation. The results 1 of route surveys were used to construct a large-scale (1 : 25000) geobotanical map of actual vegetation on 1

Fig. 4. Distributions of plant communities of seven forest types at the Verkhneussuriysky Biogeocenotic Station plotted on the basis of (A) field surveys and (B) calculated models. Forest types : (a) XII, (b) IX, (c) XIII, (d) VIII, (e) XIV−XVI (for their names, see the text).

1 km

A B
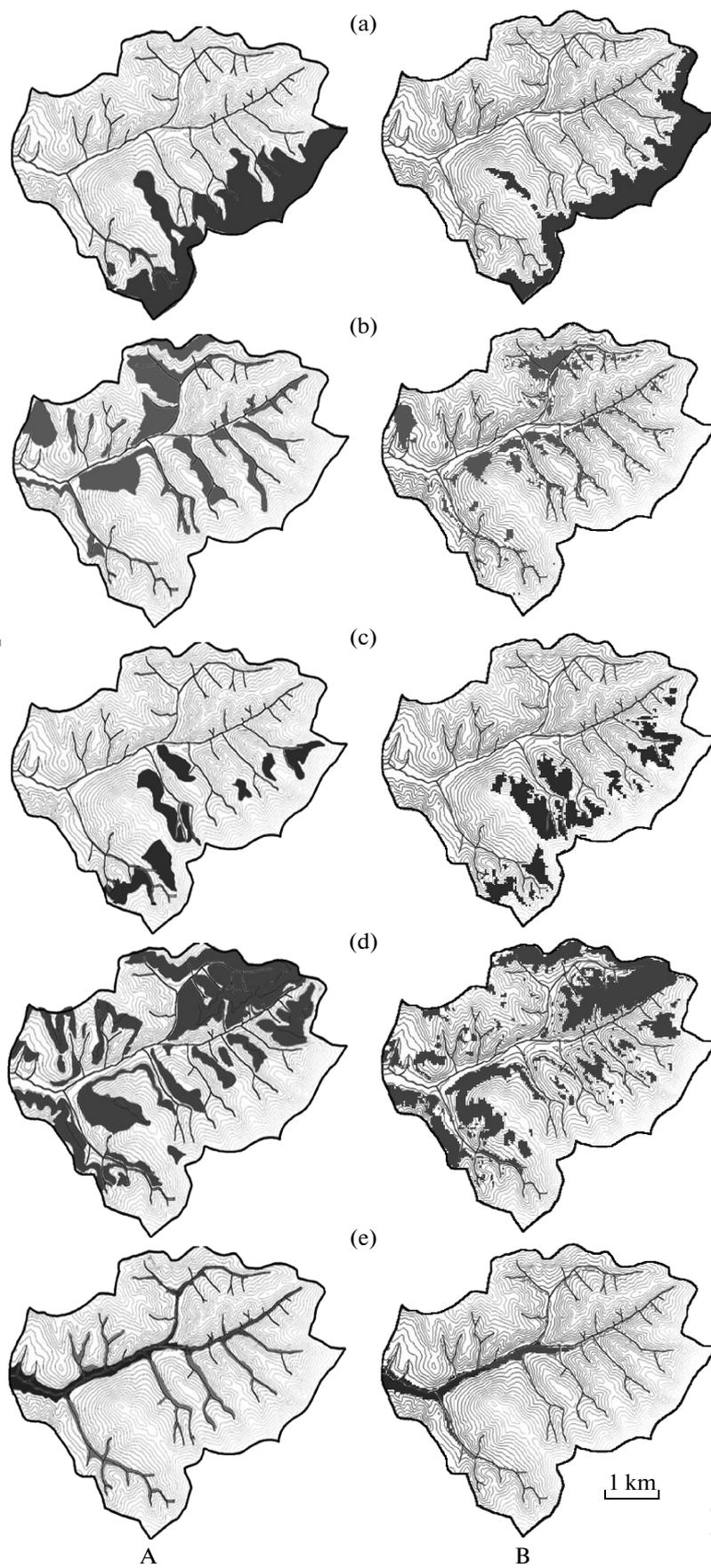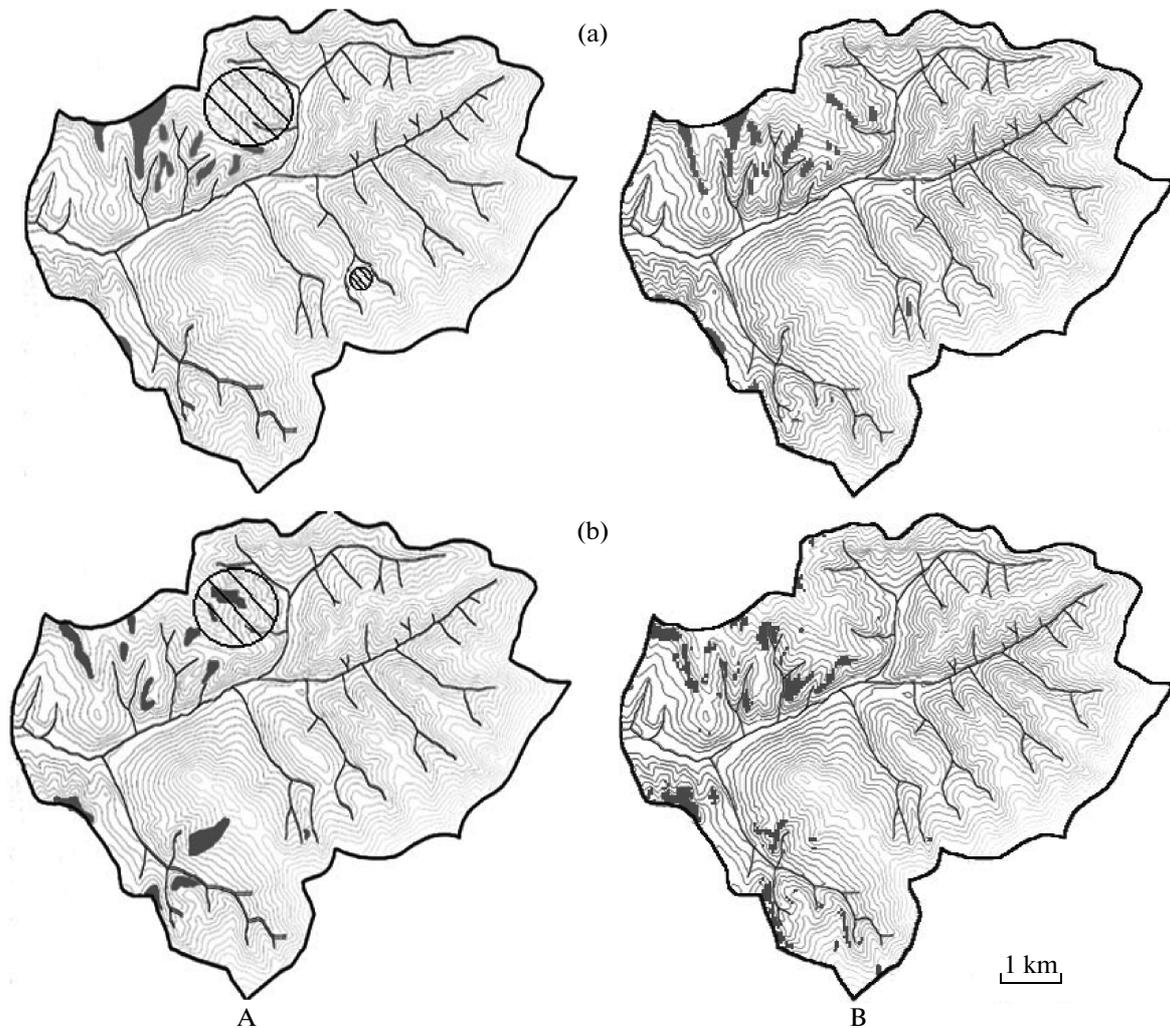
Fig. 5. Distributions of plant communities of two forest types at the Verkhneussuriysky Biogeocenotic Station plotted on the basis of (A) field surveys and (B) calculated models: (a) oak−Korean pine forest of rhododendron−cowberry type; (b) oak−Korean pine forest of filbert−rhododendron−small sedge type.

the territory of the Verkhneussuriysky station (Fig. 2). Derivative forests (white birch and willow−poplar stands in burned-out and cutover areas) are shown in white diagonal hatching.

The legend to this map provides data on specific features of composition of the above forest types and their variants and on corresponding site conditions, which are presented in a tabular form. Two geomorphological complexes are distinguished in the forest vegetation: (1) forests on mountain slopes and elevations, and (2) forests growing in foothills and river valleys. Forest types on the slopes and elevations are considered as components of the above ecological complexes (A−E).

As follows from this map, the largest area at the station is occupied by Korean pine−dark conifer communities with stone birch of the sedge−leptorumohra forest type (XIII) occurring mainly on flat, shady (northern) slopes. Oak−Korean pine forests with sig-

nificant proportions of mesoxerophyte and xeromesophyte species (*Rhododendron mucronulatum* Turcz., *Vaccinium vitis-idaea*, etc.) (types I−IV) occupy relatively warm and dry sites on steep slopes of southern exposure and convex tops of low ridges. Broadleaf−dark conifer−Korean pine and dark conifer−Korean pine forests with well-developed shrub and dwarf shrub−herb layers prevail on western and eastern slopes with intermediate heat and moisture regimes. Broadleaf−Korean pine forests (types V−VII) occur mainly in the middle and upper reaches of the Pravaya Sokolovka River. Cool, mesic−moist dark conifer−Korean pine forests with broadleaf tree species (types VIII−X) are well represented all over the study area. Dark conifer−Korean pine forests with stone birch (types XI−XIII) and prevalence of boreal species (*Leptorumohra amurensis* (Christ) Tzvel., *Dryopteris expansa* (C. Presl) Fras.-Jenk.et Jermy, etc.) in subordinate layers are being formed on protracted northern

slopes and in narrow valleys of small rivers, under relatively cool conditions.

Map of the potential vegetation. A sequential discriminant analysis made it possible to arrange geobotanical releves into relatively uniform groups of plant communities classified with 15 forest types and characterized by certain values of forest site parameters. Thereafter, coefficients and weights of variables in classification functions were calculated (table) to formulate a discriminant classification function for each forest type or its variant.

The discriminant classification function for the ith forest type has the following form:

$$F_i = w_{i1}H + w_{i2}E + w_{i3}K + w_{i4}S + c_i,$$

where F_i is the classification score of this forest type; H, E, K, and S are the observed values (grades) of elevation a.s.l., slope exposure, steepness, and topographic location of corresponding forest communities; w_{i1}, w_{i2}, w_{i3}, and w_{i4} are the weights of these four forest-site parameters in the classification score; and c_i is a constant.

These discriminant functions made it possible to determine the most probable forest type for each cell (characterized by the four parameters). Thus, a prognostic map of the spatial distribution of forest types was obtained.

Its comparison with the large-scale geobotanical map of the study area showed fairly good coincidence between the contours of different forest-typological units delimited on each map, especially at the level of larger units such as ecological complexes (Fig. 3a). Minor discordances between the calculated and observed locations of some communities concern mainly areas disturbed by human activities (tree cutting, fires, etc.).

Ecological complexes are indicative of certain site conditions, and their segregation is accounted for by direct effects of major environmental factors. Forest communities representing the ecological complex of cool, mesic–moist dark conifer–Korean pine forests with broadleaf tree species (*C*), which are indicative of mesophytic and hygromesophytic site conditions, are most widespread on the territory of the station (Fig. 3a). A slightly smaller area is occupied by communities of cool, moist Korean pine–fir–spruce forest with stone birch (complex *D*) characteristic of sites with moderate temperature–moisture conditions, which usually exist in the middle and lower parts of northern slopes. Moderately warm, mesic broadleaf–Korean pine forests of ecological complex *B* grow on steep and moderate slopes, usually with a sufficient insolation level. The smallest relative area at the station is occupied by communities of warm, dry oak–Korean pine forests with a large proportion of Mongolian oak (complex *A*), which grow mainly in the upper parts of convex, well-insolated slopes and on tops of ridges. Communities of moist conifer–broadleaf and broadleaf forests with Manchurian ash *Fraxinus mandshurica* Rupr) and Japanese elm (*Ulmus japonica* (Rehd.) Sarg.) (complex *E*) concentrate in cool, well-moistened sites with rich soils, which in the study area are found in the valleys of mountain rivers and streams (Figs. 3, 4).

The model map (Fig. 3b) confirms the main trends revealed in the distribution of different forest types. An example of adequate predicted spatial distribution is provided by the pattern of communities representing seven forest types (Fig. 4): (a) Korean pine–dark conifer forest with stone birch of sedge–leptorumohra type (XII), the communities of which occupy moist habitats in the upper and middle parts of gentle, shady slopes and on flat watersheds at elevations of 750 to 950 m a.s.l.; (b) dark conifer–Korean pine forest with red-twig Korean maple (IX), with its communities concentrating on high terraces, in foothills, and lower parts of flat, shady (mainly northeastern and eastern) slopes at elevations of up to 550–600 m a.s.l.; (c) Korean pine–dark conifer forest of mixed shrub, herb–sedge–leptorumohra type (XIII); (d) broadleaf–dark conifer–Korean pine forest of liana–shrub, mixed fern type (VIII); and three dark conifer–elm–ash forest types growing in plain areas (XIV–XVI).

The coincidence of contours between the prognostic and real-time maps is most frequent in anthropogenically undisturbed areas, while differences in the distribution of forest communities are best manifested in areas that have been exposed to clear tree cutting or fire over the past two decades. Thus, obvious differences are observed when comparing the distribution patterns of communities of the oak–Korean pine rhododendron–cowberry forest type (I), which grow in the upper parts of steep, convex slopes of southern exposure and on tops of low ridges (Fig. 5a). This situation may be explained by the effect of fire on regeneration of the Korean rhododendron (*Rhododendron mucronulatum*), the main indicator species of this forest type: its plants in burned-out areas are suppressed and grow slowly because of high density of birch undergrowth. Since rhododendron in the postfire community is no longer an indicator species, the community is classified with the filbert–rhododendron–small sedge forest type (III). In the prognostic map (Fig. 5b), this forest type is not indicated in the corresponding site, but contours of all other communities fully coincide with those on the map of present-day vegetation. The distribution of oak–Korean pine forest communities of the magnolia vine–filbert type markedly differs between the maps for the same reason: the shrub layer in the burned-out area is suppressed by dense undergrowth of small-leaved saplings. Slight differences are also observed in the distribution of communities representing some other forest types and their variants that rarely occur in the study region or occupy a small area, such as communities of the oak–Korean pine forest of rhododendron–iris–small sedge type or the broadleaf–Korean pine forest

with Amur linden of liana−shrub, sedge−chloranthus type.

CONCLUSIONS

(1) Multifactor analysis of the interrelationship between structural characters of plant cover and environmental factors makes it possible to determine the pattern of spatial distribution of plant communities representing different forest types on the basis of site parameters (elevation a.s.l., slope, exposure, and location within the slope area).

(2) Comparison of the spatial distribution patterns of forest types in the prognostic model and in the map of actual vegetation of the study area (the Verkhneussuriysky Station) has revealed good coincidence between the contours of vegetation units delimited on the maps, especially at the level of large ecological complexes.

(3) The test of this method at the Verkhneussuriysky Station has shown that the input parameters are sufficient for constructing prognostic vegetation maps for different forest-typological units (ecological complexes, forest types, and their variants). For more accurate prediction, however, analysis should be performed with regard to specific features of relationships between dominant species at different stages of succession.

(4) The proposed method may be used for creating large-scale potential vegetation maps for wide and hardly accessible territories. In addition, it can accelerate the process of mapping and make it less expensive.

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SPELL: 1. geobotanical, 2. leptorumohra