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The Phytoecological Map as a Means for Evaluating the State and Anthropogenic Transformation of Vegetation

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Abstract—The methodological principles of making a phytoecological map reflecting the degree of anthropogenic transformation of the plant cover are described.

Key words: vegetation, anthropogenic transformation, assessment, mapping

Vegetation strongly depends on environmental conditions and can serve as an integrated indicator of these conditions. The basis of phytoecological mapping consists in revealing the spatial and temporal heterogeneity of the plant cover and analyzing its interaction with the environment. The process of mapping involves identification of ecologically important natural boundaries and ecologically determined territorial complexes of vegetation and provides material for understanding natural spatial differentiation of the environment and analyzing ecological conditions and processes occurring in ecosystems under the effect of human activity.

Phytoecological mapping is among the rapidly developing fields of modern plant ecology and geobotany. A phytoecological map can be based on different principles, depending on the purpose of mapping (Sochava, 1979; Il'ina and Yurkovskaya, 1999; Ozenda, 1986). In this work, methodological principles and the experience of constructing the phytoecological map reflecting the state of vegetation and the degree of its anthropogenic transformation the described using the example of Sverdlovsk oblast.

BASIC METHODOLOGICAL PRINCIPLES

A phytoecological map contains information about the consequences of the anthropogenic impact on the vegetation and natural environment of a certain area and the current state, conditions of transformation, and trends in the dynamics of different zonal–typological subdivisions and territorial complexes of vegetation. This information is presented in a concentrated form readily accessible for analysis. The process of making a phytoecological map includes several stages.

Stage 1. The mapping of existing vegetation. The analysis and generalization of available data on the zonal–typological structure of vegetation and trends in the distribution of individual syntaxa. Identification of basic taxa in indigenous (quasi-natural) vegetation and, correspondingly, basic units to be mapped. A geobotanical map (if available) can be used at this stage.

Stage 2. Studying successions occurring in the vegetation under the effect of anthropogenic factors, determining the composition of secondary plant communities and cultivated plant communities (semicultural vegetation). Establishing the criteria for evaluating the degree of anthropogenic disturbances in different plant communities (forests, tundras, bogs, meadows, steppes, etc.) and developing the scale reflecting the degree of transformation. For this purpose, plant communities disturbed to a certain degree are compared with the undisturbed reference communities. The scale of transformation indices should be universal, but the criteria of transformation can differ depending on the class of plant communities.

Stage 3. Mapping the units of primary, secondary, and cultivated vegetation at an accepted scale. The detailedness in reflecting anthropogenic changes in plant communities depends on the purposes of mapping and the map scale.

Stage 4. Phytoecological differentiation of the territory, with territorial complexes of differ ranks demarcated on the map. Such complexes differ from one another in the set and ratio of the mapped units of primary and secondary vegetation and the degree of vegetation disturbance, but each complex is characterized by floristic, cenotic, and ecological unity and some specific conditions of the local environment. The size of the complexes depends on the degree of heterogeneity of the plant cover and the scale of mapping.

Stage 5. Assessing the state of the plant cover. The ratio between the areas of relatively undisturbed primary and secondary plant communities and cultivated vegetation can be used as the main criterion. In the course of cartometric analysis, the indices of anthropogenic transformation at the levels of zonal–typological

Table 1. Anthropogenic transformation of plant cover (by zonal–typological units)

Units of the plant cover	Proportion of vegetation, % of total unit area			Index of transformation $T_1 = \frac{Ss + Sc}{Sp}$
	primary (*Sp*)	secondary (*Ss*)	cultivated (*Sc*)	
High mountains:				
Mountain tundra	0.25	0	0	0
Low subgoltsy forests	0.58	0	0	0
Forests:				
Northern taiga	8.43	0.86	0	0.10
Middle taiga	21.87	7.75	2.50	0.47
Southern taiga	9.46	12.79	8.20	2.22
Broad-leaved–coniferous (subtaiga)	2.72	2.83	8.22	4.05
Forest–steppe:				
Small-leaved forests and meadow steppes	0.04	0.05	1.15	30.0
Intrazonal vegetation:				
Bogs	12.0	0	0.30	0.02
Total	55.35	24.28	20.37	

units of the plant cover and its territorial complexes are determined.

Stage 6. Completing the map.

The degree of preserving the diversity of plant communities (tundra, forest, meadow, bog, steppe, etc.) and, consequently, the gene pool of plants within these communities reflect the index of anthropogenic transformation at the level of zonal–typological units of the plant cover. This index (T_1) characterizes the ratio between the areas of transformed vegetation—secondary (*Ss*) and cultivated (*Sc*)—and primary vegetation (*Sp*) and is determined by the formula $T_1 = (Ss + Sc)/Sp$. We accepted the following grades of T_1 values: <0.1, very weak transformation; 0.1–0.2, weak; 0.2–1, moderate; 1–10, strong; and >10, very strong transformation.

The degree of anthropogenic disturbance of ecosystems in individual parts of the mapped territory can be characterized by the index of plant cover transformation at the level of territorial complexes (T_2). In this case, instead of separate zonal–typological units, the entire set of such units typical of a certain part of the territory is considered. This index characterizes the ratio between the area of transformed vegetation irrespective of its type, both secondary (*Ss*) and cultivated (*Sc*), and the total area of the natural complex (*S*) and is determined by the formula $T_2 = (Ss + Sc)/S \times 100$.

The concept of the territorial complex of vegetation is similar to the concept of phytocenochores proposed by Sochava (1979), who distinguished phytocenochores of the planetary, regional, and typological levels. In this case, we are dealing with phytocenochores of the typological level. We graded T_2 values as follows: <10%, very weak transformation; 10–30%, weak; 30–50%, moderate; 50–70%, strong; and >70%, very strong transformation.

EXPERIENCE IN CONSTRUCTING AND ANALYZING THE PHYTOECOLOGICAL MAP OF SVERDLOVSK OBLAST

The work on the phytoecological map of Sverdlovsk oblast was largely based on the results of our own studies. The principles of altitudinal differentiation of vegetation in the Urals and the Ural region were described previously (Gorchakovskii, 1975, 1989). According to the scheme proposed in these papers, the following altitudinal belts are distinguished in the mountain part of Sverdlovsk oblast: mountain forests, subgoltsy vegetation, mountain tundras, and cold goltsy deserts (the latter are fragmentary and found only in the northernmost part of the oblast). Horizontal zonality is observed in the plains adjoining the mountains: in the north, the boreal forest (taiga) zone subdivided into the northern, middle, and southern taiga subzones; to the south, the broad-leaved forest (nemoral) zone, which is represented by only a small fragment of the broad-leaved–coniferous forest subzone, and the forest–steppe zone. The subzones of the northern, middle, and southern taiga, expressed in the Transural part of the oblast, merge with corresponding areas in its mountain part. Small forest–steppe islands are found in both Pre- and Transural parts of the oblast, and the subzone of broad-leaved–coniferous forests is represented only in the Preural part, on the Ufa Plateau.

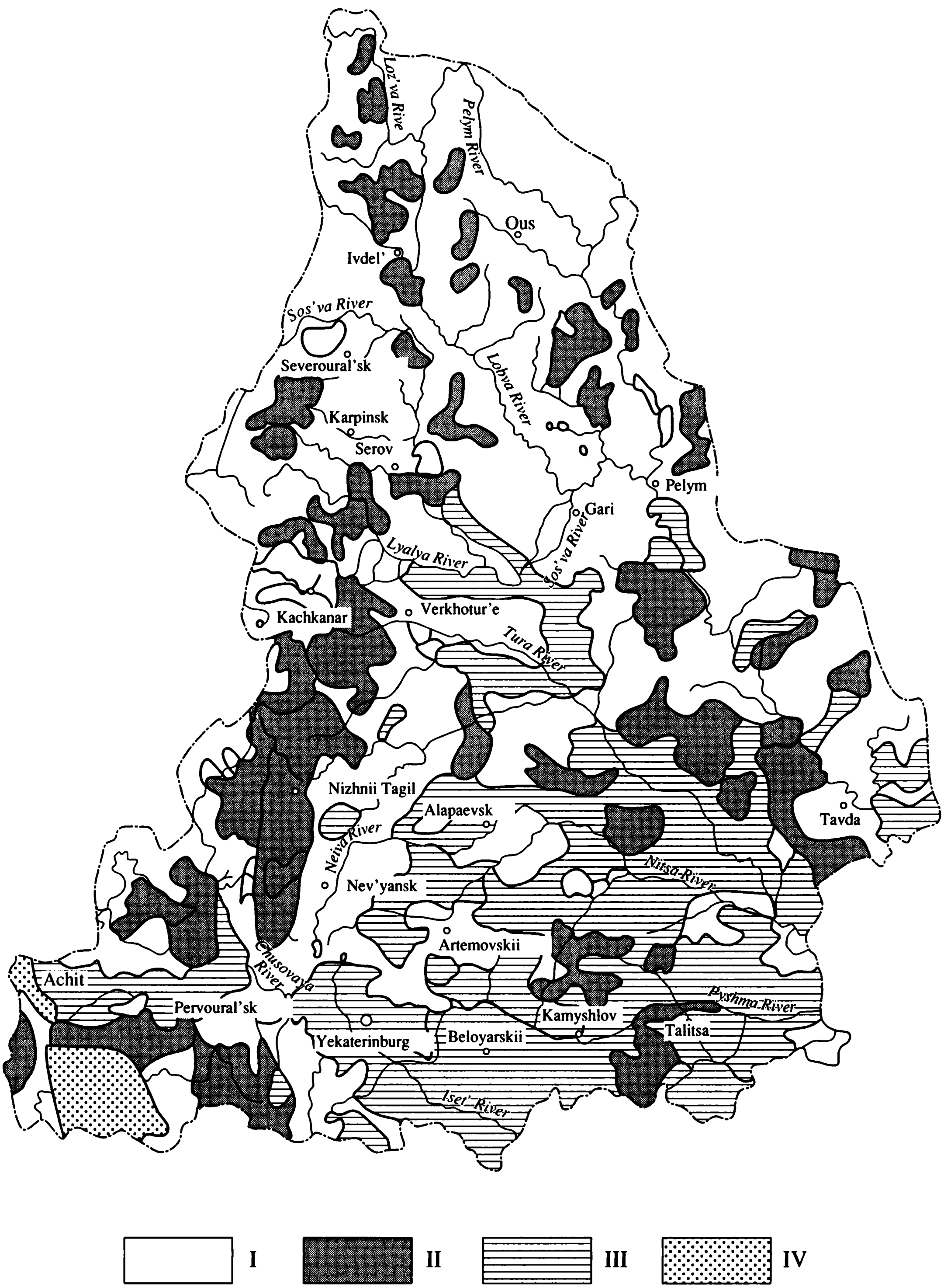

Fig. 1. Anthropogenic transformation of plant cover at the level of its zonal–typological units (Sverdlovsk oblast). Stages of transformation: (I) very weak and weak, index <0.2; (II) moderate, index 0.2–1; (III) strong, index 1–10; (IV) very strong, index >10.

Geobotanical maps are essentially ecological, as the plant cover is an integrated index of environmental peculiarities and its distribution characterizes the ecological differentiation of habitats.

Together with M.I. Sharafutdinov, we performed geobotanical mapping of the Urals and Ural region, including Sverdlovsk oblast, over several years. The results were included into the Vegetation Map of the European Part of the Soviet Union, 1 : 2500000 (*Karta rastitel'nosti ...*, 1979), and the Geobotanical Map of the Nonchernozem Zone of the Russian Federation, 1 : 1500000 (*Geobotanicheskaya karta ...*, 1976); the

Table 2. Main territorial complexes (districts) of vegetation in Sverdlovsk oblast

No.	Name	Relief	Prevailing vegetation
1	Konzhak-ovskii	High-mountain, watershed part of the Northern Urals; the highest point is Mount Konzhakovskii Kamen', 1569 m a.s.l.	In the mountain forest belt, open northern-taiga Siberian stone pine–spruce forests; in the subgoltsy belt, open and crooked forests with birch, Siberian spruce, and Siberian larch; in the mountain tundra belt, lichen–moss–dwarf shrub, dwarf shrub–moss, and grass–moss tundras; in the belt of the cold goltsy deserts, communities of lichens, mosses, and a few species of vascular plants
2	Kachkanar-skii	Foothill–middle mountain; the highest point is Mount Kachkanar, 990 m a.s.l.	Middle-taiga fir–spruce and spruce–Siberian stone pine forests
3	Chusovskoi	Foothill–low mountain, 300–350 m a.s.l.	Southern-taiga fir–spruce and spruce–fir forests; in the northeast, mountain forests of the middle-taiga type (fir–spruce and spruce–fir with Siberian stone pine); large areas are occupied by secondary birch and aspen forests and agricultural lands replacing dark coniferous forests
4	Saraninskii	Part of the Sylvinskii Ridge and Ufimskoe Plateau, up to 400–450 m a.s.l.	Subtaiga broad-leaved–spruce–fir forests with small-leaved linden, Norway maple, Scotch elm, and (rarely) oak
5	Ivdel'skii	High foothills of the eastern slope of the Northern Urals, about 400–450 m a.s.l.	Northern-taiga open pine forests with larch; in the south, larch–pine forests of the middle-taiga type; numerous secondary birch and pine–birch forests
6	Nizhne-tagil'skii	Low foothills of the eastern slope of the Middle Urals, 300–400 m a.s.l.	Larch–pine forests of the middle-taiga type and pine forests of the southern-taiga type, with larch and (often) linden in the undergrowth; numerous secondary birch and pine–birch forests
7	Beloyarskii	Slightly raised peneplain with flat low hills, up to 280 m a.s.l.	Larch–pine forest of the middle-taiga type, pine forests of the southern-taiga type, with larch and (often) linden in the undergrowth; large areas are occupied by agricultural lands that replaced birch, pine–birch, and aspen–birch forests or, in the south, steppificated meadows
8	Verkhnepe-lymskii	Upper reaches of the Pelym River within the limits of Severo-Sos'vinskaya Upland (West Siberian Plain), up to 170 m a.s.l.	Open northern-taiga pine forests, sometimes with Siberian larch, and sphagnum bogs
9	Ousskii	Southern part of Severo-Sos'vinskaya Upland	Middle-taiga pine forests with spruce; Siberian stone pine–spruce and spruce–Siberian stone pine forests
10	Pelymsko-Tavdinskii	Western part of Kondinskaya Lowland, up to 90 m a.s.l.	Sphagnum bogs; spruce forests of the middle-taiga type, sometimes with Siberian stone pine; paludal pine forests
11	Sos'vinsko-Turinskii	Turinsko-Tavdinskoe Interfluve, central part of the Sos'va River basin within the limits of the Transural sloping plain, about 140 m a.s.l.	In the west, pine forests of the middle-taiga type with spruce, paludal pine forests; in the southeast, Siberian stone pine–spruce and spruce–Siberian stone pine forests of the middle-taiga type, paludal pine forests, sphagnum bogs
12	Nitsinskii	Part of the Transural sloping plain crossed by the Nitsa, Tagil, and Tura rivers, about 110–130 m a.s.l.	Pine forests of the middle- and southern-taiga types, with spruce; sphagnum and hypnum bogs; secondary birch and pine–birch forests; agricultural lands replacing coniferous and deciduous forests
13	Pyshminskii	Part of the Turinskaya sloping plain, about 120 m a.s.l.	Agricultural lands replacing meadow steppes and birch and aspen forest islands; amid them, areas under pine and secondary birch and aspen–birch forests
14	Krasnoufim-skii	The lowest part of the Preural foredeep, a sloping piedmont plain with hills and knolls, up to 250–280 m a.s.l.	Agricultural lands replacing meadow steppes; on hilltops, areas of stony and meadow steppes or steppificated meadows

data on Sverdlovsk oblast, 1 : 2500000,were published separately in the atlas of Sverdlovsk oblast (*Atlas* ..., 1997). The work on the phytoecological map of Sverdlovsk oblast, including the cartometric analysis, was largely based on the data included in the aforementioned geobotanical map, as these data were more detailed. In addition, we used the data obtained from various departments, including those of forest and land inventories and peat exploration. The first variant of this map was published earlier (Gorchakovskii *et al.*, 1995).

In terms of the aforementioned horizontal and vertical differentiation, the indigenous (quasi-natural) vegetation in the territory of Sverdlovsk oblast is represented by the following zonal–typological units:

(a) Mountain tundras, including dwarf shrub–moss and dwarf shrub–lichen tundras.

(b) Low and crooked subgoltsy forests (*Picea obovata, Larix sibirica, Betula tortuosa*) in combination with alpine meadows and mountain tundras.

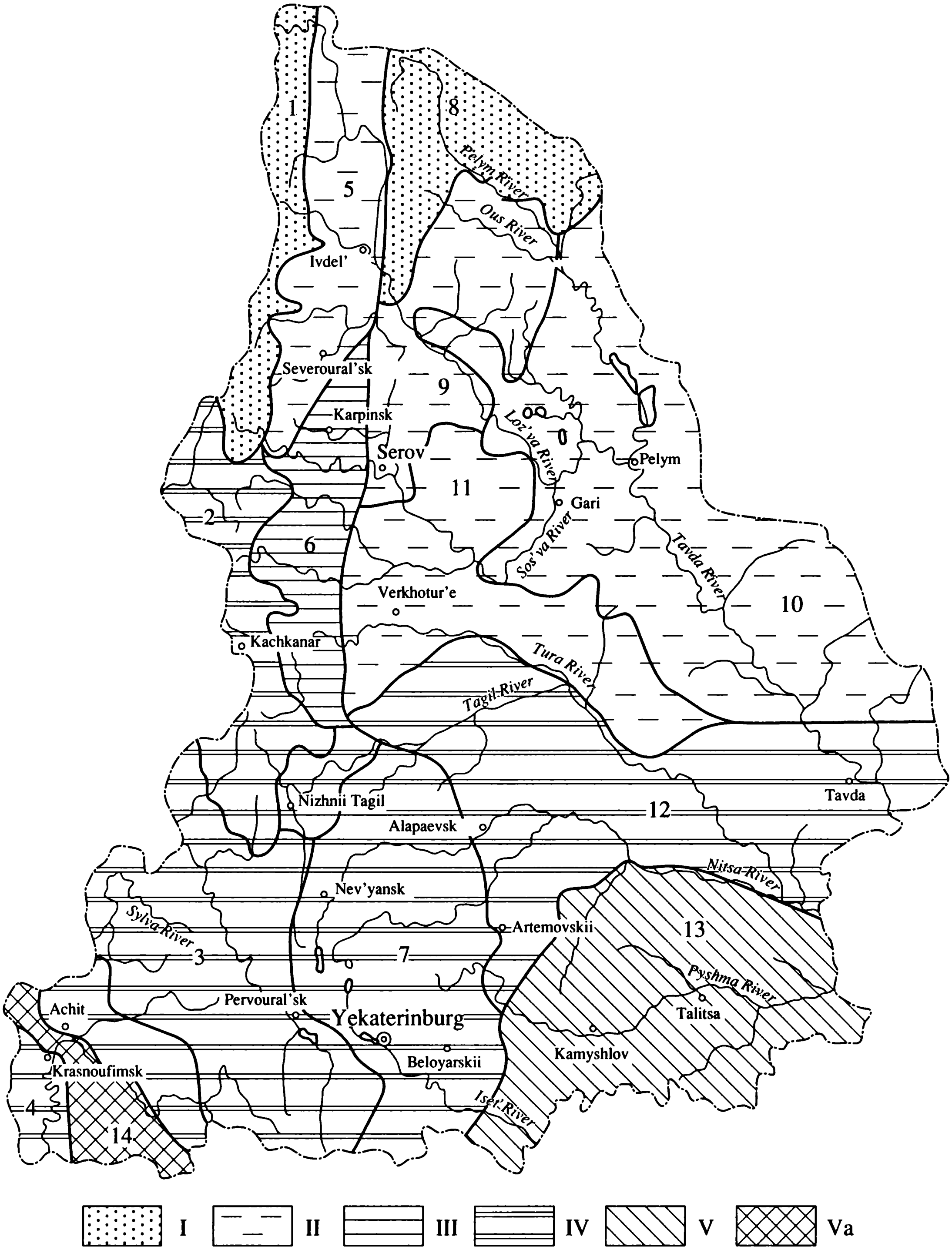

Fig. 2. Anthropogenic transformation of plant cover at the level of its territorial complexes (Sverdlovsk oblast). Stages of transformation: (I) very weak, index <10%; (II) weak, index 10–30%; (III) moderate, index 30–50%; (IV) strong, index 50–70%; (V, Va) and very strong (respectively 70–90% and >90%). The numbers of territorial complexes (1–14) correspond to those in Table 2.

(c) Northern taiga forests: lichen–moss–dwarf shrub spruce (*Picea obovata*) forests or, in the plains, haircap-moss (*Polytrichum commune*) and sphagnum (*Sphagnum* spp.) spruce forests; pine (*Pinus sylvestris*) forests, sometimes with Siberian larch (*Larix sibirica*). The latter are lichen–moss and green-moss–lichen (*Pleurozium schreberi, Rhytidiadelphus triquetrus*, etc.) light forests with dwarf shrubs and, in the plains, sphagnum.

(d) Middle taiga forests: fir–spruce (*Picea obovata* + *Abies sibirica*), Siberian stone pine–spruce and spruce–

Table 3. Anthropogenic transformation of plant cover within its territorial complexes

No.	Territorial complex	Total area of territorial complex S, km^2	Area under vegetation, km^2			Index of transformation
			primary (Sp)	secondary (Ss)	cultivated (Sc)	$T_2 = \frac{Ss + Sc}{S} \times 100$
1	Konzhakovskii	5604.75	5010.75	594.0	0	10
2	Kachkanarskii	5757.75	2751.75	2934.0	72.0	52
3	Chusovskoi	15885.0	5463.0	6738.75	3683.25	66
4	Saraninskii	4758.75	1608.75	47.25	3102.75	66
5	Ivdel'skii	6255.0	4491.0	1543.5	220.5	28
6	Nizhnetagil'skii	7926.75	4455.0	2576.25	895.5	44
7	Beloyarskii	15232.5	5784.75	3345.75	6102.0	62
8	Verkhnepelymskii	8019.0	7481.25	537.75	0	7
9	Ousskii	9238.5	6723.0	2207.25	308.25	27
10	Pelymsko-Tavdinskii	27256.5	19723.5	5305.5	2227.5	28
11	Sos'vinsko-Turinskii	16184.25	12903.75	1509.75	1770.75	20
12	Nitsinskii	26462.25	9823.5	7940.25	8698.5	63
13	Pyshminskii	18443.25	2886.75	2893.5	12663.0	84
14	Krasnoufimskii	2940.75	229.5	108.0	2603.25	92

Siberian stone pine (*Pinus sibirica* + *Picea obovata*); green-moss and herbaceous–dwarf shrub forests; green-moss and herbaceous pine (*Pinus sylvestris*) forests, sometimes with Siberian larch (*Larix sibirica*), paludal in the plains.

(e) Southern taiga forests: fir–spruce and spruce–fir (*Abies sibirica* + *Picea obovata*) herbaceous–dwarf shrub and herbaceous forests, sometimes with nemoral grasses and linden (*Tilia cordata*) in the undergrowth (in the mountains and foothills) or with haircap moss (*Polytrichum commune*) and sphagnum (in the plains); pine forests (*Pinus sylvestris*), sometimes with spruce (*Picea obovata*) and Siberian larch (*Larix sibirica*), paludified on plains.

(f) Broad-leaved–coniferous (subtaiga) forests: in the Preural region, fir–spruce (*Abies sibirica* + *Picea obovata*) forests with linden (*Tilia cordata*), Norway maple (*Acer platanoides*), and Scotch elm (*Ulmus glabra*) in the undergrowth or the lower layer of tree stand or, rarely, with English oak (*Quercus robur*); in the Transural region, pine (*Pinus sylvestris*) forests with broom (*Cytisus ruthenicus*) in the undergrowth, a thinned moss cover, and an admixture of steppe and forest–steppe plants in the herbaceous cover.

(g) Birch (*Betula pendula, B. pubescens*) forest islands typical of forest–steppe.

(h) Meadow steppes and steppificated meadows.

Anthropogenic influences lead to the replacement of indigenous (quasi-natural) plant communities by secondary ones, impoverishment of the flora at regional and local levels, anthropophyte invasion and the establishment of apophytes, simplification of the floristic composition and structure of plant communities, the decrease of their stability and productivity, and the appearance of agricultural lands with cultivated plants in the areas previously covered by natural plant communities (Gorchakovskii, 1979, 1984). Anthropogenic successions in coniferous forests of the boreal zone are usually accompanied by the replacement of dominants and the formation of small-leaved forests with the prevalence of birch (*Betula pendula, B. pubescens*) and aspen (*Populus tremula*). In the forest–steppe zone, cultivated vegetation has spread to the areas previously occupied by birch forest islands and meadow steppe.

Table 1 shows data on anthropogenic transformation of the plant cover in Sverdlovsk oblast at the level of its zonal–typological units, obtained in the course of cartometric analysis. The distribution of such units anthropogenically transformed to different degrees is shown in Fig. 1.

As follows from these data, mountain tundras, low subgoltsy forests, bogs, and northern taiga forests have the lowest index of anthropogenic transformation (0–0.1) and mainly consist of primary communities. In the middle-taiga subzone, the secondary small-leaved forests have replaced the primary coniferous forests almost by half (index of transformation 0.47). The area of secondary and cultivated vegetation in the southern taiga and subtaiga forests is two to four times greater than the area of primary vegetation. Plant communities of the forest–steppe zone are especially endangered: meadow steppes and forests have been lost almost completely, and the area of transformed vegetation exceed the area of primary vegetation by a factor of 30. Retrospective and prognostic vegetation maps of the Krasnoufimsk forest–steppe, which reflect the state of plant communities in the period from the late 17th century to the beginning of the 21st century, provide evidence that radical changes in the forest-steppe landscape have occurred as the result of human activities (Nikonova *et al.*, 1987).

We distinguish 14 main territorial complexes of vegetation in Sverdlovsk oblast (Table 2). The analysis of indices of plant cover transformation at the level of these complexes (Table 3, Fig. 2) makes it possible to reveal some interesting trends. Very weak transformation (index 10%) is characteristic of the Konzhakovskii and Verkhnepelymskii complexes located, respectively, in the watershed part of the Northern Urals and in the extreme north of the Transural part of the oblast (Severo-Sos'vinskaya Upland). Weak transformation (up to 30%) is observed in the Ivdel'skii (foothills of the eastern slope of the Northern Urals), Ousskii, Pelymsko-Tavdinskii, and Sos'vinsko-Turinskii (the northern Transural flatland part of the oblast) complexes. Moderate transformation (up to 50%) is typical of Nizhnetagil'skii complex (low foothills of the eastern slope of the Northern Urals). The Kachkanarskii, Chusovskoi, Saraninskii, Beloyarskii, and Nitsinskii complexes (the foothill–middle mountain and foothill–low mountain parts of the Middle Urals, the flatland and slightly elevated parts of the Preural and Transural regions) are characterized by strong transformation (up to 70%); and the Pyshminskii and Krasnoufimskii complexes (the forest–steppe zone of the Preural and Transural regions), by very strong transformation (index more than 70%). In forest–steppe regions, the significant prevalence of the area under cultivated vegetation over the area of primary vegetation creates the risk of losing genetic resources of the aboriginal flora.

CONCLUSION

The state and dynamics of plant cover in a certain territory can be assessed integrally with the aid of a phytoecological map, which reflects the degree of anthropogenic transformation of vegetation and the ratio and distribution of areas under the primary, secondary, and cultivated plant communities. The cartometric analysis performed in the course of phytoecological mapping provides the basis for determining the indices of anthropogenic transformation of vegetation at the levels of both its zonal–typological units and territorial complexes.

The phytoecological map makes it possible to assess the degree and environmental consequences of human activities at the local and regional levels and can be used for ecological monitoring, assessment, and prognosis of the state of ecosystems. Moreover, the phytoecological map gives an ecological warning and provides the basis for making decisions concerning changes in the management and utilization of plant resources in certain regions of the area covered by this map.

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