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ASSESSMENT OF THE VEGETATION COVER CONDITIONS FOR THE CENTRAL PART OF THE MURMANSK REGION BASED ON FIELD AND REMOTE SENSING DATA

ABSTRACT: Research of the forest ecosystems dynamics of northwestern Russia on the Kola Peninsula (the Imandra Lake watershed) under the influence of strong anthropogenic impacts caused by the industrial complex "Severonikel" over the last 70 years was carried out. Statistical analysis was used for comparison and interpolation of field data, multispectral remote sensing data (MRSD), and digital elevation model (DEM). From this analysis, the classification of natural and anthropogenic classes of the vegetation and land cover was developed; the model highlighted the key driving forces behind the spatial differentiation of vegetation (altitudinal climate gradients, anthropogenic disturbance, water supply, and development of the natural vegetation communities). In addition, the map of the current vegetation conditions at a scale of 1: 100 000 was created. This map characterizes the large part of the Lapland Nature Reserve, the territory of the Khibiny mountains, as well as the polluted area near the metallurgical plant.

KEY WORDS: forest ecosystems dynamics, anthropogenic disturbance, discriminate analysis

INTRODUCTION

The causes of the vegetation cover spatial differentiation are a subject of discussions because of existing uncertainty of the factors (driving forces) defining its variety. Therefore, the assessment of vegetation cover conditions at different levels of its organization, including assessment of the local and regional features of anthropogenic modifications of natural vegetative communities, is an important and urgent problem.

Remote sensing data on the structure, in particular for different scale mapping, of vegetation cover are used worldwide [Bartalev & Malinnikov, 2006; McRobert, 2006; Puzachenko & Puzachenko, 2008; Tomppo et al., 2008]. The accumulated information in this field makes it possible to use it in a wider array of applications for assessment of the current state of the vegetation cover and identification of existing spatial-temporal organization laws under anthropogenic influence. Especially vulnerable to external influences are vegetation communities of the "boundary" type. Therefore, the goal of the research was spatial assessment of the actual conditions of the vegetation cover and investigation of the natural and anthropogenic driving forces of its formation at the northern limit of the extent of boreal forests for the Kola Peninsula.

The modern development of methods of statistical analysis and technical tools for measuring and data processing allow performing quantitative assessment of the vegetation cover, which raises considerably the objectivity, efficiency, and quality of the analysis. In this paper, this approach is applied based on the assessment of vegetation cover conditions at the regional level.

MATERIALS AND METHODS

The research area (67°50′N 32°35′E, Kola Peninsula) is located in the central part of the Murmansk area (Fig. 1) and extends through the northern taiga subzone of the temperate zone of the western Atlantic-Arctic region. The original heterogeneity of the environmental conditions in the region (relief complexity with elevations from 100 m to 1200 m a.s.l.) formed under the impact of various anthropogenic factors (air pollution, cutting, fires) defined high heterogeneity of the land cover. Air pollution caused by the nearby metallurgical plant "Severonikel" is the main factor of the forest cover transformation.

The approach presented in this paper integrates the field survey and remote sensing data for the assessment of the current state of the vegetation cover and the identification of the main driving forces of its differentiation. The characteristics of vegetation measured in field were compared with MRSD that reflect the character of the transformation of solar energy by landscape, and also with DEM and its derivates, that are considered a defining factor in the redistribution of moisture, matter, and solar energy and cover all the area under investigation [Puzachenko, 1997; Turcotte, 1997].

The approach is based on the stepwise canonical discriminant analysis [Puzachenko, 2001; 2004; Kozlov et al., 2008, Puzachenko et al., 2008; Electronic statistics..., 2011]. The core of the approach consists of generation of a set of independent linear combinations of "external" variables (MRSD and DEM) and is the greatest degree help in discriminating between classes (groups, types, gradations) of vegetation characteristics. In the two-class case, discriminant analysis is analogous to multiple regression. When there are more

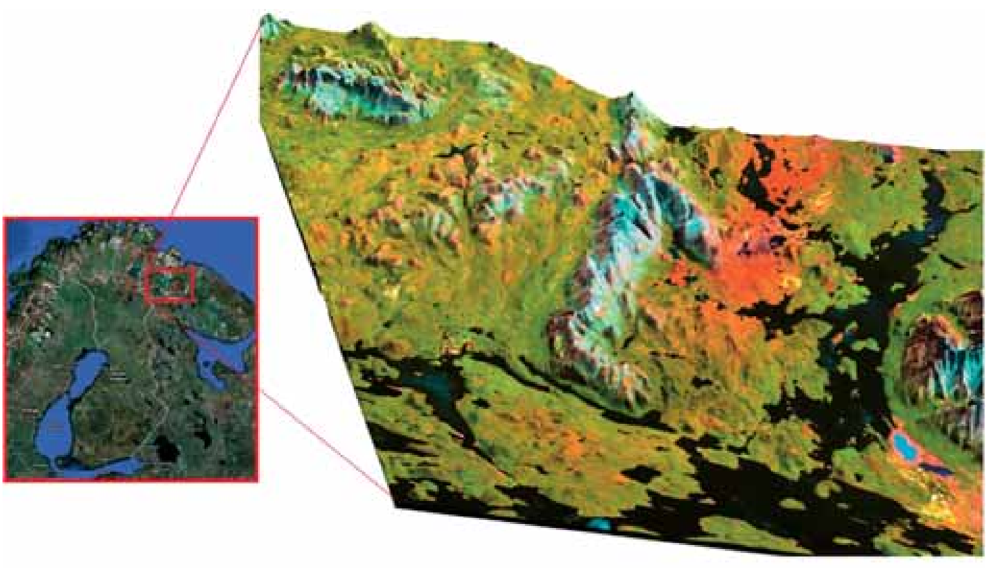

Fig. 1. The research area location and relief of testing area draped of MRSD in 3D-view

than two classes, the first regression provides the greatest overall discrimination between the classes, followed by the second, and so on. The presence of the statistically significant relationships between the classes and the linear combinations of "external" variables (discriminant axes) allows interpolating the classes for the whole territory of the investigation. The relative quality of discrimination is defined as the percentages of the correctly defined classes from a sample that was originally specified.

The statistical accuracy for the discriminant axes is measured by the lambda-criterion. The discriminant axes are the basis for the multidimensional analysis of the linkages between characteristics of vegetation and can be interpreted as determining the driving forces of its spatial differentiation. The latest is possible because of the assessable linear relations between the discriminant axes and the characteristic measured in the field plots, MRSD, and DEM. This paper demonstrates the use of this approach for the assessment of aggregated characteristics of the vegetation cover that are expressed through the types of vegetation communities. The classification of the vegetation communities at different levels (for example, formations level, group of the associations, etc.) is based on characteristics measured in the field.

The analysis was based on field geobotanical data, MRSD from the Landsat satellites (Landsat system description), and topographical maps used for the DEM.

The field data (361 sites) were collected in accordance with the standard geobotanical method for the sites of 20 × 20 m, with GPS positioning. The field sites are located in such places that characterize the basic ecological phytocoenotic conditions of the region. The total area of the investigated region is about 6 700 km^2. The special attention was given to the investigation of the anthropogenically-modified vegetation communities located in the area of the pollution caused by the "Severonikel" metallurgical plant near the Monchegorsk city.

The ecology-dominant classification of the field sites takes into account the storey structure and composition, as well as the ratio of the components of the vegetation community (dominants, subdominants, ecological groups of species, storey structure, etc.). The classification was made using expert analysis of the plant communities' characteristics. The classification was based on the literature [Neshataev & Neshataeva, 2002; Koroleva, 2009; The diversity of plants..., 2009], as well as on the original investigations for the pollution-influenced types of communities [Chernenkova et al., 2009; 2011]. As the main classification unit, a group of vegetation associations is chosen (in some cases – association), which unites plant associations with similar species dominant composition for each storey, existence of a typical core of connected species, community structure, and habitats conditions.

Additionally, for a more complete description of the land cover, the land cover types that are not presented in the field data (mostly in places without vegetation cover or with sparse vegetation) are derived with the help of topographic and thematic maps. This allowed characterizing the spatial diversity of the vegetation and land cover for the whole region using 1 968 plots.

The DEM was created using topographical maps (scale 1 : 50 000) to characterize the heights and other derivate relief characteristics. DEM extraction is based on vectorization of the isohyps, altitude points, as well as on water bodies with the altitude marks by nonlinear interpolation (ErdasImagine). The grid size (pixel) was set at 60 m, according to the topographic maps' resolution and the area of the investigated territory. Finally, the entire model territory was presented by 1 869 484 points.

The linear dimensions of the mostly represented relief structures were determined from the relief spectral density analysis. Eight hierarchical levels with the average linear sizes from 0,18 km to 9 km were identified. These values determined the size of the sliding window for calculation of the relief derivates (relative altitudes, slope, the minimum and maximum curvature, shaded relief from the East and the South at 45° sun position, profile, plane, longitudinal and cross-sectional convexity).

The Landsat satellites images were used as the source of MRSD. They have a large number of spectral bands, high spatial resolution, and a long period of regular survey. The research area is located at the edges of three images and it was necessary to combine them. The images without or with little cloud were chosen from the free on-line database. Then four mosaics were created from the images close in dates (day and month) during 1984–2009: a) at the end of May – beginning of June; b) end of June – beginning of July; c) middle of July, and d) beginning of October. To obtain the seamless mosaics, local histogram equalization of relative brightness values separately for each spectral band was performed. The original resolution of 28,5–30 m pixel size was aggregated into 60 m for the DEM. Then, a set of indexes based on spectral bands was calculated. Commonly, indices are presented by bands difference (VI) or normalized difference (NDVI), which have some physical interpretation. These were computed in attempt to better extract information from the spectral bands.

The field data (vector point format) were compared in the GIS environment with the multilayer grid containing the MRSD and DEM.

RESULTS AND DISCUSSION

Ecological-dominant classification of vegetation communities at the typological level for the group associations (associations) allowed isolating 33 classes that describe the diversity of all vegetation types (forests, open forests, bogs, mountain tundra) and 10 types of land cover including the most highly polluted areas.

The relative quality of the discriminate model averaged at 76% for all classes (Table 1). At the same time, the relative characteristics for separate classes were different. These differences are associated with a number of objective and subjective reasons: limited number of the field sites for some classes, incomplete reflection properties of vegetation cover through the MRSD and DEM, inaccurate interpretation of field characteristic of the fields sites, subjectivity of the vegetation communities classification, a high degree of continuity for the natural vegetation, overlay shift of the field sites, the MRSD and DEM, etc.

In accordance with the discriminate model, the forest types cover about 60% of the territory, of which 26% are pine forests, 20% are spruce, and 14% are small-leaved forests. The pine forests with the dwarf shrub-green mosses ground cover occupy the largest area (7,5%), spruce dwarf shrub-green mosses forests – 6.6%, small-leaved dwarf shrub-moss and herb-ferns with sparse mosses forests – 6,2%. Eleven and a half percent of the territory is determined as lichen-stony type of land cover; tundra, mountain birch forests, and swamp make 4% each. Water bodies occupy about 13,5% of the territory. The map of the ground cover types is shown in Fig. 2. A more detail classification of the natural and secondary communities is given in Table 1 and Fig. 3. The group of associations was chosen as the main vegetation classification unit.

A close correspondence was revealed from the comparison of both typologies based on Braun-Blanquet [Koroleva, 2011] and the dominant classification. Typology of secondary forests was presented at first. The example of the spruce forests' differentiation along the ecological and pollution gradient is presented below.

Lichen and moss-lichen spruce forests *(Picea obovata) with pine (Pinus sylvestris)* and birch *(Betula pubescens, B. pubescens* subsp. *czerepanovii)* (**11**) is spread on poor well-drained soils at the highest boundary of the forest vegetation distribution. Under the anthropogenic impact, the transformation

Table 1. The results of discriminante analyses of the vegetation and land cover classification for the central part of Murmansk area

Type of land cover/type of vegetation/group of vegetation associations	The relative quality, %	N of points	Area, %
1. *Nival zone	71.1	45	0.04
2. *Stone barrens (goltsy)	84.2	120	1.3
3. *Sparse vegetation of a epilithic lichens and fragments of a moss communities in stone barrens	82.4	545	11.5
Mountain tundras			
4. With dwarf shrubs and lichens	33.3	12	0.5
5. With dwarf shrubs	33.3	9	3.1
6. With sedge-dwarf shrubs junceto-caricosa	66.7	9	0.7
Subarctic open birch forests (*Betula pubescens subsp. czerepanovii*) with spruce and pine			
7. Lichen, moss-lichen, dwarf shrub-lichen-moss	60.0	5	2.2
8. Herb-dwarf shrub-lichen (*Trapeliopsis granulosa*)	60.0	5	0.9
9. Dwarf shrub	40.0	5	0.2
10. Prostrate dwarf shrub with moss (*Pohlia nutans*)	75.0	8	0.4
Spruce forests (*Picea obovata*) with pine and birch			
11. Lichen, moss-lichen	66.7	6	5.2
12. Dwarf shrub-moss	47.8	23	6.6
13. Tall herb-moss	75.0	4	0.7
14. Dwarf shrub-peatmoss	40.0	5	2.4
15. Herb-peatmoss	22.2	9	1.9
16. Grass (*Avenella flexuosa*) – dwarf shrub-lichen (*Trapeliopsis granulosa*)	77.8	9	0.5
17. Dwarf shrub-liverworts (*Barbilophozia* spp.)	32.1	28	1.4
18. Dwarf shrub	8.7	23	1.1
19. Grass (*Avenella flexuosa*)-dwarf shrub	14.3	7	0.6
Pine forests (*Pinus sylvestris*) partly with birch			
20. Lichen	62.5	8	2.2
21. Moss-lichen	33.3	9	3.4
22. Dwarf shrub-moss	19.2	26	7.5
23. Dwarf shrub-peatmoss	36.4	11	2.3
24. Herb-peatmoss	22.2	9	2.7
25. Dwarf shrub-lichen (*Trapeliopsis granulosa*)	33.3	15	1.4
26. Dwarf shrub, grass (*Avenella flexuosa*) – dwarf shrub, dwarf shrub- liverworts (*Barbilophozia* spp.)	52.6	19	2.0
27. Dwarf shrub-moss (*Polytrichum* spp.)	14.3	7	3.7
28. Prostrate dwarf shrub with mosses (*Pohlia nutans*)	80.0	5	1.1

Continue Table

Type of land cover/type of vegetation/group of vegetation associations	The relative quality, %	N of points	Area, %
Birch forests (*B. pubescens*) partly with spruce and pine			
29. Dwarf shrub-moss, herb-ferns with sparse moss	50.0	10	6.2
30. Dwarf shrub-peatmoss, sedge-herb-peatmoss	66.7	3	3.2
31. Dwarf shrub-lichen (*Trapeliopsis granulosa*)	42.9	7	1.4
32. Dwarf shrub, dwarf shrub-liverworts (*Barbilophozia* spp.), dwarf shrub-moss (*Polytrichum* spp.)	19.0	21	1.4
33. Grass-ferns	20.0	10	0.6
34. Prostrate dwarf shrub with mosses (*Pohlia nutans*)	26.7	15	0.7
Bogs			
35. Dwarf shrub-peatmoss	50.0	4	1.6
36. Sedge-herb-peatmoss	27.3	11	1.7
37. *Water bodies	90.8	185	11.8
38. *Polluted water bodies	82.6	69	1.5
39. *Settlements	95.6	45	0.2
40. *Waste dumps and careers	87.9	132	0.8
41. *Meadows and agricultural lands	95.9	123	0.5
42. *Industrial barrens	96.1	77	1.1
TOTAL	76.0	1698	100

Note: * Classes derived from topographic maps and MRSD.

of these communities takes place. They are replaced by chionophobous lichens of genera *Cetraria* and *Flavocetraria* form cortical lichens (*Trapeliopsis granulosa*) that cover the open soil surface. Thus, the type of **dwarf shrub-crustose lichen *(Trapeliopsis granulosa)* spruce forests with birch** (type **16** in Table 1) is the first stage of digression. At the second stage (type **34 – prostrate dwarf shrub with mosses *(Pohlia nutans)* *birch forest)*, spruce trees** are gradually disappearing. Mosses species that are typical for the initial succession stages*,* such as ***Pohlia nutans****,* dominate at the above ground cover. The species composition of these communities is extremely poor; the soil horizon is actively weathered. The base rock is exposed.

Under zonal or close to them conditions of ecotype on dry and fresh soils of an average depth and moderate drainage, pristine **spruce forests with dwarf shrub-mosses** (**12**) are widely spread. Near the metallurgical plant due to the anthropogenic activity, a rich spectrum of secondary succession types is presented. The main types are: **dwarf shrub-lichen** (**11**) and **dwarf shrub-liverworts (*Barbilophozia* spp.)** (**17**) **spruce forests partly with birch and pine**. They are formed due to soil xerophytisation along with a high content of toxic compounds of heavy metals in the environment, an increase in soil acidity, and the impoverishment of its mineral nutrition elements.

Spruce communities with rich lichen cover are close to postpirogenic demutation types described by V.V. Gorschkov and I.Ju. Bakkal [2009]. However, spruce communities with liverworts dominated in the moss layer are rare and are typical only for the postindustrial successions stages. There, green mosses (*Pleurozium schreberi*, *Hylocomium splendens)* are replaced by liverworts (*Barbilophozia* spp., *Lophozia* spp.).

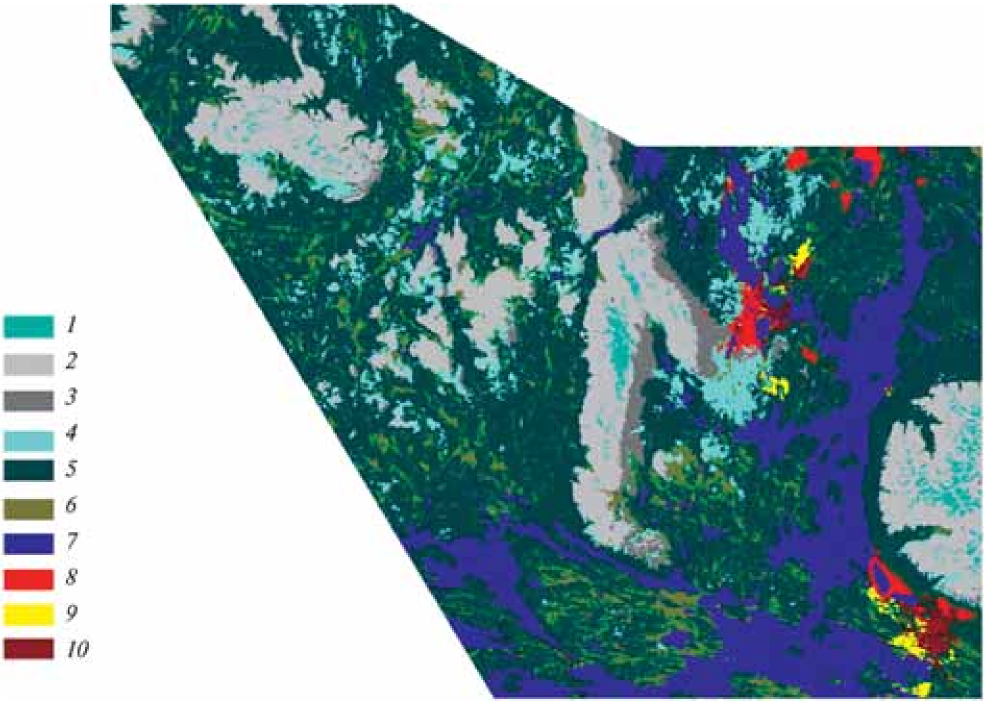

Fig. 2. The map of cover types

1. Nival-glacial. 2. Stone goltsy barrens. 3. Mountain tundras. 4. Open birch forests with spruce and pine. 5. Forests with spruce and pine. 6. Swamps and swamped forest. 7. Water bodies. 8. Industrial barrens. 9. Meadows and agricultural lands. 10. Settlements

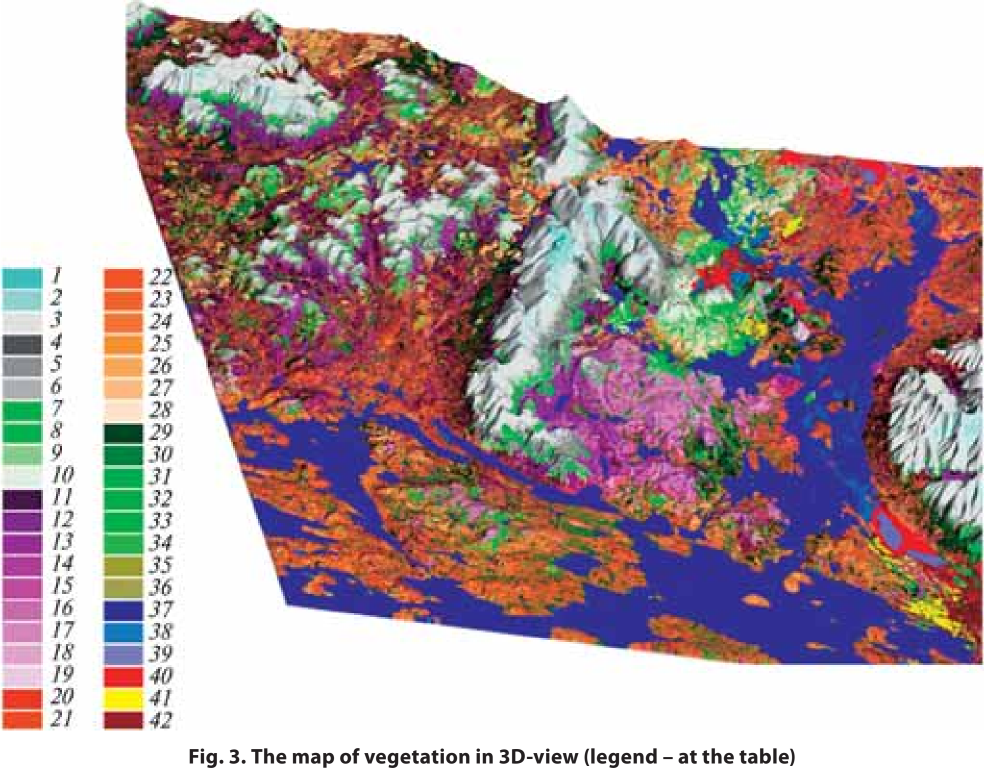

Fig. 3. The map of vegetation in 3D-view (legend – at the table)

Further transformation of dwarf shrub-mosses spruce forest in conditions of deeper pollution impact goes towards forming such types of communities as **dwarf shrub (18), grass *(Avenella flexuosa)*-dwarf shrub** (**19**), **prostrate dwarf shrub with mosses *(Pohlia nutans)*** (**34**)**, and spruce and small-leaved forests**. At the stand layer, small-leaved species (*Betula pubescens, Salix* spp., *Populus tremula)* replace coniferous trees. Moss-lichen cover almost disappears, leaving only partly small areas of *Pohlia nutans and Politrichum* spp.

Tall herb-moss spruce forests (13) are common for the valleys of streams and rivers and on raw and fresh moderately drained soils. In intact areas and under the technogenic influence, **herb-peatmoss (14) and dwarf shrub-peatmoss (15) spruce types** are formed. They are the most resistant to anthropogenic factors.

Overall, the statistical and expert analysis techniques characterizing differentiation of the vegetation cover mutually complemented each other.

The vegetation and land cover classes are presented as a vector map of the central part of the Murmansk area (Fig. 2 and 3). The assessment of the certainty of the interpolation was done for each point by the equation: $ERR = ((p_1)^2 + (p_2)^2 + ... + (p_i)^2)^{0,5}$, where p_i is the probability for the pixel to be defined as i-class. The certainty minimum for all 42 classes is 0,15, which is almost twice smaller than the uncertainty obtained in the analysis, i.e., 0,28. The smallest uncertainty was identified for the lowland territories occupied by forests.

The physical interpretation of the twelve valid discriminant axes shows that the main driving forces for the vegetation and land cover differentiation are: altitude climate gradients, anthropogenic disturbance, water supply (which is determined, in the most essential part, by relief forms at different hierarchical levels of its organization), and, lastly, self-development of the natural vegetation communities.

CONCLUSIONS

The analysis resulted in the development of the classification of the natural and anthropogenic classes of the vegetation and land cover for the central part of the Murmansk area. Good correspondence was received between the different classification approaches; the statistical and expert analysis techniques mutually complemented each other. Typology of secondary forests was identified.

Based on statistical analysis, the map of the current vegetation conditions (1 : 100 000 scale) was created. This map characterizes the largest part of the Lapland Nature Reserve, the territory of the Khibiny mountains, and the polluted area near the metallurgical plant.

Thus, the usage of statistical analysis methods and various sources of spatial data on vegetation conditions and habitats provide not only spatial assessment of the current state of vegetation, but also allows highlighting the key driving forces behind the spatial differentiation of vegetation. Along with this reliably identified classification, the impacts of human activity on the transformation of the composition and structure of the vegetation cover at the regional level were assessed.

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