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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 derivatives, 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
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 (Land-
sat 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 km². 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 derivatives (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 lichen                                       | 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                     | 77.8                    | 9          | 0.5     |
| (Trapeliopsis granulosa)                                              |                         |            |         |
| 17. Dwarf shrub-liverworts (Barbliophozia 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 (Barbliophozia 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     |
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.*).

| 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 | 19.0 | 21 | 1.4 |
| 42. *Industrial barrens | 96.1 | 77 | 1.1 |
| **TOTAL** | 76.0 | 1698 | 100 |

Note: * Classes derived from topographic maps and MRSD.
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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