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USE OF THE SPOT VGT-S10 PRODUCT TO DISCRIMINATE AND EVALUATE ECOSYSTEMS FOR ECOLOGICAL APTNESS AND FOR THE DESIGN OF AN ECOLOGICAL NETWORK

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ABSTRACT

The Design of General Schemes of Ecological Networks is realized in the frame of a WWF project for Yakutia (Republic of Sakha). Project realization uses an approach connected with ecological network concepts (cores, ecological corridors). Remotely-sensed data (RSD) and a digital elevation model (DEM) are the information basis for designing the ecological network. RSD is the primary information source because of the vast area and weak direct studies of the Yakutia region. As a result the SPOT/VEGETATION (VGT-S10) product is most useful for this project as it does not require preliminary processing. SPOT VGT-S10 product on North-East Asia for March, May, June and October year 2001, are used in the project. A rectangular area, including the territory of Yakutia (Northeastern Asia), was retrieved from the initial product. The primary spatial resolution of 1x1 km was aggregated to a 4x4 km based on objectives, scale and hardware resources. Assessment of the hierarchical organisation of the territory, extracting the liniments of territory, creation the land cover map, landscape metrics calculation are based on the VGT-S10 product. Creating the integral RSD image by spectral bands and non-linear coefficient like NDVI for all dates is executed for the analysis of the hierarchical structure of the studied area. Integration is carried out by PCA method with summing taking into account weight of components. The basic hierarchical levels are distinguished by a 2-D spectral analysis for the integrated image. For the identification of liniments, the integral image that generalizes the satellite data and the DEM is modified by the wavelet analysis on the scale corresponding to the chosen hierarchical levels. The liniments are buffered according to the chosen hierarchical levels and interpreted as potential ecological corridors. When overlaying differently oriented corridors, we obtain cores of the network of protected areas with corresponding rank. A map of landscape cover types was compiled based on the SPOT bands and their ratios like NDVI processed with PCA. The classification was made by Euclid and Buniakowski metrics using the K-means method with the hierarchical procedure by binary base. Assessments of land cover diversity are carried out on the basis of low level of classification (173 clusters) using landscape metrics.

The landscape metrics calculated with sliding squares according to the chosen hierarchical levels. Values of landscape metrics are then compared with cores of the network of protected areas. As a result, estimation of cores diversity status by different aspects of land cover diversity is realized. Thus, by VGT-S10 product design General Schemes of Ecological Network ecological corridors and cores with assessment of its diversity by the different hierarchical levels.

1. INTRODUCTION

The extension of a network of special natural reserves as protected areas is considered as an important component of sustainable development [1, 2, 3]. This allows countries to more efficiently implement international commitments on the conservation of biological diversity and to adequately implement their national policy. Most countries are conducting work on the development of ecological networks. The optimal disposition of protected areas is based specially elaborated criteria [5, 6, 7].

In the former USSR and Russia, the main principles of creating zapovedniks (reserves) based on landscape-geographical and phytogeographical criteria [11]. According to these criteria, a network of zapovedniks should include all the main types of landscapes and their regional modifications as natural standards. Actually, the selection of territories for creating zapovedniks, national parks, and zakazniks was carried out, as a rule, on the basis of the facts gathered by individual investigators, and the criteria were used only to confirm a high environmental value of the already-selected territories. The inadequate study of nature over the vast territory of Russia has caused the concentration of protected areas in the most investigated regions (European part of Russia). As a result, this network of protected areas was incomplete and inefficient in terms of nature conservation.

In Europe, the selection of protected areas is performed according to several projects (NATURA 2000, Emerald Network, IPA, IBA, BEAR), which supplement one another and differ mainly in protected objects. Their specific character dictates different criteria for selection. All these projects are aimed at the conservation of the most valuable territorial combinations of habitats, ecosystems, and landscapes and creation unified Pan-European network of Protected areas.

The similar program "Green Infrastructure" directed at the creation of the unified network of protected areas has been developed in the USA. There are International programs for conservation of some important habitats (Ramsar) or whole ecosystems (MAB).

Eventually, this practically acting schemes rest on the approach is based on the theoretical background of island biogeography [8] and landscape ecology [9, 10]. Representative territories of large areas with high species and habitat diversities are selected as core areas. However, special attention is given to the creation of small protected areas for conservation of individual species populations, their habitats or territory related groups. Continuous or discontinuous corridors ("stepping stones") provide relations between core areas. The corridors are natural or semi-natural habitats providing the possibilities for genetic exchange between plant and animal populations. In many cases, functions of corridors and "stepping stones" may be compatible with some kinds of human activities.

A system of core area and corridors forms an ecological network of a region, an original "archipelago" of nature conservation in the "ocean" of direct use of natural resources. The concept of ecological corridors is the most contradictory one in this system. Usually, ecological corridors are distinguished as relatively linear territorial formations with habitats, which greatly differ from those in the surroundings. As a result, river valleys with complexes of riparian forests and meadows are more often considered as corridors. Formally, in order to reveal real corridors, studies of existing migration ways of animals, as well as of winds' directions in the period of flowering and fructification of anemochorous plants are need. The data on these problems is not enough, and distinguishing the corridors is rather conventional. If a network is composed of protected areas so that between large protected areas there are many areas of smaller size the latter (along with functions of conserving local diversity) can perform the functions of "stepping stones" [12].

The criteria for selecting the elements of the protected areas network as assumed in global applications, requires an direct inventory of the state of populations, communities, habitats, and territorial combinations of landscapes. Over the vast Russian territory, such a venture can be fulfilled only in densely populated regions of the European part of Russia. For most other regions, the direct criteria might be applied where it possible. However, as a rule, it is difficult to be conform with before mentioned requirements. In a first approximation, the solution of this task is based on the information on drivers potentially responsible for biological diversity. Particularly, N.I. Vavilov used a natural way when he substantiated the world centers of crops' origin [11]. He considered the environmental diversity and particularly diverse climatic conditions as the main criteria for distinguishing these centers. Mountain systems within areas of climatic barriers primarily correspond to these criteria. This fundamental principle is manifested in the relationship between the number of protected species and the number of protected areas [9]. A similar function was deduced from a model of spatial distribution of species [12].

The relation of species to space is quite different: stable populations of some species can exist in a relatively small territory, others require vast space. Some species need highly diverse habitats, others, a relatively homogenous area. The relation between species (within one life form) and territory is determined by the allometric relationship "mass of an individual – area of population" [14]. This relation determines the necessity to create a hierarchically organized network of protected areas. Alternately, the spatial arrangement of a landscape is generally accepted [10]. Thus, the diversity of habitats or any territorial structures should be considered at different hierarchical levels or on different spatial scales. The hierarchical organization of a network of protected areas implies a certain proportion of their sizes and certain combinations in their spatial distribution.

However, we can determine such direct parameters through indirect one. Topographic maps and spaceborne imagery provides the information on habitat diversity and hierarchical organization of the earth's surface. The use of remotely sensed data (RSD) allows one to consider the entire territory investigated and makes it possible to distinguish pro-

tected areas within a unified system.
A solution for the problem set is possible based on methods of “spatial analysis”. The consecutive solution of the tasks given in Table 1 may decrease the influence of a subjective factor when selecting potential protected objects. Below we describe briefly stages of the Design of General Schemes of Ecological Networks from the example of Yakutia (The Republic of Sakha, Russia). The work has been fulfilled in the framework of the WWF project.

2. MATERIAL

The basis for planning protected areas is a digital elevation model (DEM) from a topographic map (1:1 000 000), the four SPOT/VEGETATION satellite bands and the vegetation index (NDVI) with an initial resolution of 1x1 km (VGT_S10 product). In our work, the data obtained in March, May, June, and October of 2001 were used.
A rectangular area including the territory of Yakutia (Northeastern Asia) was cut from the initial product. Primary spatial resolution 1x1 km was aggregate to 4x4 km reasoning from goal, scale and hardware resources. In addition, the information from the vegetation Map of the USSR, digital vector map of forests of the USSR, digital raster map of the ground cover of Northern Eurasia [15] was also used in planning the network of protected areas.

3. CONSTRUCTION OF A GENERALIZED IMAGE

Direct use of the space born information for various dates in several bands results in duplication of the information due to correlation between bands and dates. Thus for discrimination the hierarchical organization of territory is necessary obtained the generalized image on the basis of which the spectral analysis is realized.
Integration of an image is performed on the basis of SPOT VGT-S10 imagery for every season and indexes similar to the NDVI. These characteristics are widely used in remote sensing as indexes reflect a nonlinear component in relationships in reflective band (for example B2-B1/B2+B1, B2/B1).
The whole set of initial (bands) and new variables (indexes) is being modified by the PCA. Firstly, twenty components completely describe the variation of all variables (initial and derived). Since the twenty components are arbitrarily independent, their sum (with due regard for their contribution into the description of the total variation of all variables) represents an integral single-layer image of a territory that most fully reflects the spatial variation of SPOT VGT-S10 imagery for different dates (Fig. 1).

The production of a generalized image of RSD and DEM (Fig. 1) is carried out based on an integral RSD image, a DEM and the relationship between them based on PCA analysis. This procedure enables to eliminate the correlation between RSD and DEM (linear correlation coefficient -0.15).

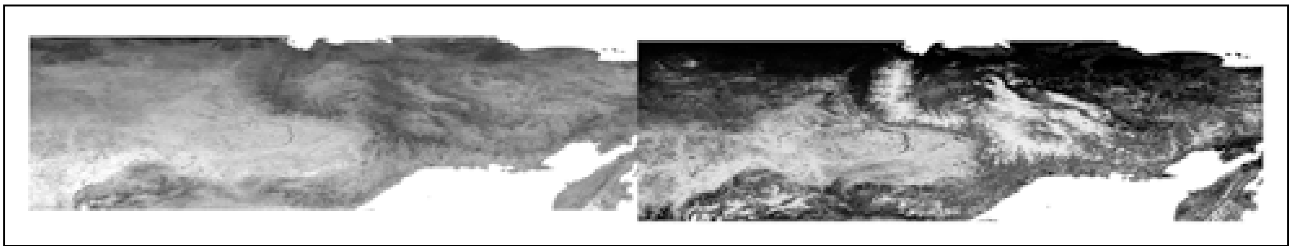

Fig. 1: *Integral image by SPOT VGT-S10 product and generalized image by SPOT VGT-S10 product and DEM Thus focusing on non-correlated information the hierarchical organization of the landscape cover can be analysed*

4. DISTINCTION OF HIERARCHICAL LEVELS OF ORGANIZATION, ECOLOGICAL CORRIDORS, AND NODES

Ecological corridors and their intersection (node) are the essential parts of ecological network. Their distinction may is made for various spatial scales. Optimization of this procedure may proceed by quantitative distinction of hierarchical levels of investigated territory organization.

Methods to study hierarchical levels is based on analyzing spectral density of imagery by Turcotte [16] method are described in detail by Yu.G. Puzachenko et al. [13]. Spectral density (Sp) or Fourier density is a function of wave number or frequency (w):

$$\mathrm{Log}Sp=\mathrm{a}+\mathrm{b}*\log(\mathrm{w}) \quad (1)$$

If a declines spectral density from the regression curve (Eq. 1) does not contain regular components, a set is purely fractal (fractal dimension is (7-b/2)), and hierarchical levels are absent.
If there is a nonrandom component in declines spectral density from the regression curve, periods of the highest variation of values in the investigated image may be identified (Fig.2). These periods reveal levels of hierarchical organization of the studied territory.

Tasks	Task descriptions	Method (s)	Deliverable
Creation of general image of the region of interest (ROI)	Exclude spatial correlation of variables from the analysis	PCA	Imagery of region of interest reflecting the spatial variation of its specific features contained in the initial information
To discriminate the levels of hierarchical organization of a ROI	Discrimination based on the general image determination rules of the hierarchical structure of the ROI	Two-dimensional spectral analysis	The number and linear sizes of hierar chical levels in the spatial organization of a ROI.
Selection of independent spatial structures and selection of linear structures ("ecological corridors")	Transformation of the general image for hierarchical level with the provision of its independent (orthogonal) spatial components. Determination of orthogonal linear structures	Wavelet transformation, special filter	Construction of three images reflecting the independent spatial structures of different hierarchical levels. Maps of orthogonal linear structures
Selection of cores (nodes) within a territorial network	Superposition of linear orthogonal structures	Buffering, overlay	A node map with evaluation of its importance
Compilation of a landcover map, with emphasis on a landscape classification key	Selection of land cover types	Dichotomous classification by the K-means method	Landcover map
Assessment of the diversity (completeness) of landscapes	Calculation of indices describing different aspects of the mosaic pattern of local territories based on the landcover map	Landscape metrics (Table 3), PCA	Compilation of landscape metrics maps reflecting various aspects of completeness of particular territories for the assumed hierarchical levels
Selection of territories with high environmental (protection) value based on criteria of landcover complexity	Ranking of the different evels of landscape metrics in regard to their representation in the studied territories	GIS transformation	Compilation of maps of "high quality areas" according to the landscape metrics ranking with identification of the most uneven and the most even areas (high and low value of landscape metrics)
Distinction of elements in a network of protected areas according to two criteria: nodes and diversity	Combination of node maps and maps of of "high quality areas" by landscape metrics with integral evaluation of their quality	Overlay in GIS	A map of potential protected areas with estimates of their importance
Elaboration of a general scheme of disposition of protected areas	Selection of potential protected areas	Buffering, overlay, visual correction	GIS of the general scheme for protected areas

Table 1. *The sequence of solving a set of tasks when designing a scheme of protected areas*

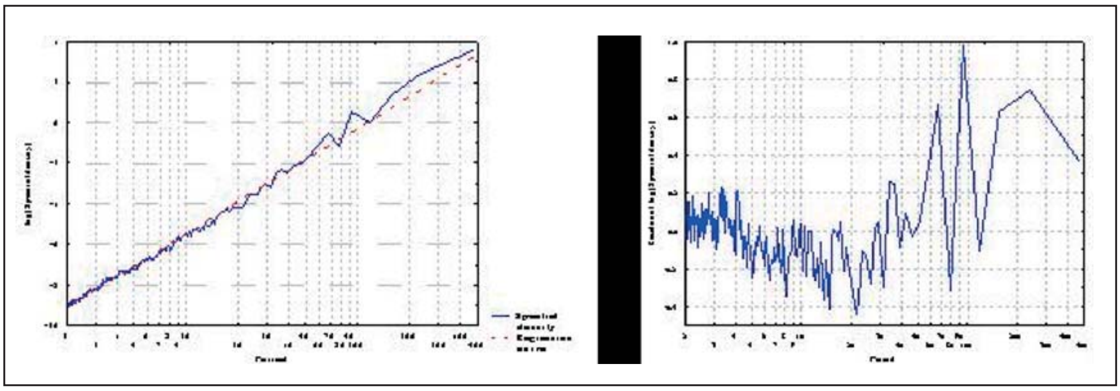

Fig. 2: Spectral density of the generalized image and regression curve (Eq. 1); and residuals from difference between spectral density and regression curve

The estimates of the hierarchical organization based on the generalized image.

The hierarchical levels corresponding to periods 5-7 (20-28 km), 11 (44 km), 17 (68 km), 37 (148 km), and 60 (240 km) pixels are assumed as the main ones.

For the identification of corridors, the integral image that generalizes the RSD and the DEM is modified by wavelet analysis on a scale corresponding to that of a chosen hierarchical level.

We used wavelet analyse because of its give possibility to allocate orthogonal structures on determined hierarchical level.

According to the purpose of this study, the wavelet modification was made for two hierarchical levels – 240 and 148 km.

The first level helps to select the largest structures, the second level, subordinate ones. Fig. 3 shows three orthogonal images obtained by wavelet analysis for a level of 240 km. As a result, four types of linear structures were obtained for every hierarchical structure: with predominant latitudinal orientation, with longitudinal orientation, and two diagonal ones.

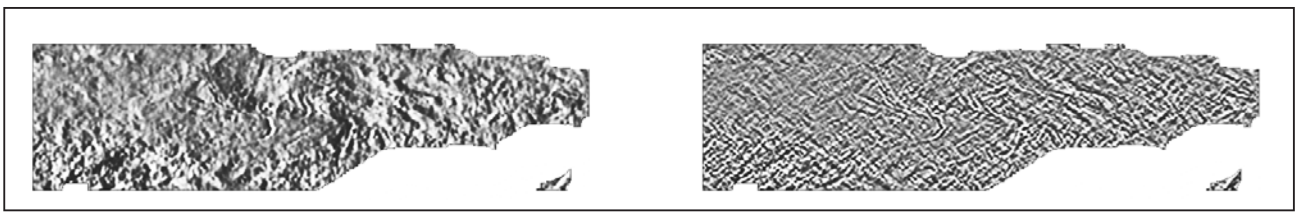

Fig. 3: Wavelet transformation for the level 240 km: vertical component, horizontal component, and diagonal component

The width (buffer diameter) of a corridor is assumed to be equal to one tenth of the linear size of a hierarchical level: 24 and 14.8 km for 240- and 148-km levels, respectively. When overlaying differently oriented buffered corridors, we obtain nodes in points of their intersection. Finally, these nodes may be formed by the intersection of two, three and more corridors of different direction and different hierarchical levels. The nodes obtained are associated with cores of the future network of protected areas. Evidently, a node formed by the intersection of several corridors represents a more complex territory that is more tightly related its neighbours. The number of corridors (with due regard for their hierarchical levels) composing a node determines its status. In this instance, the status of the node (St) is determined according to the following qualitative Eq 2:

$$St=2*(n1-1)+(n2-1) \qquad (2),$$

where n1 (*n2*) is the number of corridors of the first (second) hierarchical level forming the node given.

According to this scheme, the node's area is measured by its buffering capacity and includes all contacts or intersections of different corridors. The nodes obtained may also be overlaid and make contact with one another. Such nodes are integrated in a common one containing the sum of their status. For the territory of Yakutia, 471 nodes with a mean area about 260 km2 and 90-km perimeter are obtained. Fig. 4 shows the distribution of nodes and corridors over the territory of Yakutia. The minimum status of a node is 1, the maximum one, 36. The mean value is 2.65. As Fig. 4 shows, the territory is almost evenly covered with a network of nodes forming a large archipelago with alternating "islands" of different sizes.

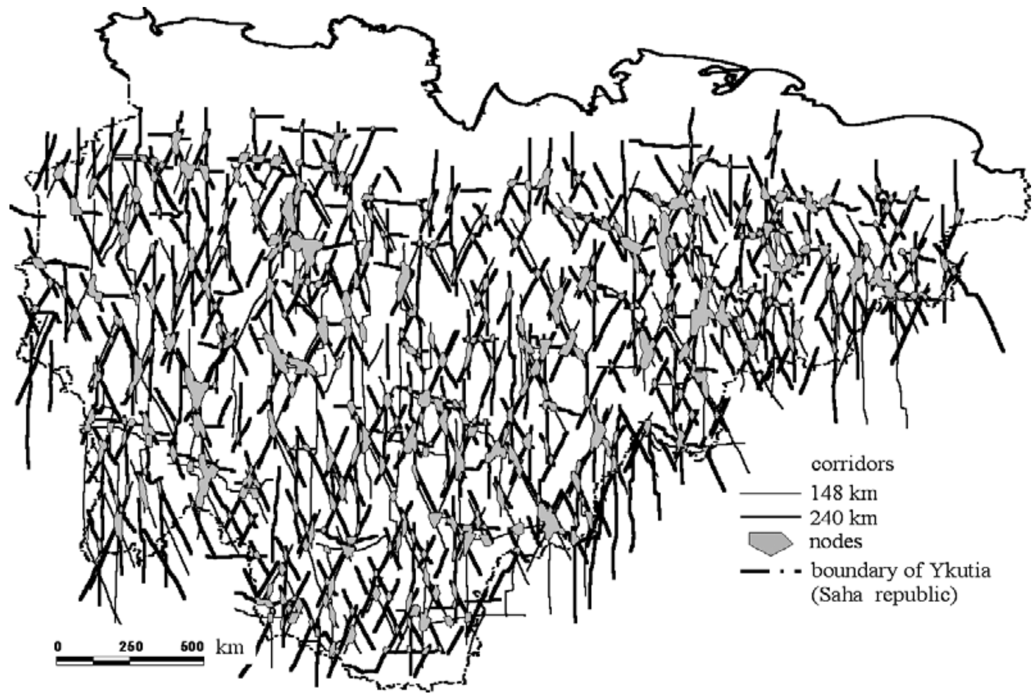

Fig. 4: Arrangement of corridors and nodes based on the wavelet analysis for two hierarchical levels

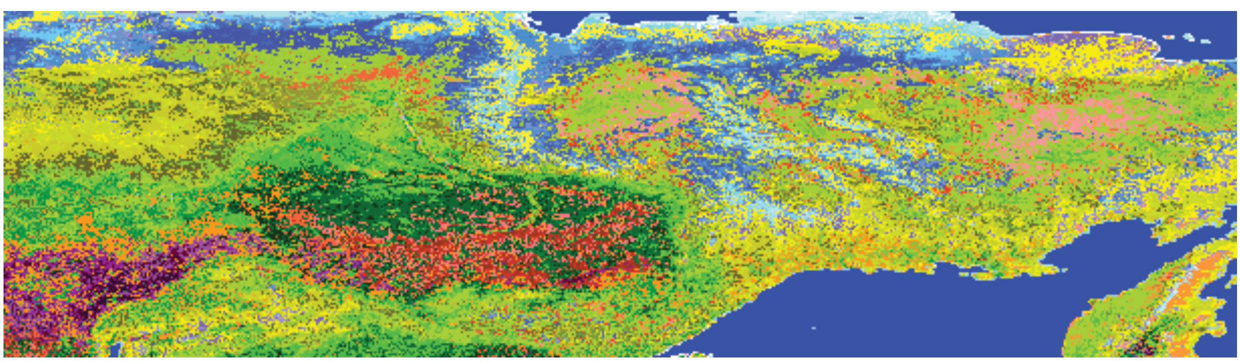

Fig. 5: Land cover types (see legend in Table 2)

N°	Land cover type	% of the land cover types	
		included into protected areas	of the total area of protected areas
1	Dark coniferous forests of southern taiga	15.3	2.0
2	Pine forests of middle and southern taiga	11.9	2.1
3	Mixed coniferous (larch, pine, Siberian pine, fir) forests of middle taiga	12.01	6.7
4	Larch forests with participation of birch forests (middle taiga)	12.2	10.5
5	Larch forests with participation of birch forests (northern taiga)	12.7	22.5
6	Larch forest-tundra with swampy complexes	10.2	5.4
7	Mountain larch forest-tundra	11.1	5.4
8	Larch sparse forests with different proportion of forest-tundra and tundra patches	11.7	14.6
9	Dwarf Siberian pine elfin woods	16.5	7.7
10	Alder-Dwarf Siberian pine elfin woods	10.8	0.5
11	Yernik and sedge-cotton grass tundra	8.5	8.4
12	Hummock tundra	7.6	1.5
13	Low bush tundra	7.6	4.6
14	Moss and lichen tundra	7.6	4.3
15	Arctic tundra, seaside tundra meadows and dispersed vegetation of high mountains	10.2	3.8
	Water bodies	-	-
	Total	11.2	100

Table 2. *Percentage of protected area according to land cover types*

5. COMPILATION OF A LANDCOVER MAP

A map of land cover types was compiled based on the SPOT VGT-S10 product bands and their proportions processed by the principal component method. The classification was made by the Euclid and Buniakowski metrics using the K-means method. In this study, a hierarchical procedure with a binary base was applied. This procedure represents the division of a sampling into two classes at the first level, then each of the obtained classes is also divided in two, and so on. Such a procedure is more convenient, since it allows one to control the content of the classes distinguished and to arrange all the classes by their similarity. If a class is homogeneous and not divided into two objects or contains only one object, it is transferred to the next hierarchical level without change.

For the investigated territory, 173 classes are categorized at the eighth level (max 256 classes). These classes differ in the proportion of brightness values of VGT bands and times associating with landscape cover types.

The identification of the type of class obtained is performed on the basis of the Vegetation Map of the USSR and data on the reflection of classes in VGT bands and NDVI. Fifteen main types of landcover are categorized (Table 2, Fig. 5).

Each the main landcover type includes several (on average, 8) classes reflecting differences in density of the plant cover through reflecting in bands, proportion of tree species, different shrub species, moistening degree, and so on. Since reflectance values per band elicit true physical properties of habitats, hence these classes are physically different. Their mosaic pattern reflects in essence the land cover diversity of particular territories. Thus, the compiled map of landcover types reflects diversity at the regional level and characterizes its present spatial distribution.

6. ASSESSMENT OF THE DIVERSITY AND COMPLEXITY OF THE YAKUTIAN LANDSCAPE

All landscape indices (metrics) (Table 3) were calculated for a sliding square of 5x5 pixels (20 km) corresponding to the lowest level of the levels determined earlier. This makes it possible to evaluate in detail the spatial variation of the land cover types by calculated indices.

”Landscape metrics” are widely used in landscape ecology [4, 13].
Each of the metrics reflects specific aspects of the complex spatial organization of a landscape; some of them duplicate each other. Correlated indices are integrated using PCA. Five independent indices are considered for the qualification of the territory:(1) a integrated index based on the indices of relative richness, patch density, entropy, and dominance; (2) diversity of relations index; (3) fragmentation index; (4) fractal dimension index, and (5) uniqueness index.

Territories apt for protection should be of extreme complexity (very highly diverse) or exclusively homogeneous (very low diverse), or with unique habitats or the most typical ones.
Thus two components are determined for each index: 10 % of the highest and 10 % of the lowest values. As a result, every index is divided into two conflicting constituents.
Each of these is divided into five levels and each level assigned a number: <0.5% (5), 0.5-1 (4), 1-2.5 (3), 2.5-5 (2), and 5-10% (1).
The number zero characterizes the rest of the territories.
As a result, we obtain maps for the qualitative estimation of landscape indices for Yakytia territory using each index.
When summarizing estimates of both constituents for all indices, we obtain a map characterizing the total value of Yakytia territory based on landscape indices as objects for protection (Fig. 7).

7. IDENTIFICATION AND QUALITY ASSESSMENT OF PROTECTED AREAS BASED ON A SET OF SELECTION CRITERIA

Maps of nodes and indices create a common system of criteria for the selection of protected areas. The qualitative estimation of the aptness of territories for environmental protection can be expressed as integration of nodes value and landscape metrics.
As a result, every node gets an integral estimate of ecological quality.
At the same time, potentially ecologically valuable areas not included in nodes are selected based on landscape indices.
A map of nodes transformed to a map of potentially protected areas is considered as the basis for protected areas identification.
It is assumed that the area of a protected area is larger than the node distinguished.
The higher the ecological quality of the node, the greater the area of the protected area selected on its basis. The area of a node increases in proportion 1/10 with the integral estimate of its ecological quality (the radial distance is 1 to 10 km). Furthermore, boundaries of the protected areas selected are refined based on spatial indices.
Every selected territory gets its own integral estimate of environmental quality.
This estimate consists of the node status and the sum of mean and maximum numbers of landscape indices characterizing the area distinguished.
The higher the integral estimate, the greater the importance of the area in the future protected area network. Although nodes provide a regular system for the arrangement of protected areas, there are territories with high values of integral quality (according to landscape indices) that do not enter the system of nodes.
These territories are also included into the designing network.
Thus, the selection of elements for a network of protected areas is carried out using all the criteria. For each protected area, a set of its land cover types and the dominant land cover type are determined. Finally, GIS of protected areas is set up.
This system contains the whole initial cartographic information, a scheme for disposition of protected areas, and a database with the necessary information about their properties.
In Yakutia, 185 areas (Fig. 6) are recommended for special protection on the basis of the accepted criteria.

Index	Formula	Description
Diversity of relations (H)	H = Hmax- I, where Hmax = 0,5Klog(2πe) is the maximal diversity at Δ = 1, I = -logΔ is the information measure of relations between pixels of sliding square, Δ is the determinant of covariation (correlation) matrix between pixels for initial bands of an image within a sliding square, K is the number of bands	The closer the relationship between VGT bands of RSD, the lower the diversity of a territory
Diversity (entropy) (E)	E = -Σpilogpi, pi = ni/N, where ni is the number of pixels of i-type in a sliding square with central point i, N is the number of pixels in a square	Entropy value will approach to zero at the significant predominance of one type
Dominance (D)	D = Hmax- H, Hmax= logK, where K is the number of types of elementary territorial patches	The more the maximal diversity differs from the measured one, the higher the dominance of one land cover type among another land cover types
Relative richness (R%)	R% = 100 (n/nmax), where n is the number of types in a sliding square, nmax is the total number of types for the whole image	The more the land cover types of images in a sliding square, the more diverse the territory
Patch density (P)	P = n/N, where n is the number of patches (contours consisting of pixels of one type) in a square, N is the number of pixels in a square	The greater the number of patches (contours) consisting of pixels of different land cover types, the higher the index value
Fragmentation (Fr)	Fr = (n-1)/(N-1), where n is the number of types that digger the square considered from neighboring ones, N is the number of pixels in a square	The more the number of individual land cover types (in relation to surroundings), the higher the degree of fragmentation
Uniqueness (informativeness) (Jav)	Jav = -1/N(Σlogpi), where pi = in/K, pi is the number of pixels of i type on the whole image containing K pixels, ni is the number of pixels of i type for the whole image, N is the number of pixels in a sliding square	The higher the number of pixels of one land cover type, the lower the uniqueness (informativeness)
Fractal dimension (FD)	FD = (7 - b)/2, where b is coefficient responsible for slope of the logSpi = a + blog(1/P), function where P is the period, Spi is the spectral power within a sliding square, a is a parameter	Reflects spatial complexity for a particular territory

Table 3. *Landscape indices used in designing a scheme for disposition of protected areas*

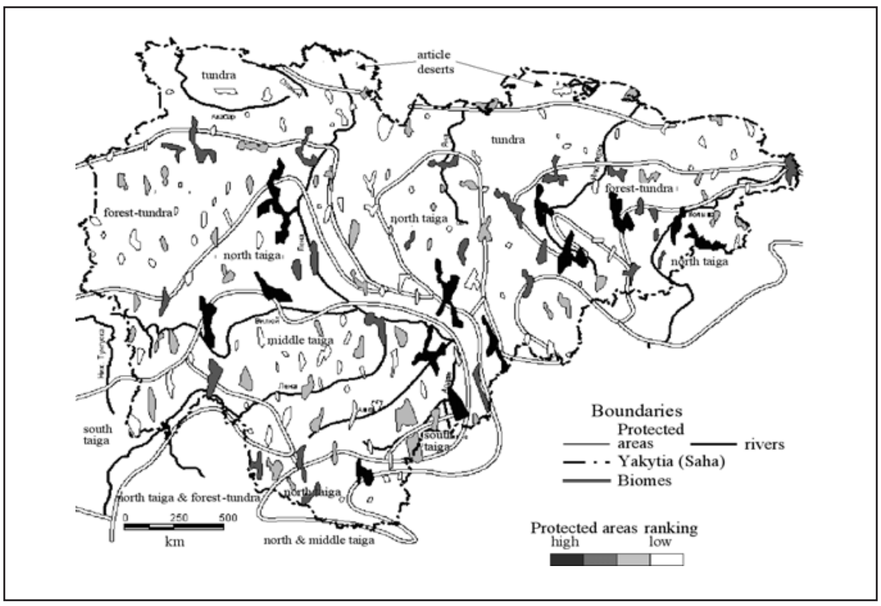

Fig. 6: *General scheme of protected area distribution and ranking in Yakutia (Republic of Sakha)*

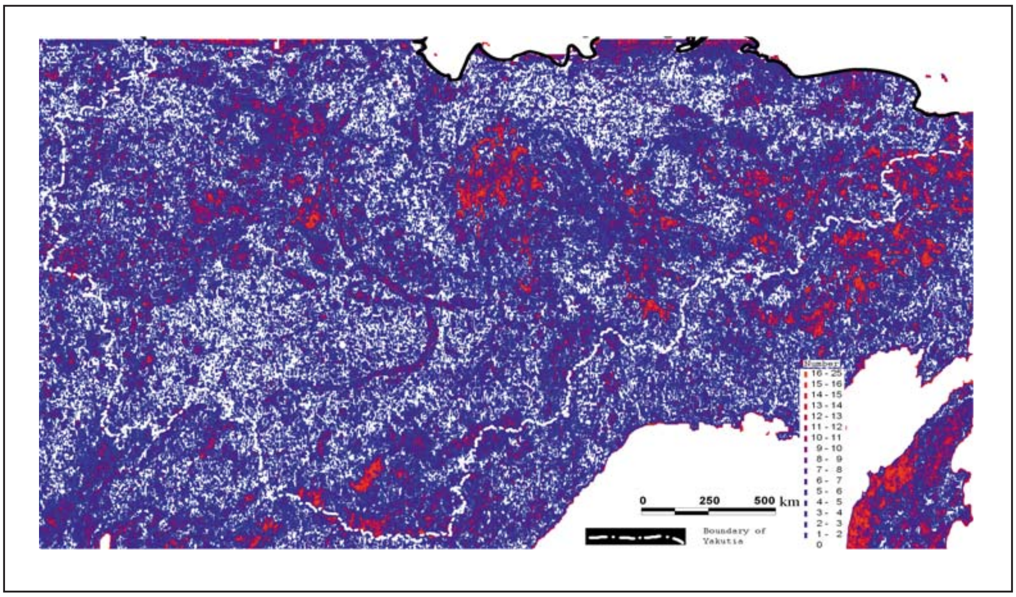

Fig. 7: Total value of Yakutia territory based on landscape indices (landcoverdiversity/homogeneity)

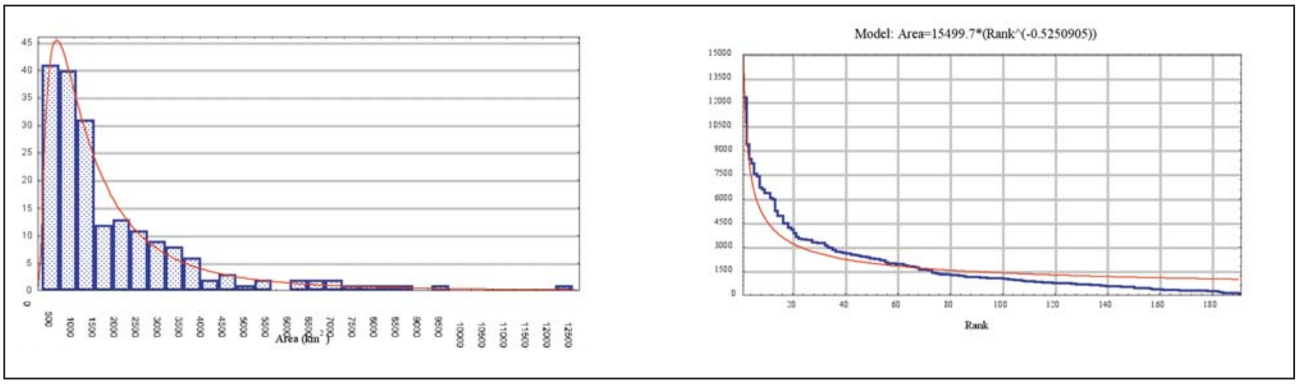

Fig. 8: Distribution of the areas of protected areas and connection of areas protected areas with their rank (order number)

The Yacutia territory is evenly covered with protected areas. About 1/3 protected areas are disposed on biomes boundary. The structure of the land cover types to protected areas is given in Table 2. As seen from Table 2, all types of land cover included into the network of protected areas cover less than 7% of the total area of these land cover types. On the whole, 11.2% of the territory in Yakutia (338 718.6 _m^2) is recommended for environmental protection. These obtained parameters make it possible to protect nearly 70% of all species [9]. For the Yakutia territory with a relatively low taxonomic diversity, there is reason to believe that approximately 100% of species populations will be protected.

The hierarchical organization areas (histogram) of a network of protected areas (Fig.8) are describing by a logarithmic normal distribution, that correspond to theoretical conceptions [12]. As a result of approximation of the area of protected areas from their rank (order number) by sedate function, received the following dependence (Fig. 8). From Fig. 8 follows, that the areas of protected areas well coordinated to sedate function and have rank distribution. The areas of the smallest of protected areas concerning model are underestimated.

The areas of average protected areas - are a little bit overestimated.

Thus, the use of a complete system of criteria that rests on SPOT VGT-S10 product and DEM enables one to elaborate a scheme for the arrangement of protected areas. The scheme allows focusing an attention to potentially the most valuable objects needing immediate legitimate registration.

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