IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Cartographo-Mathematical Modelling of Landscape Diversity for Land Use Planning Purposes

To cite this article: A Osipov *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **574** 012058

IOP Conf. Series: Earth and Environmental Science **574** (2020) 012058 doi:10.1088/1755-1315/574/1/012058

Cartographo-Mathematical Modelling of Landscape Diversity for Land Use Planning Purposes

A Osipov[1*], V Dmitriev[2], V Kovyazin[3], A Romanchikov[3]

[1]Department of Cartography, *A.F. Mozhaysky Military-Space Academy,* 13, Zhdanovskaya Street, Saint Petersburg 197198, Russian Federation
[2]Department of Land Hydrology, *Saint Petersburg State University,* 7/9, Universitetskaya Embankment, Saint Petersburg 199034, Russian Federation
[3]Department of Engineering Geodesy, *Saint Petersburg Mining University,* 2, 21[St] line of Vasilevsky island, Saint Petersburg 199106, Russian Federation

*Corresponding email: zoyaks@yandex.ru

Abstract. It is necessary to increase the informational supply of land-use planning so it causes the significance of investigation. Different cartographic materials are important part of this supply. For reaching this goal, authors developed the method of landscape diversity cartographo-mathematical modelling using GIS-technology. During the process of investigation, we got following results. We developed the method of landscape diversity modelling. We defined indexes describing landscape diversity, including: fragmentation index of natural region enclosures (amount of enclosures by landscape area unit); landscape complexity index (amount of enclosures and natural regions by its average area unit); landscape fragmentation index (ratio of average area of landscape enclosure to landscape area), pattern index (average amount of natural region enclosures to one group); Margalef and Menchinik indexes (relative abundance of natural region groups). We proposed the relationship for landscape diversity integrated index calculation and developed the quality determination scale for its evaluation. We tested the method on the East of Leningrad region including 16 landscapes (grouped to 5 types) and 1876 natural region enclosures. Landscape maps were main materials for investigation. Obtained results of landscape diversity evaluation have no contradictions with other researchers' works.

1. Introduction

One of the main properties of natural and natural-anthropogenic ecosystems is their diversity. Its research has connection with biology, ecology and geography spheres. Nowadays, biodiversity conception has realization in fundamental and applied researches. At the same time landscape diversity conception has weak development at geography sphere. It should be considered that landscape diversity is the fundamental for biodiversity conservation and condition of sustainable development of the land area.

Landscape diversity research makes possible to get knowledge in the field of environment response management of natural resources. This is essential for social and economic development of land areas. For example, it is important to consider that during high biodiversity landscape reclaiming one can design a big amount of nature use types. For land areas with low landscape biodiversity one can design one or couple of same nature use types. Therefore, landscape diversity evaluation should be obligatory part of land use planning.

Main hypothesis of investigation is following: if we create the method of cartographo-mathematical modeling of landscape diversity for land-use planning purposes then environmental safety and ecosystem stability will increase.

2. Methods and Materials

Developed method includes four parts: 1) landscape structure analysis; 2) set of landscape diversity indexes; 3) landscape diversity integrated index calculation; 4) making of landscape diversity maps. In created method, we consider landscape diversity on geosystem level as diversity of natural systems of diverse taxonomy ranks. These systems create spatial structure of scoped land area. This concept bases on system approach allowing considering land area as structured system with well-organized coordination of natural complexes.

On local level landscape structure is presented as land elements (facies – stows), on regional level as classification (facies-genus-type-class of landscape) and taxonomic (section – province – region) units. Every unit (except facies) contains set of natural regions of smaller rank [1].

In this paper, under landscape diversity we mention number and frequency of natural region occurrence. We propose to make evaluation with cartographo-mathematical methods. They allow determining landscape metric parameters using landscape maps in GIS-systems [2].

There are 6 subscript indexes and 1 integrated index. Subscript indexes are: fragmentation index of natural region enclosures (amount of enclosures by landscape area unit); landscape complexity index (amount of enclosures and natural regions by its average area unit); landscape fragmentation index (ratio of average area of landscape enclosure to landscape area), pattern index (average amount of natural region enclosures to one group); Margalef and Menchinik indexes (relative abundance of natural region groups).

We used next relationships for subscript indexes calculation [3-8]:

$$I_d = n / S , \tag{1}$$

where, I_d – fragmentation index of natural region enclosures; n – number of enclosures in landscape area; S – area of landscape.

$$I_s = n / S_0 , \tag{2}$$

$$S_0 = S / n , \tag{3}$$

where, I_s – landscape complexity index; S_0 – average area of natural region enclosure.

$$I_r = \frac{S_0}{S} \cdot 100 , \tag{4}$$

where, I_r – landscape fragmentation index.

$$I_m = \frac{n}{N} , \tag{5}$$

where, I_m – pattern index; N – number of natural region groups forming landscape.

$$I_{mg} = \frac{(N-1)}{\ln S} , \tag{6}$$

where, I_{mg} – Margalef index.

$$I_{mn} = \frac{N}{\sqrt{S}} , \tag{7}$$

where, I_{mn} – Menchinik index.

We propose next relationship for integrated landscape diversity index calculation:

$$Q = \sum_{p=1}^{m} (I - \min I) \times [1/(\max I - \min I)], \quad (8)$$

where, Q – integrated landscape diversity index; I – landscape diversity index; min I, max I – minimal and maximal landscape diversity index values; m – amount of landscape diversity indexes.

For integrated landscape diversity index values classification we developed the scale presented in table 1.

Table 1. Integrated landscape diversity index quality determination scale.

Value	Landscape diversity class				
	1	2	3	4	5
Q	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0

3. Results and Discussion

We provided the test of developed method on the East of Leningrad region with an area of 30 948 km^2. It contains 16 landscapes grouped by 5 types [9] (table 2) and 1876 natural region enclosures.

Table 2. Landscape types distribution.

N.	Landscape type	Name of landscapes corresponding to type
1	Glaciolacustrine boggy sand plain landscapes	Nizhnesvirsky, Tikhvinsky, Sudsko-Chagodsky, Yandebo-Shokshinsky
2	Morainic boggy plain landscapes	Pashsko-Syassky, Vishersky, Verkhnesvirsky, Svirsko-Olonetsky
3	Kame and kame-glaciolacustrine landscapes	Sredneoyatsky
4	Landscapes of knob moraine uplands on noncalcareous bedrocks	Kapshinsky, Svirsko-Oyatsky, Shokshinsky, Olonetsky
5	Landscapes of knob moraine uplands on calcareous-dolomite plateau	Vepsovsky, Tikhvinsko-Chagodoscshensky, Megorsky

Glaciolacustrine boggy sand plain landscapes. They took 36% of investigated area. Their surface is made up of sands and sandy loams with 1-3 m depth. Deeper there is boulder loam or varved clays. Groundwaters depth is shallow which causes bogging of the area. Bogs (mainly raised bogs) are rounded with pine forests growing on peaty gley soils. Green moss pine forests with cowberry and heater grow on places with well-drained soils. Sometimes one can found lichen pine forests too.

Morainic boggy plain landscapes. They took 26% of investigated area. Their surface is made up of boulder loam often eroded and sandy. Weakly dissected relief and weak soil permeability cause active bogging of land area. Podzolic soils generated on moraine have higher soil fertility than ones generated on sands. However, they are boulder and acidic. In natural conditions, bilberry spruce and wood sorrel forests grow on these soils. With distance from the rivers, they transform to spruce and pine haircap-moss and sphagnum forests.

Kame and kame-glaciolacustrine landscapes. They took 2% of investigated area. They relate to rugged glaciolacustrine relief. Hilly parts alternate with flat sandy plains. Relative elevation of sand hills is 50-60 meters. Hilltops are covered with dry pine forests, hillsides – with cowberry and heather pine forests. Cols are covered with haircap-moss and sphagnum pine forests or small mires and lakes.

Landscapes of knob moraine uplands on noncalcareous bedrocks. They took 19% of investigated area. They relate to rugged relief. Monticulate-morainic parts alternate with undulating morainic plains, hill groups and glaciolacustrine depressions. In general, primary spruce forests are replaced by small-leaved forests. Hollows between hills are covered with mires or small lakes.

Landscapes of knob moraine uplands on calcareous-dolomite plateau. They took 17% of investigated area. Western part of plateau is rugged. It relate to beds of Oyat, Pasha, Kapsha, Syas and other rivers. Spruce, spruce-small-leaved and small-leaved forests dominate in vegetation. One can observe broad-leaved species on particular small-leaved forest sites with surface bedding of calcareous bedrocks.

During landscape diversity evaluation, we chose natural region types that can describe landscape distinctiveness as objects of evaluation. It lets correctly describe all properties of investigated environmental area.

Landscape maps are main material for this research. We calculated subscript landscape diversity indexes using (1)-(7) relationships and provide results in table 3.

Table 3. Subscript landscape diversity indexes.

Code	Landscape	S_0	Landscape diversity indexes					
			I_d	I_s	I_r	I_m	I_{mg}	I_{mn}
23	Sredneoyatsky	9.18	0.11	6.75	1.61	15.50	0.47	0.17
7	Nizhnesvirsky	14.74	0.07	12.55	0.54	61.67	0.25	0.06
34	Svirsko-Oyatsky	15.35	0.07	12.83	0.51	49.25	0.37	0.07
35	Shokshinsky	13.83	0.07	1.23	5.88	8.50	0.18	0.13
32	Verkhnesvirsky	14.44	0.07	8.24	0.84	59.50	0.40	0.10
33	Olonetsky	13.82	0.07	6.44	1.12	29.67	0.28	0.09
31	Svirsko-Olonetsky	16.18	0.06	4.14	1.49	22.33	0.29	0.09
30	Yandebo-Shokshinsky	7.79	0.13	16.05	0.80	31.25	0.44	0.13
36	Megorsky	10.21	0.10	5.68	1.72	19.33	0.31	0.12
8	Tikhvinsky	14.84	0.07	19.68	0.34	73.00	0.36	0.06
16	Pashsko-Syassky	24.96	0.04	6.73	0.60	42.00	0.36	0.06
26	Tikhvinsko-Chagodoscshensky	16.75	0.06	11.04	0.54	61.67	0.25	0.05
24	Kapshinsky	14.86	0.07	6.33	1.06	23.50	0.41	0.11
25	Vepsovsky	10.42	0.10	14.97	0.64	39.00	0.41	0.10
9	Sudsko-Chagodsky	17.77	0.06	9.68	0.58	57.33	0.25	0.05
17	Vishersky	12.68	0.08	6.78	1.16	43.00	0.14	0.06

After subscript landscape diversity indexes determination we calculated integrated landscape diversity indexes using (8) relationship. In addition, we made classification by table 1 materials (figure 1).

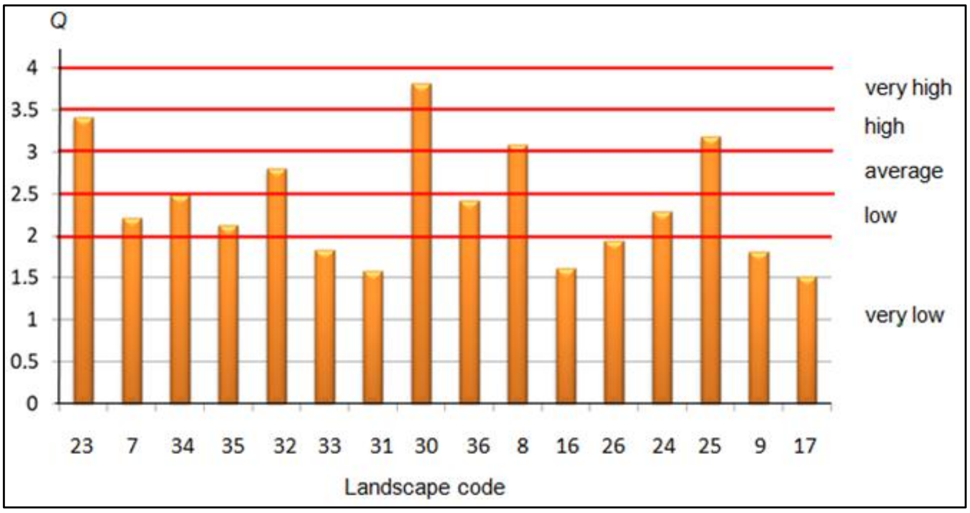

Figure 1. Distribution of integrated landscape diversity index.

After that, we vectored landscapes using Mapinfo software. In addition, every landscape got semantic information according to its properties (figure 2). Thematic map of landscape diversity was created by classification of landscapes (figure 3).

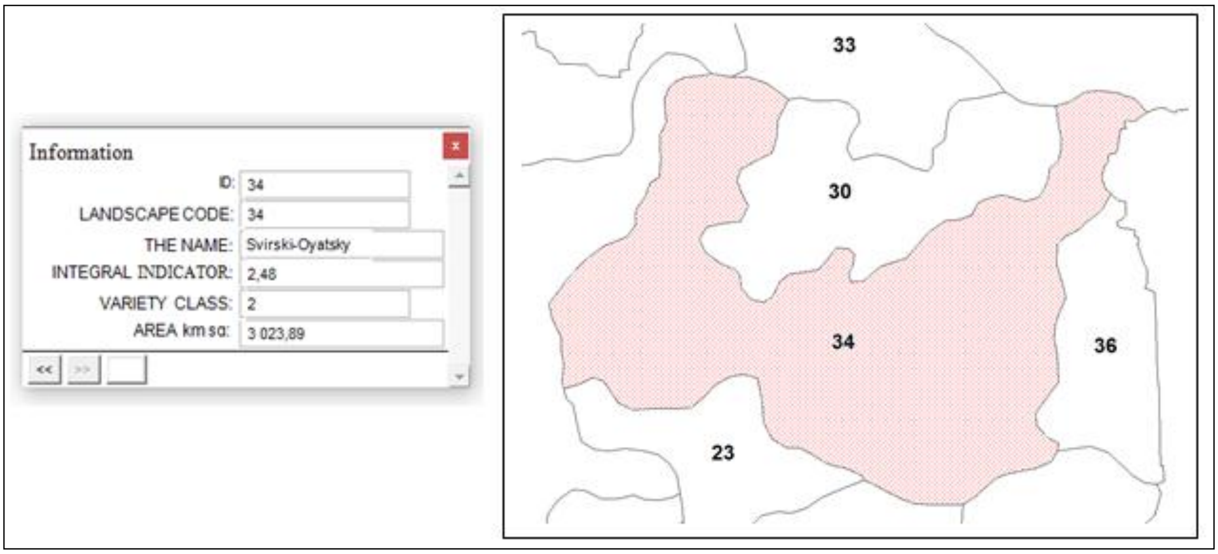

Figure 2. Semantic information of landscape diversity.

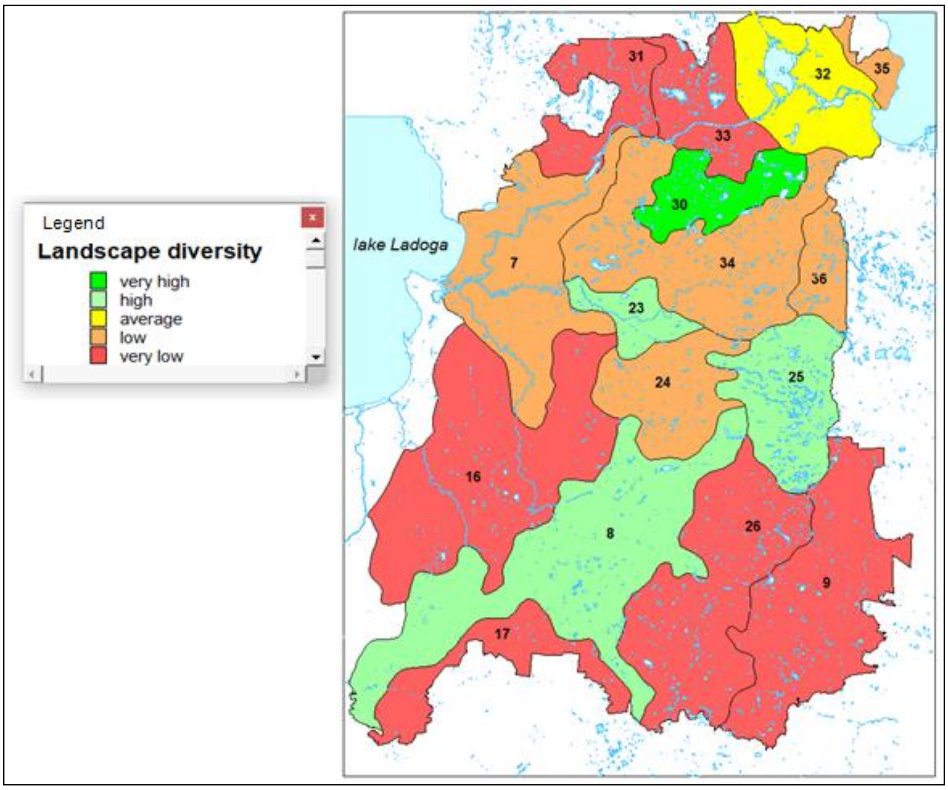

Figure 3. Landscape diversity map of eastern part of Leningrad region.

4. Conclusion

Importance of research for land use planning is essential because of landscape diversity GIS-mapping method creation. Landscape diversity maps allow making environmentally based decisions in the field of land use development. It considers environmental opportunities of socio-economic functions accomplishing.

Approaches rooted in this method base on researches provided by authors since 2003 to present [10-12]. They got an approval on number of Russian and international conferences.

Obtained results of landscape diversity evaluation have no contradictions with other researchers' works.

Future research should be carried out in the field of adjustment of created method to other regions considering its physiographic aspects. In addition, we should improve approaches to landscape diversity indexes calculation.

Acknowledgments

The reported study was funded by RFBR, project number 19-05-00683-a.

References

[1] Marcinkevich G and Schastnaja I 2005 Evaluation of Landscape Diversity of Natural and Natural-Anthropogenic Ecosystems in Belarus. [Ocenka landshaftnogo raznoobraziya prirodnih i prirodno_antropogennih kompleksov Belarusi – in Russian] *Nature Management. Institute of Nature Management of the National Academy of Sciences of Belarus* **11** 98-105

[2] Purdik L, Chervjakov A and Shibkih A 2008 Factors and Mapping Analysis of Landscape Diversity in Altai region. [Faktori i kartograficheskii analiz landshaftnogo raznoobraziya territorii Altaiskogo kraya – in Russian] *Geography and Natural Resources* **1** 156-161

[3] Sokolov A 2014 Landscape Diversity: Theoretical Bases, Approaches and Studying Methods. [Landshaftnoe raznoobrazie: teoreticheskie osnovy, podhody i metody izuchenija – in Russian] *Geopolitics and Ecogeodynamics of Regions* **1** 201-213

[4] Artemova S and Alekseeva N 2018 Landscape diversity in Penza region as condition of sustainable development. [Landshaftnoe raznoobrazie Penzenskoi oblasti kak uslovie ustoichivogo razvitiya – in Russian] *Proc. Int. Conf. on Current Landscape-Ecological State and Problems of Optimization of the Natural Environment of the Regions (Voronezh)* vol 1 (Voronezh: ISTOKI) pp 292-293

[5] Chernykh D 2011 Quantitative Assessment of Complexity and Landscape Diversity of the Russian Altai. [Kolichestvennaya ocenka slojnosti i raznoobraziya landshaftnogo pokrova Russkogo Altaya – in Russian] *Izvestiya of Altai State University* **3-2** 60-65

[6] Ganzej K and Ivanov A 2012 Landscape Diversity of Kuril Islands. [Landshaftnoe raznoobrazie Kurilskih ostrovov – in Russian] *Geography and Natural Resources* **2** 87-94

[7] Bonfanti P, Fregonese A and Sigura M 1997 Landscape Analysis in Areas Affected by Land Consolodation. *Landscape and Urban Planning* **37** 91-98

[8] Jaeger J 2000 Landscape Division, Splitting Index and Effective Mesh Size: New Measures of Landscape Fragmentation *Landscape Ecology* **15** 115-130

[9] *Nature of Leningrad Region and its Protection* 1983 [Priroda Leningradskoj Oblasti i ejo Ohrana – in Russian] (Leningrad: Lenizdat)

[10] Osipov A, Arefyev N and Dmitriev V 2003 Ecological-Geographic Environmental Evaluation for Protected Areas Designing. [Ekologo_geograficheskaya ocenka sredi pri proektirovanii osobo ohranyaemih territorii – in Russian] *St. Petersburg State Polytechnical University Journal* [Nauchno-Tehnicheskie Vedomosti SPbGPU **4(34)** 181-187

[11] Osipov A and Petrov A 2016 Creation of Ecological Framework for Land Use Planning. [Metodika obosnovaniya ploschadi ekologicheskogo karkasa pri razrabotke shem territorialnogo planirovaniya – in Russian] *Proc. Int. Conf. on Ecological Balance: Geographic Areal Structure* vol 1 (Saint Petersburg: Pushkin Leningrad State University) pp 50-53

[12] Dmitriev V, Terleev V, Nikonorov A, Ogurtsov A, Osipov A, Sergeyev Y, Kulesh V and Fedorova I 2020 Global Evaluation of the Status and Sustainability of Terrestrial Landscapes and Water Bodies. *Landscape Modelling and Decision Support* vol 1 ed W Mirschel *et al* (Cham: Springer Nature Switzerland AG)