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COHERENCE OF LAND SURFACE LAYOUT AS INTANGIBLE ENVIRONMENTAL RESOURCE (VOOREMAA LANDSCAPE PROTECTION AREA, ESTONIA)

Vooremaa Landscape Protection Area provides a specimen of native Estonian agricultural lands, alternating with picturesque moraine lakes. The overall visual environment within this area was basically changed by glacial agents and, hereafter, by cultural activities, such as crop farming. Topography consists of about 100 drumlins (some of them are cultivated), as well as depressions, filled with lakes and covered by forests and grasslands. A rich combination of the mentioned factors determined the study area selection. There was accepted, that the harmony, or pleasing organization of distinguishable units of visual environment (with no attention to their colours or textures, but regarding their geographical meaning only), depends on the system effect: the more complexity of the overall system exceeds the algebraic sum of the complexity of its components, the more its organization does. In this way, some developments of information theory could be applied to the analysis of visual environment (from top view), similarly to the analysis of the text (considering units of land relief, land cover, and land cover relief, or a land surface in total, as the symbols of some alphabet, and their diversity within the floating circle — as words, consisting of the symbols). Since mentioned notions of organization and harmony are frequently implied in the concept of landscape coherence, the latter term was used as a fixed and well-known one in the landscape and environmental aesthetics. Hartley's formula was used to compute the coherence of the land surface layout and the respective regionalization within the study area and surroundings. The effectiveness of the proposed method for representation of visual harmony was non-rigorously verified with transect of Google Street View panoramic photo series, while everyone is welcomed to use the Google Street View to compare the presented results with his own conclusions. There was found, that the proposed index coherence of land surface layout reflects the organization and visual harmony of the scene. A colouristic aspect of the visual harmony of the environment for the same study area was taken into consideration in another article, prepared for Bulletin of V. N. Karazin Kharkiv National University.

Keywords: coherence, environmental quality, Hartley formula.

Олександр Карасьов

КОГЕРЕНТНІСТЬ КОНФІГУРАЦІЇ ЗЕМНОЇ ПОВЕРХНІ ЯК НЕМАТЕРІАЛЬНИЙ РЕСУРС ДОВКІЛЛЯ (ЛАНДШАФТНА ПРИРОДООХОРОННА ТЕРИТОРІЯ ВООРЕМАА, ЕСТОНІЯ)

Потреби ландшафтного планування та менеджменту, відповідні до цілей сталого розвитку економіки, суспільства та довкілля більшості країн світу, вимагають встановлення кількісних закономірностей візуальної якості довкілля. З географічних позицій типовим є вивчення складної організованості природних феноменів, яка описується за допомогою теорій систем та інформації. Використавши системний підхід до візуальних феноменів довкілля як таких, що спрощено складаються з форм рельєфу, типів земного покриву та рельєфу земного покриву, можна визначити індекс когерентності земної поверхні, який пропонується у даній статті.

Ключові слова: когерентність, якість довкілля, формула Хартлі.

Александр Карасёв

КОГЕРЕНТНОСТЬ КОНФИГУРАЦИИ ЗЕМНОЙ ПОВЕРХНОСТИ КАК НЕМАТЕРИАЛЬНЫЙ РЕСУРС ОКРУЖАЮЩЕЙ СРЕДЫ (ЛАНДШАФТНАЯ ПРИРОДООХРАННАЯ ЗОНА ВООРЕМАА, ЭСТОНИЯ)

Потребности ландшафтного планирования и менеджмента, соответствующие целям устойчивого развития экономики, общества и окружающей среды большинства стран мира, требуют установления количественных закономерностей визуального качества окружающей среды. С географических позиций типичным является изучение сложной организованности природных феноменов, которая описывается при помощи теорий систем и информации. Использовав системный подход к визуальным феноменам окружающей среды, упрощённо состоящих из форм рельефа, типов земного покрова и рельефа земного покрова, можно определить индекс когерентности земной поверхности, который предложен в данной статье.

Ключевые слова: когерентность, качество окружающей среды, формула Хартли.

Introduction. Environmental scientists (as well as geographers) are concerned not only with a chemical or energetic pollution but also with a degeneration of the visual environment quality, reduction of geo- and biodiversity, caused by various human and social activities. Therefore, a deficit of natural beauty has determined a growing interest in the intangible values of nature for the last centuries (first of all, environmental and landscape aesthetics and attractiveness, variety of cultural landscapes or ecosystem services) [1, 3, 7]. American practitioners of land management over the course of decades use the concept of visual resources, developing concise concepts and quantitative methods of their identification, inventory, assessment [1]. We synthesized and analysed the trend of the intangible values of nature implementation into the geographical domain earlier, considering them as the intangible natural resources and arguing, that the reduction of their underestimation is possible only within quantitative and utilitarian approaches. Ukraine and Estonia know very well the failure of socialistic experiments with property rights. We argue that the development of sustainable landscape policies, management, and planning strategies, as well as an effective nature protection, require a correct estimation of natural values. Here we shift to the wider concept of intangible environmental resources, as conditioned by the need to consider the culturally-driven physical environment as well. Briefly, favourable conditions of the Earth environment, supporting human well-being through informational interaction with it, could be called intangible environmental resources. In this way, such environment of high quality and values require protection, while areas of the environment of reduced quality require an adequate response in the form of planning and management. To prevent the loss of the visual environment quality, quantitative data must be provided, whenever possible.

The research context could vary within several directions of theoretical background: landscape and environmental approaches, or their combination. M. Antrop traces different tendencies in the world landscape science, moving towards increasing addition of some subjective components to landscape notions [2]. To avoid difficulties related to this controversial subject, we distinguish here the landscape and the perceived environment. We argue, following European Landscape Convention (in some extent), J. Granö [5], M. Antrop [2] and numerous humanistic geographers, that the landscape is a mental image, an intangible product of individual experience in physical environment, a dynamic holistic phenomenon, making perceptive and aesthetical sense and values. In its turn, tangible perceived environment (land surface with water bodies and sky) , obviously, exists physically, measurable with objective scientific methods. The problem of this paper is a quantification of the visual environment harmony, namely its coherence as a measure of harmoniously complex organization of visual scene (for land surface only — skyscapes are beyond the scope of this study) with a concept of landscape in mind as an intangible environmental resource. Textural organization of the land surface is within the delimitations of the study as well.

Initial conditions. As it is proven by independent environmental psychologists [4], the process of environment perception is based on quick eye movements, called saccades, shifting between the so-called points of fixation. The more visual scene contains the points of fixation, the more values are added to this scene. Homogeneous visual scenes without vertical elements, consisting of one or a few distinguishable units, are proven to have the lowest scores of landscape preferences and values in practice of visual resources assessment [1, 6]. On the other hand, increasing the complexity of visual scene creates an inverted-U function of values and preferences; in some point, the complexity becomes excessive and visual environment is perceived as too visually «aggressive» or «messy» (for example, in many urban environments) [6, 7]. Such conclusions are in accordance with dominant theories of landscape preferences (the biophilia by O. Wilson, Appleton's prospect-refuge theory, Berlyne's and Wohlwill's theories of environmental aesthetics, information processing theory by R. and S. Kaplan, Gibson's theory of affordances) [7]. R. and S. Kaplan, giving a credit to complexity as a factor of landscape preferences, have found that coherence is more significant in explaining preferences, than complexity [6]. In this way, we can assume that the coherence of visual scene depends on distinguishable units of the visual environment with no regard to colours, while colour diversity and harmony are also recognized as important factors of landscape values [1, 5, 7]. B. Rodoman emphasizes, that people tend to discretize the continual perceived environment (at least because of language delimitations) [10]. The act of perception, having information nature, removes the uncertainty of the observer concerning the output states of geospatial systems. Yu. Markov argues, that the behaviour of the system, expressed in form of its states (or output characteristics) could be considered as an information process, reflecting the structure, inner relationships and the regularities of the system [9]. He draws parallels between a set of system states and the alphabet as a source of uncertainty. It is not surprising that the natural complexity of environment was already described within the concepts of information and cybernetics by A. Armand, Yu. Puzachenko, et.al. At the same time, despite the fact that natural complexity could be quantified with a calculation of the amount of information after different authors, the natural organization is not necessarily reflected in the information measures (no matter, Hartley's one, Shannon's one, or others). Since the coherence is a measure of harmony and overall organization of visual scene, there is no point in the simple use of information measures (at the same time, Shannon diversity index is widely used nowadays as an indicator of visual quality of environment). There are two possible ways to measure the organization of some system: with a logarithmic measure of Kolmogorov complexity (the shortest programme code, conversing one set to another) [9], and with information measures of emergence, proposed by E. Lutsenko [8]. We adapted the idea, discussed by E. Lutsenko, for purposes of GIS-analysis of the visual environment, represented as a combination of land relief, land cover and land cover surface units (land surface layout in total).

The purpose of the article is to quantify coherence of land surface layout, proceeding from the information by Hartley within the study area (Vooremaa protected landscape in Estonia). This is our second application of E. Lutsenko's Hartley emergence index for purposes of land surface coherence quantification (the first attempt for physiography of The Peneda-Gerês National Park (Portugal) is described in the paper, being prepared for publication).

Presentation of the main material. To adequately model the layout of the environment perceived visually, there was decided to take into consideration discrete units of land relief, land cover and relief of land surface (in other words, relief of vegetation and artificial surfaces as the vertical dimension of the visual scene). In this way, digital elevation model (DEM), land cover model and digital surface model (DSM), covering Vooremaa protection area and some surrounding buffer areas, were processed.

DEM, derived from raw material with grid sizes of 10 m, was provided by the Estonian Land Board (resolution was reduced to 15 m to match the one of land cover). Estonian Land Board collected LIDAR elevation data of excellent quality for this area in 2010 and 2014 with Leica ALS50-II scanner. Flying was at altitude 2400 m. Landscape-scale discretization presumes selection of mesolandforms, so we applied landform classification with the respective module in GIS SAGA, using method Iwahashi & Pike (2007) for pre-processed digital elevation model. Four classes of mesolandforms were obtained after clustering, according to three criteria: slope steepness, texture coarseness and extent of convexity. The 1st class describes land relief units with gentle slopes, coarse textures and low convexity. The 2nd class contains land relief units with gentle slopes, coarse textures and high convexity. The 3rd class means land relief units with steep slopes coarse texture, low convexity, while the 4th — with steep slopes, coarse textures and high convexity.

DSM was processed from the raw LIDAR data, requested for Vooremaa protected area with a spatial resolution of 1 m; DSM was generalized to 15 metres to match land cover resolution. The Terrain Clustering module in GIS SAGA was applied for DSM and 5 height classes were defined in total. Classes 1 and 4 cover the flattest and the largest locations, including water bodies and agricultural fields with young crops; classes 2, 3 and 5 belong to the most diverse surfaces: shrubs, forests and some parts of wetlands.

The land cover model was processed from cloud-free Landsat-8 OLI satellite image for 14.06.2014. This image was radiometrically calibrated, atmospherically corrected, and pan-sharpened to spatial resolution of 15 metres; then the supervised classification was performed and 6 classes were obtained, as follows: water bodies, forests, crops and open soil (for young crops), other crops and grassland (for mature crops and dense grass), wetlands, artificial surfaces (settlements and infrastructure).

After that, Hartley's information formula (1) was applied to the Iwahashi & Pike mesolandforms, clusters of DSM and land cover classes. Hartley's formula is a particular case of Shannon's formula for equal (the highest) probabilities of element of the plurality to appear with (Hartley's measure is structural one, while Shannon's information uses probabilistic approach), and it states, that the amount of information (I), which is needed to determine a particular element of text/landscape is the binary logarithm of the total number of elements (N):

$$I = \log_2 N = n \log_2 m, \qquad (1)$$

where N is a possible number of different spatial units; m is all number of spatial units; n is the number of spatial units in one part of a set (for example, in a cell of a regular grid or in one position of floating circle).

Focal Statistics toolbox in ArcMap 10.4.1 was used to define the number of landform classes in floating circle with a diameter of 21 pixels. The diameter of the floating circle was chosen as a compromise, attempting to show the homogeneity of landscape patches (in terms of classical landscape ecology) and catch the complexity of landscape scene (floating circle covered 315 metres on each raster, comparable with a scale of common non-panoramic visual scenes). Obtained values were multiplied with the binary logarithm of the total number of each raster classes.

Following E. Lutsenko, there was proposed, that Hartley's amount of information in the raster of classes, combining DEM, DSM and land cover classes will be more than the algebraic sum of information in DEM, DSM and land cover classes, taken separately. It is argued , that this ratio represents the coherence of land surface layout. In GIS, this operation can be presented as follows (Formula 2):

$$\varphi = \frac{I_{DEM}, DSM, land\ cover}{I_{DEM} + I_{DSM} + I_{land\ cover}}, \qquad (2)$$

where φ — coherence of land surface layout, I — Hartley's information.

Thereby, this operation was performed for the DEM, DSM and land cover models; the resulting model of environmental visual coherence is presented by fig.1.

The obtained model of coherence was verified with transect of 6 points, following Google Street View along one of the roads (fig.2). Screenshots of Google Street View were collected in this points and their content was compared to the coherence score.

In this way, computed coherence scores seem to be reliable enough. Scenes with a lack of land cover diversity, flat land relief and monotonous relief of vegetation (agricultural fields, points 2 and 6) have the lowest score of visual coherence. Scenes with a few types of land cover and several dominant vertical elements (high trees) tend to have moderate values of coherence (points 3 and 5). In their turn, scenes with significantly developed forest land cover represent the highest coherences scores (points 1 and 4). The proposed modeling will be further verified and clarified.

Discussion

It is easy to see that the substantiated index of coherence depends on the spatial discordance of land relief units, land cover, and land cover relief. Taken together as a one set, they mutually increase the complexity of the resulting scene of the visual environment. When one landform contains several types of land cover with a respective diversity of the land cover surface units, or, moreover, these units are composed of several landforms as well, the coherence index increases and indirectly represents the organization of the visual environment layout. Indeed, taking into consideration one pixel as an elementary unit of our study, it is associated with three different dimensions, diverse and complex in their own way, their system behaviour provides much more uncertainty concerning the visual output of the scene than the algebraic sum of such uncertainty, as it has been proved above.

The obtained results are in accordance with findings by Casalegno et al. (2013) — spatial variation in cultural landscape services tends to be poorly or negatively correlated with that in many other ecosystem services [3]. This means, that lands of agricultural use with simplified land cover and located on the flat relief localities, obtain the lowest scores of coherence. Also water bodies, according to the applied techniques, obtain low scores of coherence, since they are large and homogeneous. Most likely, they should be taken into consideration somehow in a positive way in further analysis. The results of coherence and colour harmony calculation are valid only for the dates of DEM, DSM and satellite imagery (in case of satellite imagery even day time matters), since the modeled visual environment has its circadian, annual and other dynamics. In further research we are going to work with multitemporal satellite imagery, attempting to catch at least phenological and long-term changes of visual environment. What is more, the observation angle and limited resolution abilities of satellite sensors impose the respective restrictions on their use for land cover analysis. However, the proposed techniques dealing with such sort of data may provide, despite all the unavoidable reductions of the physical environment in modeling, a reliable support with objective indicators for mapping of visual quality of the environment.

Conclusions. As a result, we have achieved our initial aim and computed scores coherence of land surface layout within Vooremaa landscape protection area in

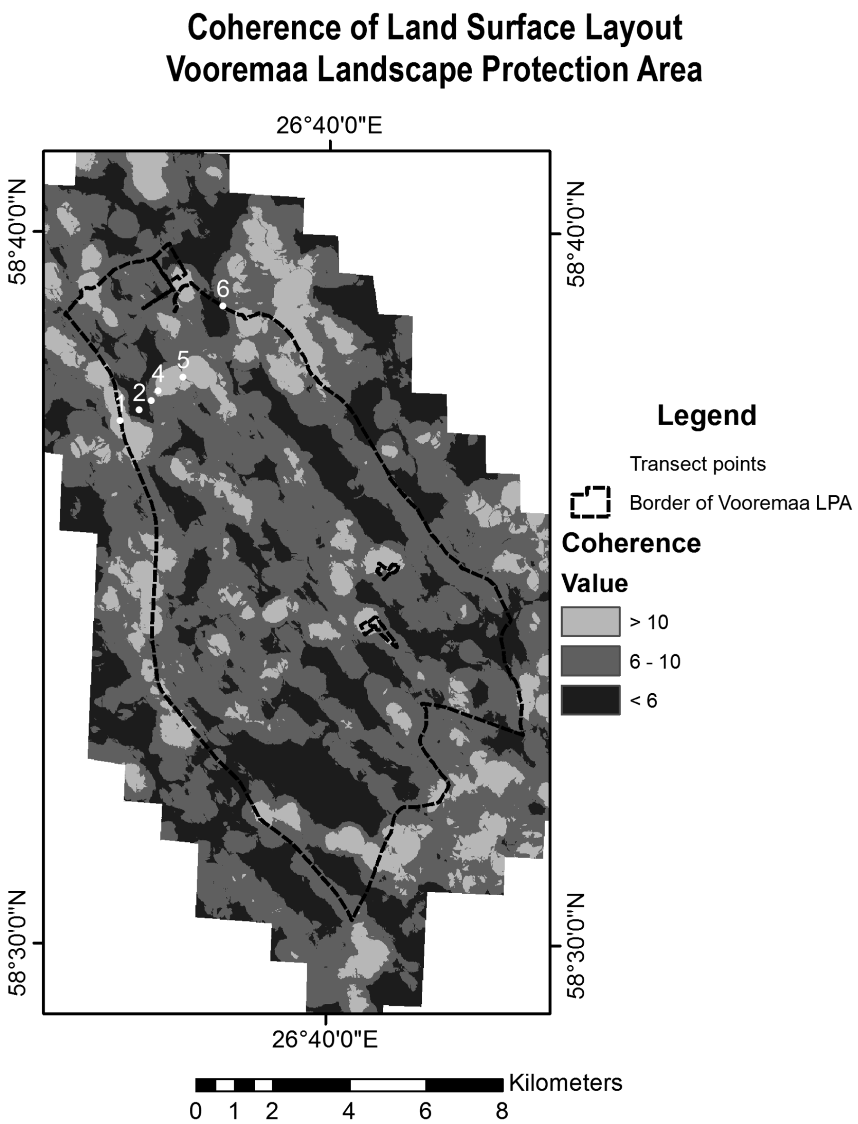

Fig.1. Map of coherence score for land surface layout

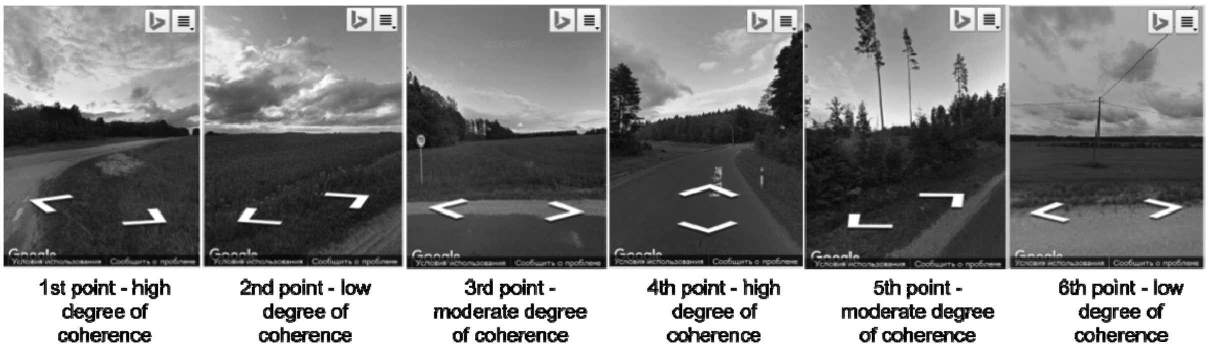

Fig.2. Photos from Google Street View, comparing to the coherence score

Estonia. The proposed new indicator of visual environment quality could be used for identification and inventory of intangible environmental resources, related to visual landscape perception. These results also could be used in practices of landscape planning and management, because they provide easy-to-use spatial and quantitative framework for the assessment of the visual quality of the environment.

Prospects for further research include multitemporal modeling and simulation of future conditions for proposed indicators, as well as deeper verification of their representativeness. The simulation would allow to forecast and develop scenarios of land use effectiveness within the concept of weak sustainability. Decision-makers in land use will benefit from clear information about the loss of natural visual quality as an asset of natural capital under the impact of particular agricultural and other practices and growth of other kinds of capital. Thereby, the proposed indicator is essentially important for surmounting the underestimation of visual environment role in our life and the life of our future generations.

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