GIS-ANALYSIS FOR LANDSCAPE AND WATERSHED MODELING AT REGIONAL LEVEL

Prof. Dr. Eugeny Kolbowsky
Assoc. Prof. Dr.Oxana Klimanova
Lomonosov Moscow State University, **Russia**

ABSTRACT
The article describes the experience of landscape sites (geotopes) and elementary watersheds modeling with the ARCMAP tools for determination of valuable forests in poorly studied areas. The authors substantiate the possibility and expediency of simultaneous use of two different matrices which represents various properties of land cover - geostationary landscape sites matrix and geodynamic river basins matrix. Biodiversity is determined by the landscape heterogeneity. Landscape units can be obtained via geomorphometry-and-landform tools in GIS software. Elementary river basin is functional unit of the landscape, providing its integrity with the transfer of matter and energy. Hydrological tools in GIS can implement the watershed modeling.
Modeling involves a number of consecutive and interconnected operations. Primary geomorphology modeling includes altitude levels, slope, aspect, plan and profile curvature, topographic index, height above the river, flow direction, flow accumulation, stream raster. Secondary geomorphology modeling is a combination of primary rasters to obtain landscape sites matrix. Vegetation cover modeling consist of spatial imagery unsupervised classification for the generation of spectrally different vegetation classes. The final step - calculation of integrated (geotops and vegetation classes) diversity via Zonal statistic tool. The river basins with the highest potential level of biodiversity may be proposed for protection as one of the High Conservation Value Forests (HCVFs) categories.

***Keywords**: GIS-modeling, landscape sites, elementary catchments, potential biodiversity*

INTRODUCTION

Absence or insufficiency of data on extensive regions, for example such as rain equatorial forests of Africa or the coniferous and broad-leaved woods of the East of Eurasia is a serious problem of preservation of a biodiversity. Raw forest exploitation often considerably advances actions for protection of valuable ecosystems in these regions. Therefore it is so important to develop preventive methods of a potential assessment of a biodiversity not only at the level of species, but also at the valuable landscape level.

The innovative methods allowing to predict a potential biodiversity on the basis of the well-known in ecology approaches – landscape- watershed integral analyst – became the matter of particular importance, especially in the conditions of the extensiveness territory and deficiency of data on a forest cover.

From the modern positions biological diversity of forest ecosystems (at the level of species and the level of biocenosis) is a function of the whole set of the factors [6, 7] providing, first, structural differentiation of a forest cover according to the relief forms and the soil`s type, secondly, their functional connectedness within the borders of the river basins. Complex of abiotic factors which create the initial spatial differentiation of the environment, forming a variety of conditions for biota – so called «sites», in Russian geographical tradition define as a «geotops». The mosaic of geotops reflects so-called geostationary landscape model [2,3] - more or less steady surface plasticity of the territory which (in interaction with other factors) generates characteristic patterns of forest cover of the mountain slopes, hillside and plains, river terraces and floodplain.

The matrix of watersheds reflects the geodynamic (geosimulation) landscape model [2, 8] - moveable «slope-and- runoff» interaction and interrelationship between sites (geotops) on the top and different parts of the slope and between the headwaters and channel of the main rivers.

GENERAL ALGORITHM OF MODELING

The proposed approach includes the sequence procedures, to simulate the matrix of the watersheds for the streams of specified size and order (1), to identify a mosaic of landscape sites (geotopos) (2), to reveal a structure of the forest cover through the distance image interpretation or by using the forest inventory data (3), to determine the correlation between the sites and a forest cover types (4), to calculate the variety of sites and forest types within watersheds (5), and, finally, to select river basins with High Conservation Value Forests (HCVF).

As a source material for modeling was used a grid elevation (Aster GDEM) of the territory; to further analyze the medium – sized images of the sensor Landsat and standard forest inventory data in digital (vector) format. Below content of separate stages of model operation are stated.

WATERSHED DELINEATION AND RIVER BASINS MATRIX MODELING

The «Hydrology» toolset of ARCGIS package are used for modeling of river basins during the two last decades, and the content of a separate script almost does not change: there are four interrelated and consistently derived thematic raster: flow direction, flow accumulation, streamraster and pour points raster. There are many descriptions and official instructions for using the «Hydrology» toolset [14], however, our experience detects the presence of important (for further modeling) and disputable problems.

On the Earth's surface there are actual catchments of a certain dimension exist, which contain the watercourse (and not just the creek or ephemeral channel) and can be considered as river basin of the first order according to Strahler, encoding i.e., represent a elementary functional unit of drainage system. This circumstance is the reason for kind of expert choosing the minimum area of the «elementary catchment» that can «generate» a watercourse - a parameter that is put in the expression of «map algebra» when reclassifying the raster «flow accumulation». However, this task does not have a "perfect" solution in the framework of a geomorphometrical model for a number of reasons, among which [4, 5]:

- the differences of the functional conditions for watercourses in the headwaters of the main river, and in the side tributaries (these differences are just considered by the Shreve river network coding but ignored in the Strahler encoding);
- the dependence of the elementary streams beginning from the character of Quaternary sediments, and biotic components of the landscape (soils, vegetation),
- the complexity of the unambiguous delineation of permanent and ephemeral streams.

Therefore, for delivering an accurate result it is advisable to use data from the satellite imagery interpretation of the first order watercourses.

PRIMARY LANDSCAPE SITES MODELING

At the current level of geographic information systems development the modeling of landscape sites cannot be completely automated, because it is connected with necessity of preliminary expert analysis of the considered factors of landscape differentiation and determination of their hierarchy (the problem of «leading factor» in the classic landscape theory [2,8]).

For majority of plain and mountain landscapes the most significant characteristic are the correspondence between the absolute altitude (altitude zones) and relative height above local bases of erosion, these features can be displayed through the use of parameters of the absolute height gradients and the height above the river (HAR) [3,9,1011].

So, for mountain and semi-mountain areas, the set of considered factors should include elevation, exposure (due to differences in the thermal regime on the northern and southern slopes or in the moisture regime on the eastern and western slopes), the slope (a parameter that is often responsible for allocation of the slope fragments, and controls the degree of involvement of other factors, for example – exposure) [11, 13]. For the hilly plains curvature of the slopes is manifested the dispersion or concentration of the substance and energy fluxes [9, 12]. The differentiation of ridge and valley surface are identified more efficiently with the assistance of a topographic index (TPI). For large river valleys with several levels of terraces and tricky arranged floodplains it is important to consider the height above the nearest drainage and the Euclidean distance to the main river. The main thematic raster layers used during modeling are shown in figure 1.

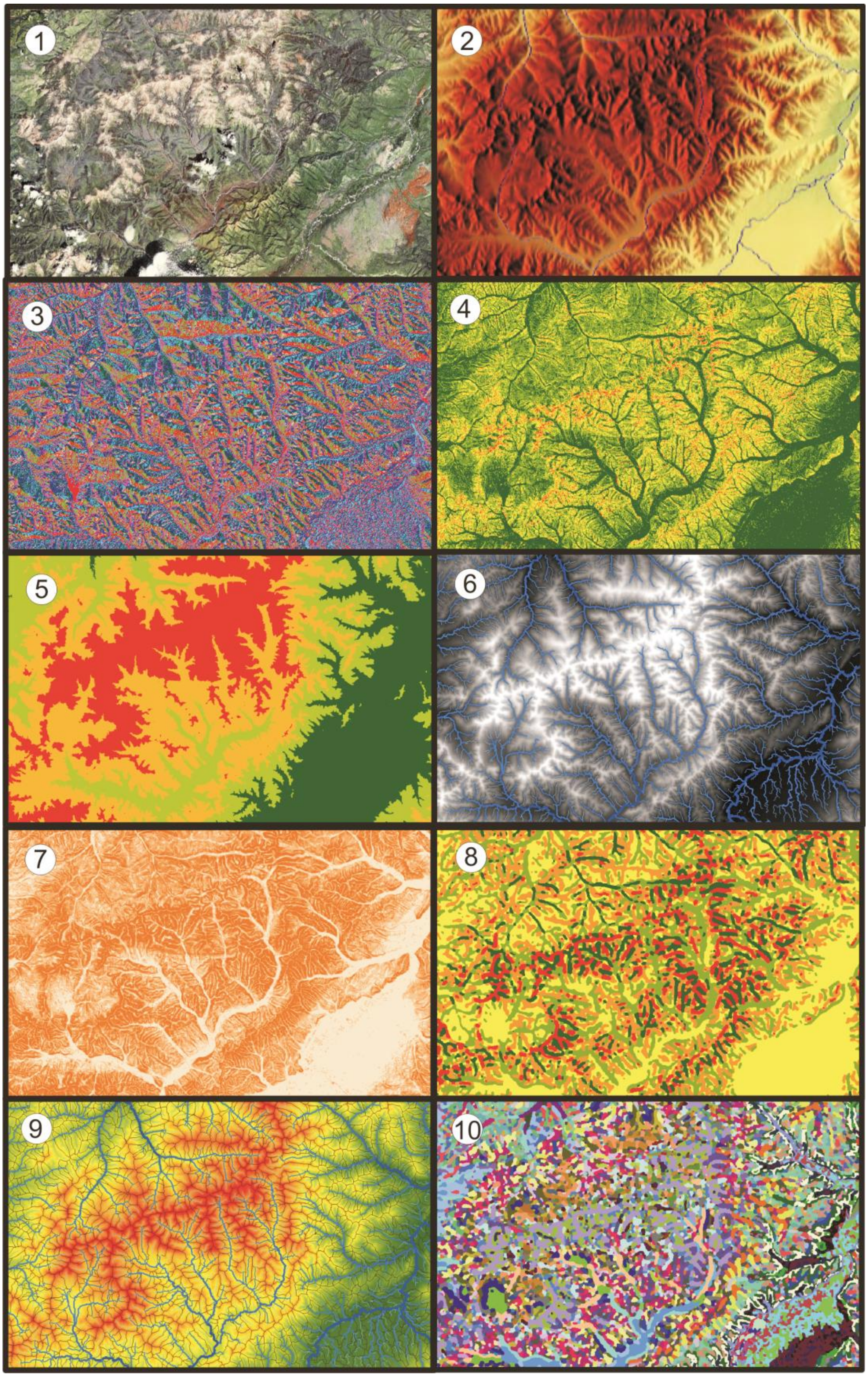

Fig.1. The main thematic rasters used during modeling: 1-space image of the key area - the mountains of Sikhote-Alin in the Russian Far East of, 2 - a shaded relief, 3-flow direction, 4 – local valleys, 5 – altitude zones, 6 – height above river, 7 – slope, 8 – topographical index (Jennies), 9 – watersheds of the 1-st order rivers, 10 - landscape sites raster

Summarized, the discussed parameters are shown in table 1. The hierarchy of factors established during the process of combining (a tool «Combine», «Spatial Analyst») so that the raster of leading factor specified in combinatory on first place and the rest factor in order of priority. The essence of the «combine» procedure leaves for the user an ability to "reassign" leading factors when working with combinatorial layer. in other words you can change the order of the columns reflected the particular characteristic and, accordingly the order of sequences in the final site`s index changed as well. Thus can be constructed the classification of sites in the framework of hierarchical and relational schemas: we can classify and characterize each site through a combination of features, for example: «hilltop slightly convex dispersive surface» or «low valley bottom concentrating surface».

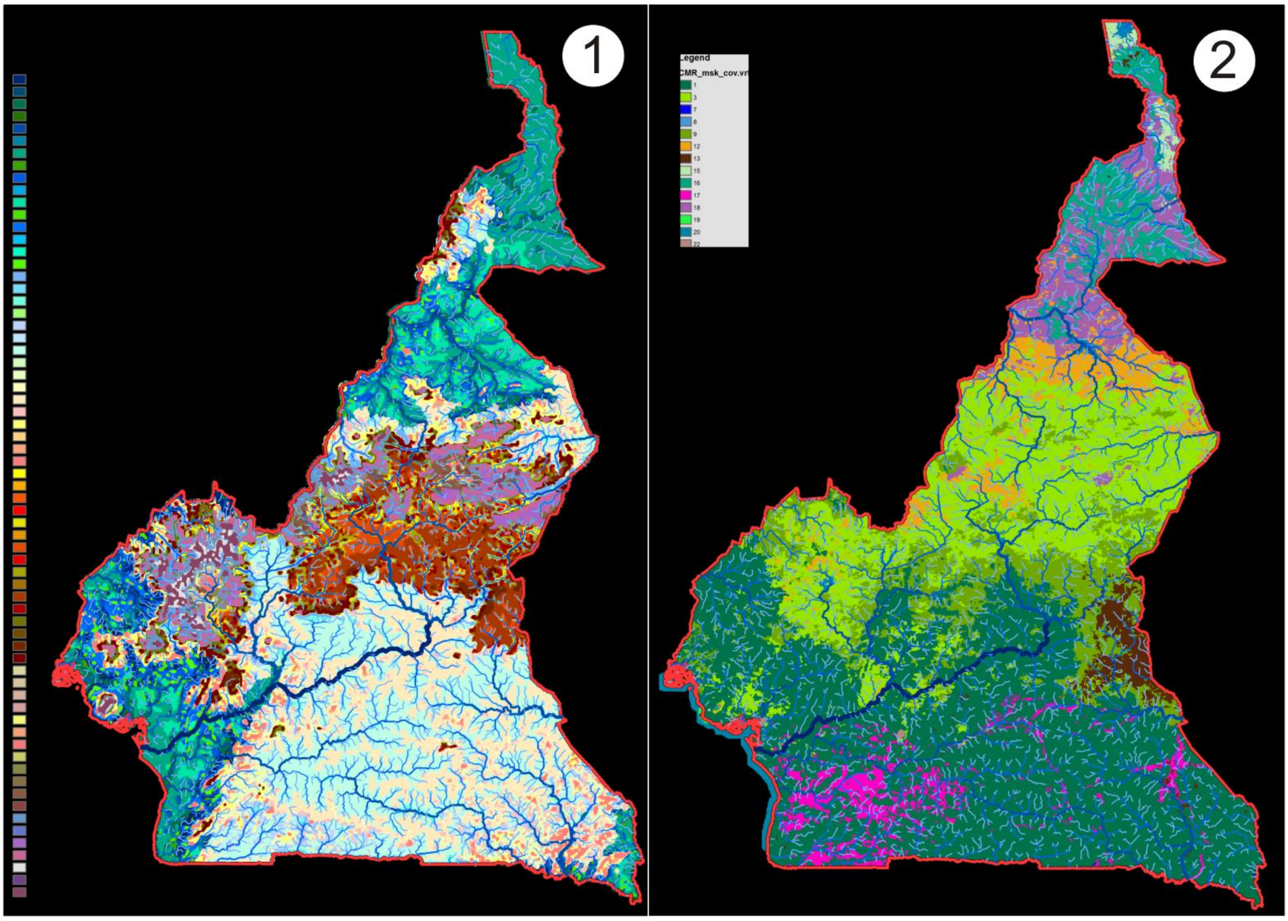

Fig. 2. Landscape sites model for the territory of Cameroon (1) and map of forest biome (sours - Congo Basin Forest Atlases

This approach gives the possibility of creating a framework for large-scale landscape mapping with further correction by including additional factors (lithology, soil, vegetation) and the results of the field verification.

Table 1. The factors of the sites differentiation and geomorphometrical variables used for their modeling

	Types of landform	**Factors of differentiation**	**Modeling variables**	**Delineated sites**
1	Valleys of largest rivers	in height above low water level, in distance to the river	height above river	the levels of the flood plains and terraces
			Euclidean distance to the main river	floodplain fragments of different types (scroll bar floodplain, central floodplain) and valley flow, terrace edge
			topographic position index	rivermane, old river channel
2	Wavy and slightly hilly plains	between flat and sloped surfaces, between concentrative and dispersive surfaces	plan curvature	concentrative upper slope and dispersive low slope
			profile curvature	convex and concave slope, positive cliff edge
			elevation	altitude levels of the plains
			slope	slopes with different steepness
3	Erosive plateaus and uplands	between flat tops, slopes and bottoms of erosion network	высота над уровнем реки	flat surface and slopes
			profile curvature	cliff edge and cliff base
			aspect	slopes of the ravines and gullies with different aspect
			topographic position index	bottoms of the ravines and gullies
4	Rolling hills	between slopes of different steepness, between slopes of different exposure between concentrative and dispersive surfaces	topographic position index	convex tops and ridge of the hills, valleys
			slope	flat top surfaces valleys and slopes
			aspect	slopes with different aspect
5	Mountain ranges and highlands	between altitudinal zones, between slopes of different steepness, between slopes of various expositions	elevation	slopes of different steepness
			slope	slopes of different steepness
			aspect	slopes with various expositions

VEGETATION COVER MODELING

Biodiversity associated with landscape sites on two spatial scales – at the level of forests (group of associations, forest types) and individual species and their populations [6] and this fact, in itself complicates the problem of choosing spatial units for vegetation modeling [7]. Another complication is the lack of standardized data for most of the unexplored areas with the exception of a small number of key areas on which field researches were conducted. Evaluation of vegetation contribution to overall biodiversity should be based on publicly available data, especially satellite images of medium resolution (Landsat sensor) or forest inventory data, (if available). In this study it was interesting use of both sources.

Forest inventory data contain many characteristics of which were empirically selected parameters exhibiting the highest correlation with site conditions: forest type, dominant species, age, dominant species, site class, fullness of the plantings. Due to qualitative (categorical) nature of the features for the study of statistically significant measure of connection landscape sites used method of constructing contingency tables of frequencies of two parameters (types of sites to each parameter of vegetation). It turned out that the closest relationship according to coefficient values of 0.6-0.8 exists for the type of the «landscape sites – a type of forest». However, considering this result as meaningful, we must note that in case of taxation experts, as a rule, "keep in mind" a kind of deterministic scheme, "forest conditions-forest type and tend to duplicate it in the field inventory descriptions.

As a second alternative data source was applied satellite imagery of medium resolution (sensor «Landsat»). Unsupervised classification with minimal further processing was used for selection of the areas with different spectral characteristics and, ultimately, to the contours of vegetation (without typological semantics) to any territory. Classification of the Landsat scenes was carried out by means of the program "Erdas" (unsupervised classification) on the notoriously excessive number of classes in order to account for the nuances in the spectral characteristics. Minimal post-processing pre-classification was conducted to eliminate the pseudo-classes, arising from irregularities in the illumination area.

To assess the diversity of landscape sites and parameters of forest cover in the matrix of the river basins was carried out using the zonal statistics for each pool and counted the number of unique sites and forest types.

DISCUSSION OF RESULTS

The comparison of the constructed models with the results of field studies undertaken in the Russian Far East showed that the model taxonomy of landscape sites corresponds to a real differentiation of the surface, although somewhat redundant. This defect can be easily eliminated with the appearance of reliable field data through aggregation of related classes - parts of the river valleys and fragments of longest slopes.

Analysis of diversity landscape sites within the watershed matrix demonstrates that the highest level occurs in the transitional zones between the river valley and low-mountain landscapes, as well as in deeply erosion-dissected mountain landscapes. The greatest diversity of forest cover corresponded to the transitional zone from the lowlands and plumes of slopes to river valleys, but the variety of forest types also «descend» to a lower topographic level terraces and floodplains

The integral index of watershed diversity was determined as an indicator of potential biodiversity. The results obtained for the territory of the Russian Far East has allowed to select the elementary river basins (to verify them as «Reference basins», according to the newly developed International Forestry Commission (FSC) standards for forest protected areas. So in the Russian Far East within the selected basins with a potentially high level of biodiversity was discovered all forest formations typical to virgin forest areas (larch, fir, spruce, cedar-stennikova, stone birch, poplar).

Of course, landscape biota has its own internal organization, manifestation of which are, gap-dynamics and successions change of a different nature. However, despite the relative autonomy of forest cover the maintenance of the natural structure of river basins with a full set of landscape sites – the most important condition (in the long term perspective) necessary for the conservation of biodiversity and for the recovery after any violations of anthropogenic or natural character. Obtained during modeling mosaic of landscape sites and watersheds net represent complete spatial matrix which could be used for accumulation, comparison and storage of other: data, (geological structure, soil cover, different types of anthropogenic impact, etc).

THE DIRECTION FOR FUTURE RESEARCH AND POSSIBLE IMPROVEMENT OF THE ALGORITHM

The presented approach to the modeling of the potential biodiversity for understudied areas is not an option fully automated algorithm. Existing ArcGIS tools allows to use the Model Builder for creating scripts for almost all sequences of processes, which greatly accelerates the process execution, and frees the operator from the considerable proportion of «manual labor». However, the expert role of the GIS cartographer continues to be critically important and appears in almost all phases of modeling. Further improvement of landscape-basin approach is to remove the effect of «uncertainty» from the most disputable phases, and also in the selection and development of tools to support systems expert solutions to set additional get parameters.

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