LANDSCAPE MAPPING: NEW POSSIBILITIES FOR ENVIRONMENTAL MONITORING

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Abstract

The paper discuss elaborated in Laboratory of Landscape Research and Ecological Mapping (St.Petersburg University) procedure of large- and middle -scale landscape-dynamical mapping and its use for environmental applications and landscape design. Landscape is considered as a very complicated system influenced by different natural and anthropogenic impacts. The long-term consequences of impacts which take tens and hundreds years are of great significance for landscape dynamics; however these changes of landscapes have not been adequately studied.

The main idea of the method proposed is creation of regional map series based on the same pattern of territorial units (landscapes). The basic concepts of landscape site and landscape state are discussed. Every map series includes: map of landscapes, map of impacts, map of present processes in landscapes, map of landscape stability, landscape-dynamical scenarios maps. Fragments of maps are presented.

1 Introduction

Landscape mapping has more than 40-year history in the countries of Central Europe and former USSR. We can say with reasonable confidence that there was a "boom" of landscape maps creating between 1955 and 1980; this process was accompanied with great number of publications including monographs and manuals. The proper teaching courses were included in the educational programs of the universities' departments of geography. The landscape map has been obligatory element of the regional and national atlases of the above mentioned countries.

The advantages of landscape approach and landscape mapping are connected with complex analysis of environment and revealing the interrelations between different natural bodies: rocks, relief, water, air, vegetation, soils etc. This approach in turn goes back to the ideas and works of Russian naturalists of the end of the XIX and the beginning of the XX centuries: V.Dokouchaev, G.Morozov, G.Vysotskiy, L.Berg and others. These concepts were also close to the German physical-geographic tradition (Z.Passarge, K.Troll).

The period of 1975-1990 was marked by advancement of applied landscape studies in the USSR and countries of Central Europe. At that time landscape maps were used as a tool for natural resources analysis, agricultural estimation of the territory, regional planning and design, evaluation of natural conditions for recreation and tourism etc. This way of landscape approach application is comparable with ideas of landscape ecology generated in Western Europe and USA.

At the moment "traditional" landscape science in the post-socialist countries comes to crisis and paradigm change. The only way to future development of the landscape approach is revising its main principles in the context of continualism, probabilistic character of interrelations between different elements of landscape, different rate of their changes. Landscape science has to use and iterpret the results of long-term investigations of field stations, especially those concerned the various effects of human activity in landscape.

Therefore traditional landscape maps need essential updating. The point is that approach to landscape as a static, non-changing object is unsuited for multiplicity of environmental management goals, particularly when it comes to planning for long-term (up to 100 years) perspective. It is significant that long changes of landscapes have not been adequately studied. In their research we are to use combinaton of diffrerent geographical methods: field studies (expeditions and stationary investigations), remote sensing, historical and archives sources analysis etc.

The five-year investigations of Laboratory of Landscape Research and Ecological Mapping (St.Petersburg University) in the north-western part of Russia have established a large-scale and long-term landscape changes caused both by natural trends and human impacts. As a result we have elaborated *our own procedure of large- and middle-scale (from 1:25 000 to 1:500 000)* landscape-dynamical mapping [1]. The principal idea of this method is creation of map series based on the same pattern (grid) of territorial units (landscapes).

2 The region studied

The basic area of our field investigations is eastern part of the Gulf of Finland basin and Ladoga Region. The landscape-ecological peculiarity of the territory is preconditioned by the following main factors:

- The contact zone between subcontinental geological structures of the Baltic crystalline shield and East European platform; differentiation of neotectonic movements in different parts of the region;
- Wide spreading of glacial and post-glacial forms of relief, which essentially complicate the landscapes' structure.
- The presence of two large water bodies which are Gulf of Finland and Ladoga lake (the largest and the deepest lake in Europe); abundance of middle and small lakes, whose area decreased last 2-3 thousand years.
- Young age (less than 10 000 years) of natural landscapes, that causes weak development of river valleys and predominance of river-lake systems.
- The combination of middle and southern taiga features and atlantic peculiarities in the vegetation and soils.

The territory is subdivided in more than 20 landscape regions. Each landscape region is considered as the individual area in which the geological structure, climate and vegetation zone are homogenous. According to the typical features of their internal structure (the set of local landscapes) landscape regions are classified in groups or types. The dominating types of landscape regions are: complexes of crystalline ridges and clayey terraces; morainic plains and highlands; lacustrine-glacial sandy low plains; hilly kame landscapes; flat lowlands on clay. For example, first mentioned type of landscape region is characterized by regular alternation of stretched granite ridges, flat clayey terraces and lakes.

The aforesaid peculiarities of the region precondition the great variety of processes of long-term landscape dynamics. The territory has been developed during several thousand years by two ethnic communities: Baltic-Finish and Slavonic. Ethnic, social and political processes repeatedly resulted in changes of environmental management and land use systems. For example, essential renovations of the land use system after the war 1939-1945 when Karelian isthmus and northern part of Ladoga Region were included in the Soviet Union, have involved very fast (10-30 years) "reconstruction" of corresponding landscapes.

The most landscape-changing human impacts over all historical period were: land cultivation and increasing of arable lands area; forest cutting (clear and selective); bog and forest drainage; forest fires; lakes lowering; creation of canals and reservoirs; peatery; railway and road building; quarries of crystalline rock, limestone and sand-pits. Last 20-30 years human activity in the region became more intensive and the above-listed impacts were supplemented by air and water pollution by industry (especially pulp-and-paper mills), municipal economy and agriculture and strong recreational press, including large areas of collective gardens.

The principal manifestation of the present worsening of the regional environmental conditions is a progressive eutrophication of large rivers (such as Volkhov, Vuoksa and others) and lakes, particularly Ladoga lake which is the major source of drinking water for St.Petersburg with its 5 millions habitants.

3 Landscape-dynamical approach

The development of landscape-dynamical mapping is based on the principles of the landscape dynamics which can be state now as a result of our investigations in the north-western Russia. These principles are:

- Any territory (or region) is considered as a combination of the landscapes (natural terrestrial complexes, geocomplexes) of a different rank.

- Any landscape is studied as an open system being in alternating states of a different duration: from diurnal states up to long-term ones (duration of tens and hundreds years). As an example of long-term states of taiga landscapes we can point hardwood (e.g. birch) forest after clear cutting of spruce forest.

- Any past, present and future regional environmental (ecological) situation is considered as a result of landscapes' states changes, that is landscape dynamics.

- The landscape dynamics is caused by natural (spontaneous) processes and diverse anthropogenic influences as well as by superposition effects of both of them. Spontaneous processes (which are mainly out of human control) include neotectonic movements, century-long climate changes, bogs evolution, autogenic vegetation successions etc. The superposition of the specified human impacts and natural trends results in strengthening of the latters. Such is the case for clear cutting in the naturally bogging pine woods on low sandy plains.

- The character and intensity of human impacts at every historical period were caused by the whole complex of economical, social, political, ethnic factors which were realized in the regional system of land use and natural management. Comprehensive analysis of the present environmental conditions of the region is impossible without studies of landscapes' changes over all historical periods in connection with concrete events, e.g change of state borders.

- Long-term consequences of any human impact on a nature are differentiated in conformity with types of landscapes, pursuant to their zonal and regional conditions, features of the geological structure, relief, vegetation and other elements of a landscape. For example, the soil pollution by heavy metals variously manifests itself in landscapes of sandy plains with pine woods, on the one hand, and in those of oligotrophic boghs on the other.

- The most effective way of study, representation and simulation of spatial and spatial-temporal aspects of the regional environmental situation is landscape-dynamical mapping. The series of maps includes: map of landscapes, map of impacts, map of present processes, landscape-dynamical scenarios maps etc. We shall consider the stages of mapping more closely.

4 Mapping of landscapes

The map of landscapes is a base (framework) of all maps in the series. It is created by the methods of field survey using remote sensing analysis. The taxonomical rank of landscape units to be mapped is defined both by map scale and features of regional landscape structure.

The principal idea of landscape-dynamical mapping is in the subdivision of all parameters used for landscape description, into 2 groups: 1) characteristics of site; 2) characteristics of state.

Site (location) of landscape is considered as combination of parameters (elements) whose time of change is always more than (and frequency of fluctuation less than) the time of simulation (forecast) that is ranged from hundreds to thousands years. Besides this, site parameters are usually not modified by common human impacts (e.g. clearings, fires, recreation).

Based on the preceding, parameters of landscape sites have to be the most stable (conservative). They include type and form of mesorelief, steepness and the form of slope, litological composition of the bedrock and degree of natural drainage (regime of moistening). The classification of sites for the North-West of Russia has been made based on aforesaid criteria. The upper level of the classification includes following types of sites:

S - ridges formed by crystalline rocks; drained and well-drained

G - hills and ridges formed by morainic deposits with abundance of rubble; well-drained

K - kames (sandy hills without cobble and rubble); well-drained

V - narrow deep valleys formed by erosion, with slopes of 15-25°; drained and well-drained

Pf - plains on sand and sandy loam (not rare with cobble); drained

Pg - plains on morainic loam with much cobble and rubble; drained

Pc - plateau formed by limestone covered by carbonatic moraine; drained

Pl - low plains and terraces on lacustrine clay; insufficiently drained (often with artificial drainage)

Lf - flat plains on sand and sandy loam (not rare with cobble); insufficiently drained and bogged

Lg - flat plains on morainic loam with cobble and rubble; insufficiently drained and bogged

Ll - flat plains and terraces on lacustrine clay; insufficiently drained and bogged (in specific cases with artificial drainage)

A - flood-plains on alluvium; periodical inundation

M - marine and lacustrine sandy beaches and shallow places

B - plains formed by peat (including peat-bogs).

Every type of site forms more wide or more close set of ecological niches for plant communities. These latter alternate each other in course of different successions (natural and anthropogenic) and cause corresponding effects in the formation of soils, while the site is not changed. Therefore state of landscape is defined as combination of parameters whose time of change is comparable with the period of simulation, that is not more than 100-150 years. State parameters are usually changed by human impacts.

Parameters of landscape states include predominantly qualitative and quantitative characteristics of vegetation (vegetation layers structure; composition of tree species and young growth of trees; dominant species of herb and small shrub layer, including their belonging to different ecological-phytocoenotic groups; total and partial cover of mosses and lichens etc.) and soils (composition of horizons; degree of development and thickness of humus, peat, podzol, gley horizons) as well as fluctuations of ground water level, features of microrelief etc. The number of possible landscape states is much more than the variety of sites; thus the classification (or typology) of states is in development stage at the moment.

By this means, the principal requirements for any map of landscapes are: 1) the maximum detailed view of diversity of sites according the map scale; 2) stability of contours (borders) in course of long-term dynamical processes (changes of states). In other words, the time of landscape sites change must be one or two orders longer than those of states mapped in contours.

The fragment of the large-scale landscape map is presented on the Figure 1. Types of landscape sites is indicated here by digits. The present states of the local landscapes are distinguished by the dominance of one or another type of phytocoenoses what is indicated by letters "a" and "b" on the map and in square brackets at the legend.

5 Mapping of impacts

Impact on landscape is considered as event caused by external (natural or anthropogenic) factors and causing comparatively rapid change of landscape state. As a rule, human impacts are predominant in dynamics of landscapes of the studied territory.

Map of impacts on landscapes is also created on evidence derived from field investigations. Besides, the analysis of old maps, different-time aerial pictures, historical and statistical data is used. Our approach does not underline what is cause of one or other type of impact (natural or anthropogenic). The characteristics of greater importance are physical, chemical or biological mechanism of impact, its age, intensity and results for different elements of landscape. The fact is that for certain impacts (e.g. forest fires) it is practically impossible to establish the cause, while the fires both of human and natural cause have the same consequences for landscape.

The mode of mapping of impact depends on its localisation. Based on this criterion we distinguish square impacts (forest cuttings and fires, bog drainage, land cultivating etc.), linear impacts (railways, roads, pipelines etc.) and seat impacts (air and soil pollutions by industrial enterprises). Every type of impact requires corresponding methods of cartographical display: contours for square impacts, lines for linear ones, symbols and diagrams for seat ones.

It is important to point out the change of mode of presentation while using the more detail scale. For example it concerns electricity transmission lines: they may be shown as lines in scales 1:100 000 or 1:25 000 and as contours in more large scale.

The problem of basic importance is what time period we have to examine for impacts mapping. It is known that the consequences of different impacts of old age (e.g. fires and cuttings 100-200 years ago) usually are smoothed up by later impacts of the same character. We have established the optimal period for mapping of impacts on landscapes of middle and south tayga as 50-100

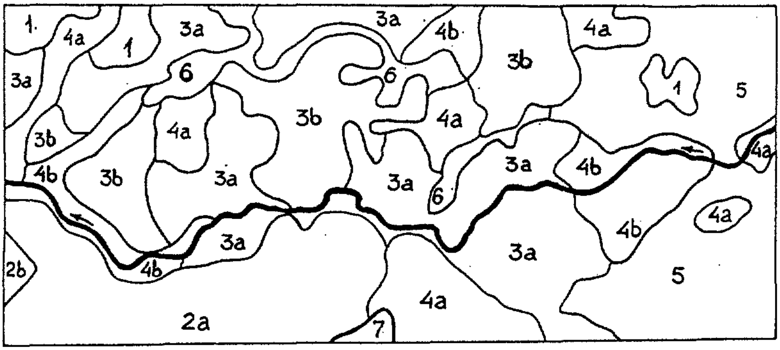

Figure 1: Local landscapes, test plot in north-eastern part of the Ladoga Region. Original scale 1:25 000. 1 - gently sloping ridges formed by granite -rapakivi, drained [pine forests with heath and green mosses]; 2 - gently sloping sandy morainic ridges, well-drained [2a - pine forests with green mosses, 2b - short grass meadows]; 3 - plains on fluvio-glacial sands, well-drained [3a - pine forests with green mosses, 3b - spruce forests with green mosses]; 4 - flat bogged plains on fluvio-glacial sands [4a - sphagnum pine forests, 4b - bilberry and sphagnum spruce forests]; 5 - oligotrophic peat-bogs [subshrub and sphagnum with pine]; 6 - mesotrophic peat-bogs [sedge-sphagnum moors]; 7 - lakes.

years. This time is need for regeneration in main features (or irreversible changing) of forest vegetation after such strong impacts as clear cuttings and crown fires.

Account must be taken of the fact of superposition of impacts which is observed in the majority of landscapes studied. So the oligotrophic bogs in tayga after drainage are usually acted upon by fires. The mean of superposition representation on map is combining of colour and hatching, or different kinds of hatching in the contours (Figure 2). It is notable that the localisation of different types of impacts by and large correlates with the site contours.

6 Mapping of present processes

Map of present processes in landscapes to a large measure is a result of synthesis of two previous types of maps. Besides, the evidence of stationary investigations of processes is need for increasing of certainty of such maps. The main principle of mapping is based on the fact that every long-term process manifests itself in different elements of landscape (natural bodies) according to their critical time of changing.

The vegetation is the most susceptible to changes: the plant cover dynamics owing to natural and human impacts may take only several years. However vegetation changes are very often followed by more slow modifications in the water regime, soils and even microrelief. An example is long-term consequences of the non-controlled recreation in the pine forests on dry sandy hills: green moss cover degradation provokes here the soil desiccation, pine-trees downfall and sand erosion and deflation in the end.

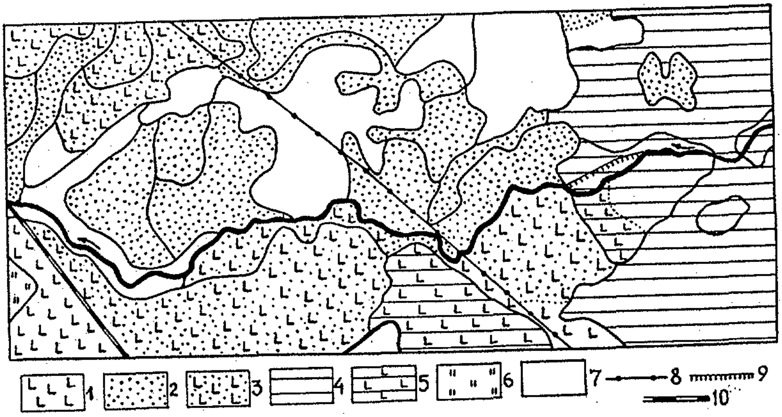

Figure 2: Impacts on landscapes, test plot in north-eastern part of the Ladoga Region. Original scale 1:25 000. Square impacts: 1 - clear cuttings (10-40 years ago), 2 - fires (more than 5 years ago), 3 - clear cuttings and fires (more than 5 years ago), 4 - bog drainage (beginning is 15 years ago), 5 - drainage and selective cuttings, 6 - periodical grazing, 7 - absence of impacts. Linear impacts: 8 - electricity transmission line, clearing 70 m wide, 9 - straightening of the river bed, 10 - one-track railway, lokal bogging.

From the preceding it is seen that no process can be described by the only quantitative parameters. The most informative way of landscape processes describing is using the qualitative characteristics. It follows that the every contour of the basic landscape map is characterized by certain qualitative properties of the processes. It makes possible shawing of superposition of two and more different processes in the same contour, without combining different hatching. The typical example of legend explanation for the map of the test plot in middle tayga: lowering of bog water level; intensive growth of pine, birch and heath accompanying by partial degradation of sphagnum cover (as a result of bog drainage, Figure 3).

The developed maps differ essentially from the "analytical" maps of the nature dynamics. We mean the maps of geodynamics, erosion processes etc. The principal advantage of the maps of present processes in landscapes is their synthetic character, what is meant the qualitative presentation of dynamical relations between different landscape elements.

7 Conclusions

The concept of landscape-dynamical mapping is further development of map series by creation the maps of: landscape stability to different kinds of human impact; permissible load on landscapes; landscape-dynamical scenarios. The methodical approaches to named kinds of maps are in development stage now. It is important to point out the necessity of the prior creation the maps of landscapes, impacts on landscapes and processes in landscapes as a common background of the all above-mentioned kinds of maps used for landscape monitoring.

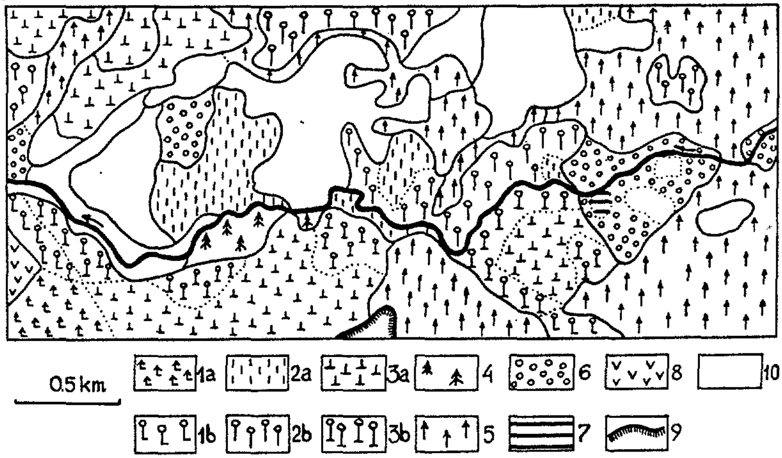

Figure 3: Present processes in landscapes, test plot in north-eastern part of the Ladoga Region. Original scale 1:25 000. Progressive successions of pine forests (whithout soil changing) : 1 - after clear cuttings, 2 - after fires, 3 - after clear cuttings and fires (everywhere: a - early stage, b - midddle and final stages). Change of dominants in the arborescent stratum (followed by slight soil changes): 4 - supplanting of pine by spruce. Processes owing to moistening (drainage) conditions changes: 5 - lowering of bog water level; intensive growth of pine, birch and heath accompanying by partial degradation of sphagnum cover; 6 - lowering of ground water level; change of arborescent layer with birch predomination, herbaceous growth and sphagnum degradation; 7 - trees downfall due to local water-logging. Processes under pasturing: 8 - grasslands soding and species composition change. 9 - overgrowing of the lake by floating bog. 10 - stable state of landscape with slightly marked dynamics.

A widespread possibilities of using the landscape-dynamical mapping for environmental monitoring and assessment derive from the fact of the complexity of ecological situation in the majority of countries. The increasing landscape fragmentation generates a need for differentiated evaluation of local landscape dynamical tendencies. When it comes to choosing of possible (or optimal) mode of the territory using, the decisions based only on present state of the landscape may be quite short-sighted.

By way of illustration let us consider the landscape dynamics of the Karelian isthmus (a territory between Gulf of Finland and Ladoga lake). The present state of the majority of local landscapes (particularly the dry sandy plains) is predominance of young and middle-age pine woods. This landscape image is traditionally considered as existing for a long period. However the measures of forest protection against clear cuttings and fires during last 30-40 years have created the conditions for spruce advancement (as a natural trend) in forests. The development of this process in future 30-50 years can be resulted in dominance of spruce woods in all sites except tops of the granite ridges and oligotrophic bogs. These landscape states are less preferable both for recreation and for the wood production. The use of landscape-dynamical maps (particularly maps of present processes in landscapes) will avoid strategic errors in long-term environmental planning and landscape design. In this case the landcapes of Karelian isthmus need special measures which could be favourable for the conservation of the state of pine forests.

It is no doubt that computer mapping has much more possibilities on the way of landscape-dynamical applications for environmental monitoring. The next steps will be connected with regional GIS creation based on landscape-dynamical approach [2]. In conclusion it should be particularly emphasized that the futher progress in GIS for long-term environmental planning is essentially defined by advancement in landscape dynamics studies. The case in point is the treatment and analysis of long-term observations on natural processes and results of human impacts on landscapes. The further enrichment of the maps' contents would be connected with obtaining of such parameters as rate, intensity and characteristic time of the long-term processes. This is also true for the poorly explored consequences of air and soil industrial pollutions for different landscapes.

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