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GIS-based Environmental Monitoring of Montane Forest Ecosystems in Protected Areas

[1] Nikolay A. Bityukov
[2] Nina M. Pestereva
[3] Lev M. Shagarov

[1]Sochi State University, Russia
Sovetskaya street 26a, Sochi, Krasnodar region, 354000
Dr. (Biology), Professor
E-mail: nikbit@mail.ru
[2]Sochi State University, Russia
Sovetskaya street 26a, Sochi, Krasnodar region, 354000
Dr. (Geography), Professor
E-mail: pnm_06@mail.ru
[3]Sochi State University, Russia
Sovetskaya street 26a, Sochi, Krasnodar region, 354000
Leading specialist in R&D
E-mail: lev049@me.com

ABSTRACT. This paper includes results on a study of montane forest ecosystems in the present-day climate change environment. We have worked out the principles and criteria for ecological monitoring of montane forest ecosystems. It is established that iconditions, the object of research, the basic requirements for ecological monitoring is a catchment. To assess the influence of forest vegetation (and, hence, forestry and recreation) on the slopes of the water balance and hydrological regime of streams it is proposed to use a tiered system of ranking watersheds. In order to obtain up-to-date information on the condition of montane forest ecosystems it is proposed to use GIS-technologies actively.

Keywords: montane ecology; ecological monitoring system; GIS-technologies; montane forest ecosystems; North-Western Caucasus; catchment area; forest taxation.

INTRODUCTION. A forestry typological pattern of an area is of great significance for provision of environmental monitoring (primary level of environmental monitoring). Unfortunately, different approaches to fit different of types of forests and larger taxonomy units have no fixed criteria, which makes study of dynamic forest types difficult or completely impossible.

MATERIALS AND METHODS. Local ecological monitoring of montane forest ecosystems is based on method of active long-term (since 1964) experiment in 8 catchments of 2 research areas: LGS "Aibga" (basin. Mzymta quarter 8 Veselovskoe forestry) and LGS "Gorsky" (basin. Dzhubga, quarter 30 Dzhubgskoe forestry) that are representative for beech and oak forests, respectively, for all environmental characteristics.

DISCUSSION. Alongside that, forestry typological features of an area, obtained with the help of any typological classification offer an image of forest-site capacity of the habitat, allow defining a correlation of growth conditions to a productivity of timber stand, distinguishing benchmarks for planting and types of forest for particular conditions (areas) and forest-site typological regions. Benchmark and typical (representative) bio-communities are objects for deeper research on defining their breeds, forestry-biological and taxonomy characteristics [1, 2, 3].

Soil and typological taxonomic units describe natural resource of an area and is a sort of reference mark to evaluate their change in connection with domestic use. Using types of forests for primary monitoring should be done in areas (taxonomy-based separated) constrained on forestry-typological basis.

When choosing objects of monitoring of a higher level (elementary and river watershed areas) it is essential to consider their representative factors in relation to a typological structure. In reserve areas, benchmark and representative forest ecosystems are objects of thorough studies aimed at defining population interconnections of flora and fauna, biotic and abiotic parts of ecosystem, finding balance in production process, transforming climatic factors, setting hydrology, water protection, soil protection and, in general, nature-protection role of such ecosystems.

When organizing a network of monitoring in the mountains, one should locate benchmark and representative forest biogeocenoses according to either ecological profiles embracing all vertical zones (forest zones) or to watershed areas.

Principles and methods of environmental monitoring. A monitoring system in accordance with UNECE recommendations should form indices of defoliation, dechromation and growth change. From organizational point of view this system allows combining on-site monitoring networks for study of various functional elements:

a) Points of permanent monitoring which define indices of defoliation, dechromation, growth change, monitor the development of diseases and pests, provide samples of soil and organic substances for analysis, as well as growth cores and benchmark trees;

b) Points of visual distance control which are used to define borders of areas and forested sites with bright features of degradation.

Using GIS-technologies should provide positioning of monitoring points both on the stage of field surveys and during analysis and building different bondages for environmental forecasts. Intensity of the monitoring is defined with the degree of flora degradation. The maximum intensity (1st grade) is visible where deterioration is mostly distinctive. The second grade of monitoring intensity should be used in forests which have distinctive features of anthropogenic oppression; although dynamics of growth change, defoliation and dechromation has no negative trends and depends mostly on natural factors. Monitoring of the 3rd grade of intensity is done in forests with no visible signs of depression while radial growth having no abnormal deviations, which cannot be explained by natural factors.

The environmental monitoring has different stages defined by its tasks, and these stages should be distinguished. Thus, due to forest fieldwork and forestry management special monitoring is carried out in forests, which includes e-maps based mapping, allotment of land plots of forest for practical use, as well as control of forest management activities. This type of monitoring is held by specialized organizations and forestry-based companies.

The monitoring of forest ecosystems of various kind is of long-term research character due to scientific companies the main aim of these being setting environmental links of forest flora with their environment, short-term and long-term forecasting of their changes including those related to their location. Final tasks of environmental monitoring are elaboration of scientifically based legal acts providing reasonable use of montane forests.

The main object complying with the monitoring requirements in mountain environment is watershed, which is practical with its fixed borders and stable direction of substance and energy flows. Local monitoring implementation is mostly preferable with minimal monitoring of watershed – elementary watershed. Local monitoring includes several elementary watersheds providing an opportunity to find out mutual influence of interacting environments in an active experiment.

Environmental monitoring in the mountainous regions should be hierarchically leveled having at least 3 tiers. The main factor of delineation of these tiers is an area of watershed that can be explained by an influence of these criteria forming environmental links in ecosystems.

Tier one is a comparatively homogeneous plot of hill slope (one or several). It's characterized by an absence of brook drain (because of low concentration of ground waters) and small area – up to 5-10 hectares.

Tier two is a minimal watershed included into a hydrographic network of a river (1st level tributary) – so-called elementary watershed. Its main feature is fixed geomorphological characteristics of a watershed – area, slopes of different orientation, water corridor as well as permanent or seasonal (in winter) brook flow. Sizes of watershed can vary, depending on different natural-climatic zones of the region, from several dozens to several hundreds of hectares.

Tier three is a river watershed that has a developed river network, sustainable basis flow and entering main rivers of the region. Sizes of such basins are measured with dozens and hundreds of sq. kilometers (i.e. hundreds and thousands of hectares). Main features of such watersheds are inclusions of various soil-climatic, geology-geomorphological forestry factors that are changed along the river.

A system of criteria for ecological monitoring of different types. The criteria for monitoring ecosystems of different types are parameters characterizing separate objects (elements) inside the ecosystems. Thus, for the level of elementary watersheds these are: species composition, taxonomy features of flora and their productivity, steepness division, structure and condition of timber stand, as well as parameters characterizing forest-forming and soil-forming processes and dynamics of water and warmth balance elements. Thanks to difference in levels of the surveyed objects, the study of influence of practical use of forests for hydrology regime has different criteria of hydrology regime and models of its change.

1st level (allotment level) due to homogeneity of forest conditions has an opportunity to take the larger number of criteria into consideration, those being both of biotic and of abiotic groups of factors (dynamics of flora and hydrological regime). It is of sense to check influence of flora towards changing of certain elements of water balance in this case.

2nd level should have less such criteria while hydrological models should be less complex.

At *level 3* because of mutual overlapping of processes having controversial influence and because of neutralizing influence of an area itself, criteria of hydrological mode and conditions of forests are brought to a minimum of 1–2 integral indices. At a level of main river regional systems integrated criteria of forest ecosystems are: woodiness of the basin; taxonomy features of structure and composition of flora at the watershed.

A system of criteria characterizing ecosystems of various types is hierarchical both for different systems and inside each of the systems.

The organization of environmental monitoring of montane forest ecosystems. A comprehensive environmental monitoring should also vary according to its organization and monitored objects – both industrial and scientific-research (different in their tasks, objects, methods and hardware) companies should take part in it. Design, build and operation of a network of environmental monitoring in montane forests are based upon a concept of environmental monitoring in mountainous regions using GIS-technologies. The reviewed ecosystems must be treated and approached systematically:

- definition of each of ecosystems as an independent unit of the reviewed area;
- division of the ecosystem into multi-tier components;
- Setting up internal links between components and links of the ecosystem with other systems as well as connections with abiotic components (external climatic, geological and hydrological conditions) [8].

The network of environmental monitoring must include existing infrastructure represented by forest-hydrological stations and bio-indicator network for monitoring forest ecosystems in protected areas. At the same time a system of criteria of this monitoring includes characteristics of productivity and biomass of cultivated flora and related plants, indices of hydrological monitoring (precipitation, humidity, hard and liquid drain) as well as micro-climatic, geo-chemical and soil features. For example, databases of average monthly precipitation of a state network of weather stations for a period of instrumental monitoring [6]. The environmental profiles assess the condition of forest flora on a basis of forestry-taxonomy indices, dechromation and defoliation. Representative river catchment areas offer monitoring after environmental factors based on enlarged comprehensive integral figures of woodiness, age and river drain characteristics.

GIS-based environmental monitoring of protected areas. As a rule, biological levels of forest flora are connected with an occupied area defined by a level of an eco-system (tree, land plot, compartment, forestry, forestry farm etc.) classification of which helps practical detachment and management. If these areas are linked to geographically justified map of land plots, then many practical tasks can be solved comprehensively. Firstly, this is because GIS allows examining analyzed regions in relation to their areal interrelations that allows provision of complex assessment of the situation and creates a base for more specific and reasonable management decisions. Overall, GIS provides 5 main procedures: data input, data manipulation, data management, data request and analysis, data visualization. Geographical images for GIS purposes are uploaded in vector or raster format directly if they already exist electronically, or with the help of digitizer or scanner. Each element or object of an image is geographically linked. Any information having direct or indirect data on names, geographical or other coordinates, address, postal code, electoral district, land plot number, mile post etc., can be included into GIS. Manipulation means include various types of data transforming and separation, for example, bringing all geo-information to one scale and projection for more convenient processing. Relation databases are mostly used for storage, structuring and data management in GIS while common fields serve linking spreadsheets [7].

Maps should contain administrative-geographical information; they have borders of forestry farms, forestry and compartments, particularly protected natural areas of different status with information on their security level, as well as territories subject to protection by nature-protecting organizations. GIS is linked to a database and automatically records information on timber origin onto the map. GIS allows reporting timber origin to timber-processing plants and is an irreplaceable aid when planning checks of suppliers and land plots.

Software for GIS-based environmental monitoring includes products by ESRI: ARC/INFO, Arc View and ArcExplorer. ArcView is an end-user product. Its feature is scaled architecture of the software. It can create a range of external and internal modules, upon requirement added to the core of the package and enhancing its functions. The architecture of ArcView 9.0 provides an exclusively flexible environment for stage-by-stage connection for additional means of geographical information analysis. At the same time, enhancement of its functionality can be made at the extent of internal, external and user-defined options which mostly match user's current requirements. With the help of object-oriented programming language Avenue it becomes possible to create user-made add-ons for different functions both for environmental monitoring data processing and for support of management-made decisions. ArcExplorer is a simple and efficient tool for access, visualization and analysis of GIS-data and is a freeware.

Cartographic database is a base of the system as it accumulates and keeps all map data. This special database (MapCDB) includes: spatial database ArcSDE; attribute database Oracle; subsystem of uploading/downloading and converting cartographic data; subsystem for search of cartographic materials.

A program of comprehensive monitoring can be defined as a program of eco-system monitoring for fundamental research in various ecological processes to obtain information on condition of eco-systems and their changes stipulated by man-caused factors. This is essential for forecasting of eco-systems' development, their sustainability and preservation of flora, fauna, mineral resources and the existing structure of natural landscapes and their biota as a whole. Creating a database for main biotic and abiotic factors of state natural reserves and national parks, development of common GIS-format and GIS-technologies for obtaining operational information on the activity, condition and efficient management of particularly protected natural areas are priority trend in scientific, technological and legal activities of particularly protected natural areas in accordance with the Federal Branch Program "Ecology and natural resources of Russia (2002-2010)".

Environmental monitoring can be made on the basis of on-site and distance probing including aerospace cartography which makes possible using GIS-technologies for:

- Visualization of cadaster information (e-maps, computer animation, multimedia etc.);
- up-to-date update of resource information and its real-time use;
- Defining violations of certain kinds of natural resources by their spatial alignment with GIS means.

One of common scientific projects of the universities inside the Consortium [4] is development of geo-services and geo-portals for different users, including particularly protected natural areas.

Geo-services are a new form of GIS-solutions where both data and data-based products are provided as end-user services available via the Internet or local network [4, 5]. Geo-services are web-GIS-based (GeoMixer WEB-GIS™). The advantages of such approach are:

- access (one can get access to the system anywhere and at any time having access to the Internet);
- simplicity (use of conventional Internet browser, no technical help from IT-administrator or GIS-expert is required);

- flexible license terms (legal use of geo-data (maps, satellite photos) in the intranet and on the Internet);
- common work (sharing your project with colleagues or the whole world involves just sending them a link or embedding the project into your website using API);
- access division (one can create both public and private projects granting access to certain users only for view and editing) etc.

Mostly useful, from the point of view of environmental security, are:

1. Monitoring of spring floods on Russian rivers using up-to-date satellite photos of different resolution (http://rivers.kosmosnimki.ru). The project is done with engineering technical center "SCANEX" together with the National Emergency Center of Emercom of Russia in spring 2010.
2. Monitoring of forest fires of summer 2010 using up-to-date satellite photos of different resolution (http://fires.kosmosnimki.ru).
3. Monitoring of oil spills using up-to-date satellite photos of different resolution of Russian seas, including Black sea (http://ocean.kosmosnimki.ru).
4. Monitoring of changes / violations within particularly protected natural areas (http://oopt.kosmosnimki.ru).

Distance probing of environment from satellites using ultra-high-frequency and ultra-short waves allows obtaining up-to-date data within any period:

- Borders of forests;
- Differentiation between coniferous and deciduous forests;
- Information on "old" and "young" forests;
- Cut down borders, including illegal ones;
- Forest fires and forest recuperation;
- Soil humidity and other factors.

CONCLUSION. Thus, when developing modern models and systems of environmental monitoring of montane forests in protected areas, wide application of GIS-technologies is mostly promising including creation of specialized geo-portals and geo-services.

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Экологический мониторинг экосистем горного леса в заповедниках, основанный на технологиях ГИС

[1] Николай Александрович Битюков
[2] Нина Михайловна Пестерева
[3] Лев Мирабович Шагаров

[1] Сочинский государственный университет, Россия
354000, г. Сочи, ул. Советская, 26а
Доктор географических наук, профессор
E-mail: nikbit@mail.ru
[2] Сочинский государственный университет, Россия
354000, г. Сочи, ул. Советская, 26а
Доктор географических наук, профессор
E-mail: pnm_06@mail.ru
[3] Сочинский государственный университет, Россия
354000, г. Сочи, ул. Советская, 26а
Аспирант
E-mail: lev049@me.com

Аннотация. Работа содержит результаты исследования экосистем горного леса в современных условиях климатических изменений. Мы разработали принципы и критерии для экологического мониторинга экосистем горного леса. Установлено, что условия, объект исследования, основными требованиями экологического мониторинга является дренаж. Чтобы дать оценку влияния лесной растительности (и, следовательно, лесному хозяйству и рекреации) на склоны водного баланса и гидрологический режим ручьев предложено использовать поярусную систему классификации водоразделов. Чтобы получить своевременную информацию о состоянии экосистем горного леса, предложено активно использовать технологии ГИС.

Ключевые слова: горная экология; система экологического мониторинга; технологии ГИС; экосистемы горного леса; северо-западный Кавказ; бассейн реки; таксация лесов.