AERIAL SPACE MONITORING OF FOREST RESOURCES

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Forests is the most important component of the biosphere producing the phytomass and oxygen. They play a vital role in the environmental stabilization. As to their contribution into the biological productivity of the biosphere forests take the leading place on the Earth. Forests are of special importance in the USSR where their share makes up more than 55% of the land territory (1259.6 mil ha).

Because of the sharp increase of versatile man's impact on the environment and reduction of the forest vegetation areas on the Earth forests have become one of the most important components of the biosphere exerting a stabilizing effect on the environmental situation of the northern hemisphere. The solution of such important tasks as the increase in the biosphere productivity, rational use of land and water resources, high agricultural crops, and provision with favourable conditions for man's life depends on the proper forest exploitation.

In order to improve forest use, protection and reproduction it is necessary to develop an effective forest resources management system based on the objective assessment of the resource environment-forming capabilities of forests in various natural-economic regions of the country. Such estimates of the forest territories will give an opportunity to determine the scale of the allowable economic impact on the forest ecosystems which does not result in the destruction or loss of the environment-forming functions. Practical implementation of the ecological principles of forest management requires supplementary comprehension of the common regularities of the structure and functioning of forests, deep investigation of their nature and interrelations with other biosphere components.

To fulfil the tasks set before forestry we need voluminous, comprehensive, constantly renewing information about the forest fund on the basis of which optimal solutions on the multi-purpose forest resources use must be worked out and taken. However at present informational reports to forestry organs and other ministries and departments concerned about the forest fund state are far from being perfect, especially in the taiga regions. Almost on the half of the territory the forest fund is not studied well. Small-scale thematic forest maps are practically absent. Tradi-

tional means and methods do not ensure timely control over the forests state, forest fund dynamics and loggers' activities. To solve the problem new scientific and technical bases with the use of the latest remote monitoring methods are needed. For the solution of this important national economic task the complex special purpose program of scientific investigations on the development of forest remote sensing methods aimed at the solution of the acute forest use and nature conservation problems has been forwarded in the USSR in the early seventies.

From the scientific point of view the use of remote sensing methods is aimed at the solution of two fundamental tasks: a) forest statistics study, that is study of regularities of modern forest landscapes composition for thematic mapping and forestry region division; b) study of dynamic processes taking place in forests for forest resources control and management.

A significant part of the fundamental investigations is the study of the interaction of electro-magnetic radiation with forest vegetation. They are based on the study at different scales of tree cenoses and the analysis of their spectral characteristics with regard for seasonal, annual and long-term forest cover dynamics. These investigations are supported by ground measurements, aerial sensing and space photography. Their results are used in order to reveal geometrical and optical generalization in the process of image formation, assessment of image metrical and informational possibilities, and substantiation of spectral methods for forest study (6).

For the assessment of the informational content of remote sensing methods the whole complex of the photographic information obtained with modern space and aerial means in optical and radio regions has been analysed. This information was obtained from space with meteorological and resource artificial Earth satellites (AES), piloted space complex "Soyuz" (PSC), and automatic AES of the "Kosmos" series (3,9). The results of the generalized assessment of informational content in the photographic and scanner photography materials are given in Table 1.

Fundamental foundations and methods of aerial and space photointerpretation based on the combination of landscape, analytical-measuring and man-machine methods have been developed (3,9).

Along with the development of systematic questions of forest remote sensing much attention was given to the solution of practical forestry tasks on a new technical level.

Most noticable success in the applied use of the remote sensing methods is associated with forest resources inventory and thematic mapping, forest fire protection, and determination of current changes in land categories of the forest fund caused by natural calamities, fires, forest cuttings and other reasons.

Table 1. Interpretation Reliability (%) of the Forest Mensuration Characteristics by Multispectral, Photographic and Scanner Aerial Space Photographs Depending on Their Resolution

Characteristics	Resolution, m								
	0.1	0.25	0.5	1	2	5	10	20-50	75-100
	Forest mensuration index								
Predominant species group (dark coniferous, light coniferous, softwood forests)	100	100	100	100	100	95	95	90	85
Predominant species	95	95	95	95	90	85	85	75	60
Forest type group (types of growing conditions)	95	95	95	95	90	85	80	75	70
Stand density group	95	95	95	95	95	95	85	80	75
Density ($\sigma \pm$ density unit)	$\pm$0.1	$\pm$0.1	$\pm$0.1	$\pm$0.1	$\pm$0.15	$\pm$0.15	$\pm$0.15	-	-
Age group	95	95	95	95	90	80	75	-	-
Mean height ($\sigma \pm$%)	4	5	6	8	12	16	18	-	-
Mean diameter ($\sigma \pm$%)	6	7	8	10	13	16	20	-	-
Timber volume per forest mensuration block ($\sigma \pm$%)	10	10	15	20	25	30	35	-	-
	Land categories								
Cuts	100	100	100	100	95	90	90	80	70
Gaps	95	95	95	95	90	80	75	-	-
Burns, windthrows	100	100	100	100	100	95	90	75	70
Bogs	100	100	100	95	90	85	85	80	75
Rock outcrops	100	100	100	100	95	90	85	70	65
Haying lands	95	95	95	95	90	80	70	-	-
Clearings	95	95	95	95	95	80	70	-	-
Arable lands	100	100	100	95	95	90	80	75	70

By materials of multispectral space photography methods for compilation of a series of conjugate forest maps at scale 1:200000-1:1000000 based on the landscape basis have been developed. A series of mathematical maps for a part of the Central Siberia territory has been compiled. It included maps of the forest fund, growing condition types, bogs and marsh-ridden forests, estimate of the forest animals habitat, damage caused by forest pests, forest combustibility assessment of the post-fire state, etc. Forest regions mapping with the new methods is effective both from the point of view of the work profitableness and quality improvement and informative capacity of the cartographic material. The forest fund map of Mongolia at scale 1:1000000, maps of forests and forest types for the western part of the Baikal-Amur Railway Road have also been compiled.

New methods of inventory and large-scale (1:50000-1:100000) forest mapping aimed at the assessment of forest resources and estimate of the natural-territorial complexes productivity have been developed and put into practice. Photostatistical methods of inventory and mapping of forests in the northern and north-eastern regions and tree-shrub vegetation of the desert territories are widely used (2,4).

Remote sensing methods of the monitoring of the current changes in the forest fund land categories caused by the anthropogenic activities (forest cuttings, industrial and civil construction, mountain exploitation, etc.), and also by forest fires and other unfavourable influence are applied on hundreds of million hectares (5). The technical basis of the small-scale (1:200000 - 1:1000000) mapping of forests, their inventory and assessment of current changes is the materials of spectrozonal (multispectral) space photography from AES of the "Kosmos" series and long-term station "Salyut" (LTS) with the ground resolution of 20 m and better.

In practical work multispectral scanner space information obtained from AES "Meteor" is used for forest fire protection, control over the snow cover dynamics, determination of synoptic situation, thunder and convective cloudiness, control over the dynamics of major forest fires (1). This information makes it possible to more purposefully plan and carry out the tactics and strategy of the whole complex of measures on forest fire protection.

A number of other methods and technologies of forest study and forest state assessment based on space information use is now in the process of experimental and practical testing. Among them is the method of actualization of forest management data in the taiga regions of the country, estimate of natural forest regeneration on burns and cutovers, inventory of field-protection forests, and planning of hydro-meliorative measures. The list of the main forestry tasks the solution of which is possible and expedient on the basis of remote sensing, mainly space sensing data has been made. For each task the requirements to the materials of remote sensing as to their spatial and spectral resolution, timeliness, repeatedness and complexing of different stages of mo-

nitoring have been set (1,8).

Forecasting estimates and experience of the practical application of aerial and space photography materials in forest study and control over the forest state have lead to the conclusion about the possibility and necessity of the complex solution of main forestry tasks dealing with forest study and forest state control within the framework of special forest aerial space monitoring: on the regional level at the first stage, and on the national level at further stages.

We consider forest monitoring as a complex of remote sensing and ground means and methods of obtaining information about forest state and forest resource and ecological functions. The technical basis for monitoring is aerial space photography with the use of optical-electronic and computer methods which help to get and transform thematic information and to document its results. Thus in the process of monitoring the collection, transfer, processing and analysis of information about the forest fund and also selective delivery of it to the users of different levels of national economic and forest management beginning from the enterprise and ending with the ministry (state committee) take place. Practical tasks of monitoring include: 1) planning and providing of aerial and space photography and instrumental-visual observations and ground surveys in order to obtain information about the forest fund on different generalization levels (by forest mensuration plots, strata, natural and economic territorial units); 2) obtaining and complex thematic processing of aerial space and ground information for the solution of specific functional tasks, documenting of the results of information interpretation and processing; 3) entering of information (by plots and generalized information) into the data bank "The USSR Forest Fund", its management and renewing.

With regard for the forest fund state, ecological and economic peculiarities of different regions monitoring is to solve a wide range of tasks. In different regions of the country the priority of these tasks, degree of details and methods of information obtaining are not the same. However their methodological and technical basis must be of the same type which allows to unite the technological and information basis of the regional observations into the common national branch automated system of information obtaining.

At the first stage of forest monitoring most important tasks ensuring the rational use and reproduction of useful resources and forest properties must be solved. For example in the taiga zone of the USSR it is forest fire protection, pest control and protection from other unfavourable influences, organization of the rational forest resources use, and timely reforestation with economically valuable tree species.

As to the structural respect the first stage of forest monitoring must include five autonomous but mutually related blocks.

Block 1. Landscape-economic region division, mapping and forest

fund assessment.

This block makes up the main basis of forest monitoring represented by cartographic and statistical materials of different scales, content and levels of generalization. The obtaining of detailed information about the forest fund and its mapping at scale 1:10000 - 1:100000 (depending on the national economic category of forests and forest management intensity) must be carried out in forest management and forest inventory (2-4). The obtaining of generalized data with mapping at scale 1:200000 and at smaller scales is most advisable in the process of compilation of multi-purpose forest thematic maps (3,6,9). Source materials including those for map compilation must be written on magnetic carriers, grouped in the data bank and timely transferred in the automated regime to the users in the acceptable forms and content.

The creation of the automated bank of cartographic and statistical data on vast territories can be performed with the help of the developed methods based on the aerial space and ground information use.

Block 2. Forest fire protection.

Traditional methods of forest fire protection are based on the forest fund data, aerial and ground patrolling and forest monitoring. During the fire hazard period the search for fire centres is done practically blindly. Aerial space information makes it possible to accomplish forest fire protection more purposefully and effectively.

For forest fire protection we need data about the forest fund: forest maps, maps of forest combustible material stocks and their types, region division of the forest fund by combustibility and forecasted fire hazard. Information stored in the data bank of the forest monitoring and obtained with remote sensing and ground methods ensures their compilation.

Remote sensing for forest fire protection is to be used to solve three main tasks: 1) monitoring of moisture of combustible materials in the forest and fire hazard tension on forest territories; 2) location and assessment of forest fire parameters in any atmospheric conditions; 3) forecasting of fire spreading by landscape elements and control of the forest fire dynamics for the optimization of measures on their location.

To this end automated system "Prognosis" is being developed. It consists of three subsystems: 1) satellite operative control, 2) aerial sensing, and 3) ground centre for information reception and processing (6).

Satellite means are used for everyday assessment of the general meteorological and fire situation, detection of fires and control over their dynamics. Aerial sensing is carried out in order to locate and diagnose forest fires under the conditions of cloudiness and smoke. In the centre for aerial space information

processing information transferred through radio channels is analysed with the help of computers, operative prognoses are made up, and calculations of the optimal means for fire prevention and fighting which are used by forestry organs in their practical work are done.

Block 3. Pest control and protection against industrial discards and other unfavourable influences

Damage inflicted to the forest by harmful pests may be compared to losses from forest fires. Considerable disturbances of the forest environment result also from windbreaks, thunderstorms and industrial discards. That is why one of the most important forest monitoring tasks is timely control of the forest state and determination of the negative consequences. As investigations have shown remote sensing methods are most suitable in this case for the taiga zone forests.

The peculiarity of the taiga forest protection from pests is the necessity of their number control on large territories. For the revelation of centres of mass propagation of the most dangerous pest, gypsy moth, the landscape-key method which helps to extract natural territorial complexes favourable by their ecological conditions, tree species composition and age structure for the transition of the pest population into the outbreak stage has been developed. This method is suitable for forecasting of propagation centres of other harmful pests. Centre dynamics reconstruction by aerial space photography materials in combination with traditional forecasting methods and ground observations allows to accomplish the probability control of pest reservations excluding surprise mass pest propagation (6,7).

Damage from natural calamities (windthrows, thunderstorms) depends on the stand types and relief, and from industrial discards - on the neighbourhood of large industrial centres. So possessing in the monitoring data bank (Block 1) the maps of forest-pathological state of forests, regions of the possible showing of unfavourable natural phenomena one can assess the situation in time and reduce to the minimum the potential damage.

Block 4. Control of the forest cutting and reforestation

In multi-forest regions of the country forests have been intensively used for already a long period of time. With the present annual logging volume of about 400 million m^3 forests are cut on the area of more than 2 million ha. Logging enterprises are given forest raw material bases the forest fund of which is not homogeneous in quality and is limited as a rule. That is why the principle of non-exhausting and rational timber use provides for fixed cutting both by the volume and quality in order to ensure even timber use for the whole period of the forest base exploitation, no less than for the period of 80-100 years in ideal case.

However a common situation in practice is when the logging activities is based on the narrow interests of the present day and

the forest cutting is done not only in volumes exceding the norm (allowable cut) but also mostly at the expense of the most valuable tree stands. It causes considerable damage both to the national economy and nature. That is why one of the acute forest monitoring tasks is the control of the logging volume, rational, even use of the forest cut fund and observation of the cutting regulations.

The second important aspect of this problem is the control of reforestation which is carried out unsatisfactorily lately. On large areas of concentrated cuts on plots with former stands of valuable coniferous species reforestation with deciduous species is done. The use of new assembly logging machines results in the destruction of undergrowth and disturbance of the soil cover. On cuts in regions with the mountain relief and permafrost soils erosion and other unfavourable effects take place. The control over the root-taking of forest cultures and effectiveness of measures helping natural regeneration is low. These problems are being solved now in the forest monitoring system (3,9), but are not yet used widely in practice.

Block 5. Assessment of current changes in the forest fund

The forest fund undergoes considerable changes as a result of forest cutting, construction work, oil-and-gas extraction, forest fires, windthrows, damage of forests from diseases and pests, industrial discards, etc. Major part of these changes in the taiga regions is not practically registered with traditional methods. But this information is necessary both for timely elimination of unfavourable consequences and for the actualization of the forest fund data stored in the forest monitoring data bank (Block 1). That is why along with the ground observation data the assessment of the forest fund shanges must include the materials of aerial, mainly space, photointerpretation (3,5,9).

The constituent part of the forest monitoring must be the branch leading and regional centres of aerial space information reception, analysis and thematic processing which are connected with the branch automated system of forest management (OASU-Leskhoz) and its sub-systems: "Forest Fund", "Forest Resources Management" and "Forest Fire Protection". The centres must ensure automated processing of aerial space information and its transformation into cartographic, statistical or other materials necessary for forest management organs of different levels in order to take solutions and carry out forestry activities.

The following tasks must be solved: 1) automated differentiation of the forest fund territory with the extraction of the given (but limited) number of classes (strata) in small-scale thematic mapping, reserve forests inventory revelation of territories damaged by unfavourable effects of the natural and anthropogenic character; 2) compilation, plotting and renewing in the automatic mode of cartographic materials with their storage in the data bank, and transformation into the required scales with the preset level of generalization and thematic content; 3) automated processing of statistical data about the quantitative and qualitati-

ve forest characteristics and their transfer together with the cartographic data into the data bank "Forest Fund" OASU-Leskhoz.

If we take into account the large area of the country's forest fund and possible scope of the coming information it is expedient to create 2-3 regional centres in the European part of the USSR, in Siberia and Far East, and 5-10 stations of information processing in the rest regions. The equipment of the centres and stations must be of the same type and may differ in the capacity and scope of the work done.

Conclusions

The forest monitoring functioning must ensure the obtaining of the considerable nature conservation and national economic effect thanks to: a) the availability of reliable data and on their basis timely acquisition (in alpha-numeric and cartographic form) of information representative for the complex solution of questions dealing with the forecasting, perspective and current planning, and economic activities on the forest fund territory; b) considerable reduction of labour consumption and terms of work on forestry and logging measures, forest inventory, mapping, soil, geo-botanical, forest protection and other investigations; c) improvement of forest protection from pests and fungus diseases, and forest fire protection, timely use of the damaged timber, reforestation and preservation of environment forming functions of forests.

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