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Mapping of the Regenerative and Age Dynamics of Taiga Forests on the Basis of Remotely Sensed Data, Geographical Knowledge, and Mathematical Models

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Abstract: This paper is concerned with a new method for mapping taiga forests using high-resolution remotely sensed data and mathematical models. New technologies are suggested for processing space-acquired images. Mapping results for the northern Irkutsk region (Ust-Ilimsk district) are presented.
Key words: remote sensing; forest mapping; mathematical models
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1 INTRODUCTION

Estimating biological parameters of vegetation cover is an important element of the study on forest ecosystems. Phytoindication methods used in remote sensing are based on identifying the linkage between spectral characteristics of the image and biological parameters (such as the reserve of phytomass, and species composition), parameters of forest stands and seasonal variability of the spectral radiance coefficient.

In determining bioparameters and identifying terrestrial surface structures, high-resolution multispectral images are considered most appropriate. It is a matter of common knowledge that spectral curves of natural objects are determined by three spectral regions: green, red, and near infrared. Existing methods for processing multispectral images are represented by linear combinations of spectral bands with coefficients obtained from field measurements, and with ratio indexes of spectral band brightnesses which are usually referred to as vegetation indexes.

To map and model the regenerative and age dynamics of taiga forests we used different-quality information derived from space-based research, cartographic data, ground-level research findings, archival data, and GIS databases. The entire data set includes 1) high resolution satellite images (Landsat TM, Landsat ETM +, and ASTER/TERRA); 2) topographic maps at a scale of 1∶100000, and 1∶200000; 3) data of national forest reserve inventories, and forest assessment descriptions; and 4) field route survey materials.

The ground-based observations were made as part of the route surveys, with visual, descriptive and photographic fixing of landscapes to verify image interpretation results. The data obtained were processed using different methods with the purpose of comparing the image processing results with field investigations to generate the landscape map, the map of forest types, and predictive maps of the dynamics.

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2 METHOD

Computer-aided interpretation of images does not take proper account of the geographical principles of investigations: the territoriality, integrated character, multifactoriality, ambiguity, uniqueness, concreteness, individuality, account for local conditions, etc. The image is more frequently regarded as a whole, rather than as a territorial system of heterogeneous objects. Consequently, it is necessary to switch over to the local analysis of geoimages where not the methods of statistical processes but of mathematical analysis are mostly used, including numerical methods of analysis capturing the individual character of geographical reality.

The interpretation procedure is customarily divided into sequential logical stages, the main of which are recognition, interpretation, and decision-making. At the recognition stage, an analysis is made of the interpretation attributes to solve the problem of establishing the depicted objects, phenomena or their properties. This most easily formalizable, stage has received wide acceptance in raster image processing programs.

Thematic interpretation is performed upon completion of the recognition stage and involves constructing a model of factors influencing the state and classification position of interpretation objects. An object is assigned to a particular classification group using a set of rules that not necessarily follow from the properties and characteristics of the remotely obtained image. Interpretation uses logical categories based on correlative links between geosystems components. Decision-making in thematic interpretation is mainly associated with the procedure of graphically identifying a current object. The apparent simplicity of the decision-making stage in practice involves one of the most tedious and non-technological procedures of estimating the degree of reliability of the interpretation reference attributes for a current object.

In the process of interpreting satellite images, the following problems are solved: recognizing the boundaries of natural objects depicted on images, establishing interrelationships between individual objects and characteristic properties of their spatial location, and recognizing and recording dynamical natural processes and phenomena that occur and develop over the territory encompassed by satellite imagery.

Analysis of geoimages in delineating the ecosystems is based on representing it as a system of data, i.e. such a set of qualitative and quantitative characteristics for the territory, each of which is uniquely inferable from the others using one-type relations. In this case, a study of the system's properties reveals a great deal of new fundamental possibilities that are commonly referred to as identifiability. In an abstracting-theoretical treatment, the notion of identifiability (parametric at least) is a particular case of observability (a possibility of indirectly determining the quantities, based on measuring some other quantities and using a priori information). Parametric identifability implies a possibility of determining the parameters of a mathematical model or a process from observations spanning some time interval[1].

2.1 Jacobi's determinant

Good results from processing multiband images are provided if Jacobi's determinant, the Jacobian, is used[2,3]. There exists some invariant property of the ecosystem that retains its value within a natural contour, and within this contour brightness characteristics of satellite images are related by a definite functional correlation that varies on the boundary. If the brightness characteristics of such images are specified parametrically $x_i(x, y, t)$, where (x, y, t) are spatial coordinates of a pixel and the observation time, then Jacobi's determinant D, which is decomposed into minors, is 0, is the characteristics $x_i(x, y, t)$ are interrelated.

$$D=\begin{vmatrix} \frac{\partial x_1}{\partial x} & \frac{\partial x_1}{\partial y} & \frac{\partial x_1}{\partial t} \\ \frac{\partial x_2}{\partial x} & \frac{\partial x_2}{\partial y} & \frac{\partial x_2}{\partial t} \\ \frac{\partial x_3}{\partial x} & \frac{\partial x_3}{\partial y} & \frac{\partial x_3}{\partial t} \end{vmatrix}=0$$

$$D=\begin{vmatrix} \frac{\partial x_1}{\partial x} & \frac{\partial x_1}{\partial y} \\ \frac{\partial x_2}{\partial x} & \frac{\partial x_2}{\partial y} \end{vmatrix}\frac{\partial x_3}{\partial t}+\begin{vmatrix} \frac{\partial x_1}{\partial x} & \frac{\partial x_1}{\partial y} \\ \frac{\partial x_3}{\partial x} & \frac{\partial x_3}{\partial y} \end{vmatrix}\frac{\partial x_2}{\partial t}+\begin{vmatrix} \frac{\partial x_2}{\partial x} & \frac{\partial x_2}{\partial y} \\ \frac{\partial x_3}{\partial x} & \frac{\partial x_3}{\partial y} \end{vmatrix}\frac{\partial x_1}{\partial t}=0$$

More importantly, the way in which (or in terms of which particular type of models, this correlation holds for all models of the description of objects does not matter. D induces the presence or absence of such correlation. There appears an objective criterion for identifying homogeneous D = 0 and heterogeneous D ≠ 0 ecosystem areas. The proximity of D to 0 determines the degree of homogeneity (spatial homogeneity) of ecosystems.

Comparison of route survey results with the findings from interpreting satellite images (NDVI and identification of the boundaries of forest ecosystems using Jacobi's determinant (Fig. 1)) in order to delineate the natural boundaries suggest that the automatically identified boundaries (by Jacobi's criterion, the existence of a functional dependence) correspond mainly to regions of relief line inflection (edges, watersheds, lower parts of the slopes), as well as indicating an abrupt change in the structure of biogeocoenoses. For each ecological-geographical situation, which on images is recorded as an individual of the ecosystem, typically has its own linkage system of parameters of the tree stand, surface cover, and soil influencing the single-type character of the dependence of image characteristics in different survey channels, and this is actually recorded using the criterion selected.

Fig. 1. Results from processing space-acquired images
(a) NDVI (Landsat ETM+); (b) Ecosystem boundaries delineated using Jacobi's determinant (ASTER/TERRA).

2.2 Generating a landscape map

To explain the objective identification of the locations and of their subsequent standardization, a digital model for the relief was constructed. The 1 : 25000 landscape map at the level of facies was compiled on its basis from field observation results using space-acquired information and results from its automatic processing with the use of Jacobi's determinant (Fig. 2).

The dynamical aspect was reflected in the legend to the map: the name of landscape facies is followed (in brackets) by its dynamical state: (N) — native, (N) — imaginary native, (S) — serial, and (SL) — stable long-derivative transformed (disturbed), of different variability. The map shows also the geotechnical systems, and the character of anthropogenic transformations: anthropogenically transformed, and anthropogenically disturbed. The former, upon cessation of the anthropogenic impact, can revert to a state close to the original state, and, on the other hand, the changes have a long or irreversible character.

Legend of the landscape map:

A. ARCTIC-BOREAL NORTH-ASIAN

A_ SUBAREAL PLAINS-UPLAND TAIGA-FOREST SHARPLY CONTINENTAL MODERATELY WET AND DIFFERENT THERMAL CONDITIONS (MIDDLE-SIBERIAN)

A. I. Plains southern taiga

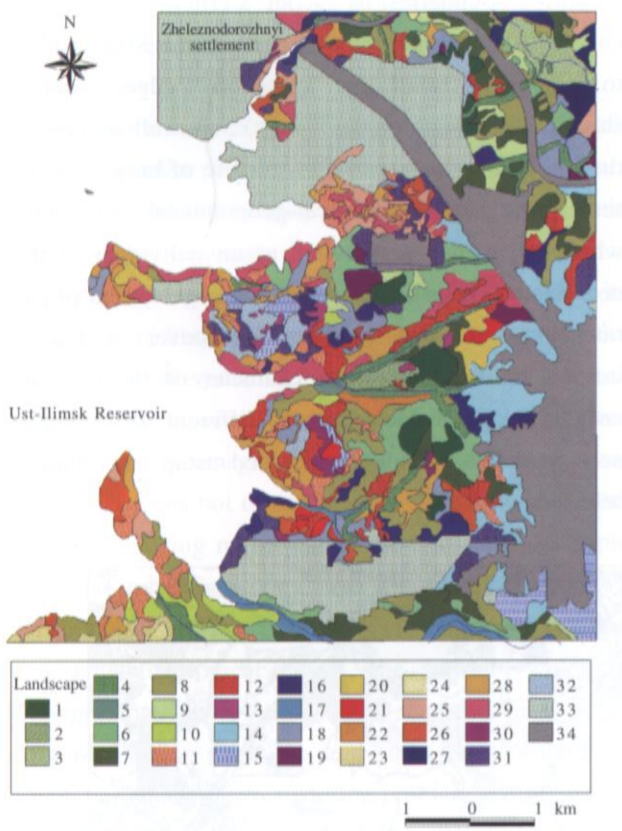

Fig.2 Landscape map for the key area

A_1I_1. Dark-coniferous denudation plateau-plains

1. Interfluve of elevated plains, fir-stone-pine with undergrowth of honey-sucke and juniper, grass-green moss, on soddy-taiga soils (N); 2. Dome-shaped tops of watersheds, fir-spruce-larch, with undergrowth of honey-suckle, grass-green-moss, on soddy-taiga soils (N); 3. Valley and floodplain spruce-fir large-grass on humus and humus-peaty soils combined with alluvial soddy (S); 4. Bottoms of creek valleys and narrow river valleys, fir (with stone pine and spruce), large-grass, on humus and humus-peaty soils combined with alluvial soddy (S); 5. Bottoms of creek valleys and narrow river valleys, fir-spruce, fir, on humus and humus-peaty soils combined with alluvial soddy (S); 6. Slope footing, fir-stone pine with the involvement of larch, with mixed undergrowth, forbs, with patches of green mosses, on soddy-taiga soils (N); 7. Gently sloping weakly dissected surfaces, dark-coniferous grass-green moss, on soddy-taiga soils (N); 8. Slopes of moderate steepness. Fir-spruce-larch grass-green-moss on soddy-taiga soils (N); 9. Slopes of moderate steepness dark-coniferous with the inclusion of larch, grass-shrubs with patches of green mosses, with mixed undergrowth, on soddy-taiga soils (N); 10. Steep slopes dark-coniferous with the inclusion of larch, grass-shrubs, with patches of green mosses, with mixed undergrowth, on soddy-taiga soils (N);

Anthropogenically-disturbed

11. Gently sloping weakly dissected surfaces pine with the inclusion of fir, forbs on soddy forest soils (SL); 12. Slopes of moderate steepness pine with the involvement of dark-coniferous species, forbs, with undergrowth of spiraea and mountain-ash, on soddy-taiga soils (SL);

Anthropogenically modified

13. Leveled areas of watersheds aspen progressive series (with larch and stone pine as undergrowth) with mountain ash and alder as undergrowth, sedge-forbs on soddy-taiga soils; 14. Flat weakly dissected surfaces birch progressive series (with fir and stone pine as undergrowth) shrub forbs on soddy forest soils;

15. Flat weakly dissected surfaces birch progressive series (with spruce and fir as undergrowth), forbs, on soddy forest low-thickness loamy and light-loamy soils; 16. Gently-sloping weakly dissected surfaces birch progressive series with the inclusion of dark-coniferous species shrubs forbs on soddy forest soils;

17. Bottoms of small creek and river valleys, birch (with stone pine and fir as undergrowth) forbs on soddy-forest soils combined with alluvial soddy; 18. Slopes of moderate steepness, birch progressive series (with fir and spruce as undergrowth) shrubs forbs on soddy forest soils; 19. Slopes of moderate steepness aspen progressive series (with fir and stone pine as undergrowth) with honey-suckle in undergrowth sedge-forbs on soddy forest soils;

A_1I_2. Light-coniferous-taiga denudation-erosion plateau-plains

20. Leveled areas of watersheds pine foxberry-forbs with mixed undergrowth on soddy-taiga soils (N);

21. Lowerings of watersheds and gentle near-watershed slopes larch with spruce and fir, grass-shrub with patches of green mosses on soddy-taiga soils (N); 22. Gentle near-valley slopes light-coniferous

with spruce and stone pine, grass-green moss, on heavy-loamy soddy-forest soils (N); 23. Gently sloping of weakly dissected surfaces larch with the inclusion of pine, grassmoss, on soddy-taiga soils (N); 24. Gently sloping of weakly dissected surfaces larch shrub-moss on soddy-taiga soils (N); 25. Slopes of moderate steepness pine sedge-forbs with mixed undergrowth on soddy taiga soils (I);

A$_2$. SUBBOREAL MOUNTAIN AND MOUNTAIN-VALLEY TAIGA OF WET AND CONTRAST THERMAL CONDITIONS OF INLAND MIDDLE MOUNTAINS AND HIGH PLATEAUX

A$_2$ I. Mountain-taiga light-coniferous southern-Siberia type

A$_2$ I. Piedmont elevations light-coniferous of optimal development

26. Gently-sloping weakly dissected surfaces pine fox-berry-forbs with sparse undergrowth of dog rose and alder on slightly loamy soddy grey forest low-humic soils (N); 27. Floodplain and terrace birch grass with patches of green mosses on floodplain-layered low-thickness soils (S); 28. Slopes of moderate steepness pine with larch with mixed undergrowth, forbs, on soddy grey forest soils (N); 29. Slopes of moderate steepness pine foxberry-forbs on soddy-taiga soils (S);

Anthropogenically modified

30. Gently-sloping weakly dissected surfaces, aspen progressive series with the inclusion of pine with undergrowth of alder and honey-suckle, forbs, on soddy forest soils; 31. Gently-sloping weakly dissected surfaces birch progressive series with the inclusion of light-coniferous, forbs, on soddy forest soils; 32. Flat weakly dissected surfaces birch progressive series (with spruce and larch as undergrowth), forbs-grass, on soddy forest thick loamy and slightly loamy soils;

B. GEOTECHNICAL SYSTEMS

33. Residential; 34. Transport-technical.

2.3 Geographical analysis of forest ecosystems

A definite natural regime of functioning and development corresponds to each facies. Within a facies, forest regenerative in cut-over and burned-over areas follows a certain sequence of biocoenoses succession to form a climax coenosis (regenerative and age series, succession). A change of states embodies time-different manifestations of the changes in ecosystems caused, in particular, by meteo-energetic factors, and by the succession-age dynamics of the biota, both natural and associated with human activity[4,5].

As is known, different ecosystems are characterized by different impacts of naturally-occurring destructions on the taiga and its different sensitivity to natural and anthropogenic effects, as well as by a different course of its restoration. Geographical patterns of the dynamics of these processes deserve study in the interests of rational utilization and conservation, improvement and build-up of the region's taiga forests. On the other hand, an understanding of the dynamics, disturbances and restoration, succession and age changes of the forest in regard to key types of landscape units and in different landscape regions is of great scientific interest, specifically for developing a theoretically well-grounded and practicable ecological-geographical classification of taiga lands, estimating the coefficients for predictive models of the taiga forest dynamics with due regard for landscape structure.

Important implications for the geographical analysis of forest ecosystems come from the regenerative and age dynamics that determines the short-term changes in forest cover, and the changes introduced by natural and anthropogenic destructive impacts which make it possible to explore and assess the potential possibilities that the forest cover would recover, its future properties and economic significance, and the changes associated with geosystems transformation processes that are responsible for the possible formation of biogeocoenoses in the new evolving environmental conditions. The first two types of changes lead to restoration and stabilization of forest cover, and the third type of dynamics is characterized as a transforming one.

3 RESULTS

3.1 Interrelationship between forest-typological and landscape-geographical units

The idea of a reconciled classification of the vegetation cover from the landscape-geographical standpoint was put forward by V. B. Sochava[6]. Forest biogeocoenoses according to the character of forest-vegetation conditions correspond to elementary individuals of a particular landscape facies.

The study of the regenerative and age dynamics of communities has a long history and received a rather clear justification in forest biogeocoenology in connection with the development of the genetic approach to forest typology by B. P. Kolesnikov[7,8]. Also, he formulated the concept of the forest-forming process as a specialized version of the general and historical concept that reflects, under present conditions, the characteristics of emergence, formation, destruction and transformation of forest cover, as well as the changes in forest-vegetation conditions and of the entire system of interrelationships of the natural complex. The forest type is regarded as a certain temporal stage of the forest-forming process characteristic for a particular type of landscape conditions. Forest types of a genetic classification reflect to a different extent the spatial-orographic differentiation of forest-vegetation conditions (the conditions of growth location, the landscape structure of the territory), and the changes in growing vegetation associated with the process of settlement, emergence and formation of forest communities, and their functioning across time, destruction, and subsequent restoration. Early in stage, the dynamical aspect reflected a combination, in a single forest type, of native and derivative (potentially native) communities of the demutation series but led subsequently to a need for a special study of the regenerative and age dynamics or assessment of forest communities in terms of their dynamical state.

Territorial characteristics of regenerative and age dynamics of taiga ecosystems can be revealed by inferring the changes in the structure of tree stands through diversity patterns of their composition. The above approach to identifying the dynamics is justified by the fact that the distribution of vegetation cover of the succession or demutation series in space can correspond to their sequential changes across time[9], and by relevant concepts suggested by N. V. Tretiakov that in studying the course of growth it is advisable to combine different-age stands having a similar history (of the same forest type), into a single natural-genetic series of development[10].

The dynamics of forest communities over time is also revealed through a mathematical-statistical analysis of the assessment data on the forest reserves. For this purpose, assessment descriptions of the areas must be classified according to forest types by averaging assessment characteristics over age classes. However, geographical interpretation requires comparing classification categories of silvics (phytocoenosis, forest community, biogeocoenoses, assessment area, forest type, and the type of regenerative conditions) and landscape studies (elementary individual, facies).

3.2 Progressive series of forest types

The processes of regenerative and age dynamics, observed in the Irkutsk region, have been brought about mostly by forest fires and, to a significant extent, by continuous felling[11]. The other factors that destroy tree stands or introduce dramatic changes into the environmental conditions in them, have a very infrequent occurrence over this territory.

The trend of regenerative and age dynamics of forests is determined by the territory's landscape structural features (forest vegetation conditions). In small areas, the differences of this process depend on soils and position relative to relief elements. And, to a lesser extent, this process is also influenced by climatic factors; therefore, in different parts of the Irkutsk region, even at places with similar soils and relief, the regenerative and age dynamics of the forests is proceeding in a different fashion.

In the Irkutsk region, the following progressive series of forest types are rather clearly identified according to L. V. Popov (Fig. 3)[12].

I. Series of dark-coniferous taiga on soddy-podzolic and soddy-forest ferruginous loamy soils of drained watersheds and slopes.

II. Series of dark-coniferous taiga on soddy-podzolic and soddy-forest ferruginous loamy and clayey soils of flat watersheds and wet slopes.

III. Series of pine stands on soddy-podzolic and soddy-forest ferruginous soils with intermittent fires.

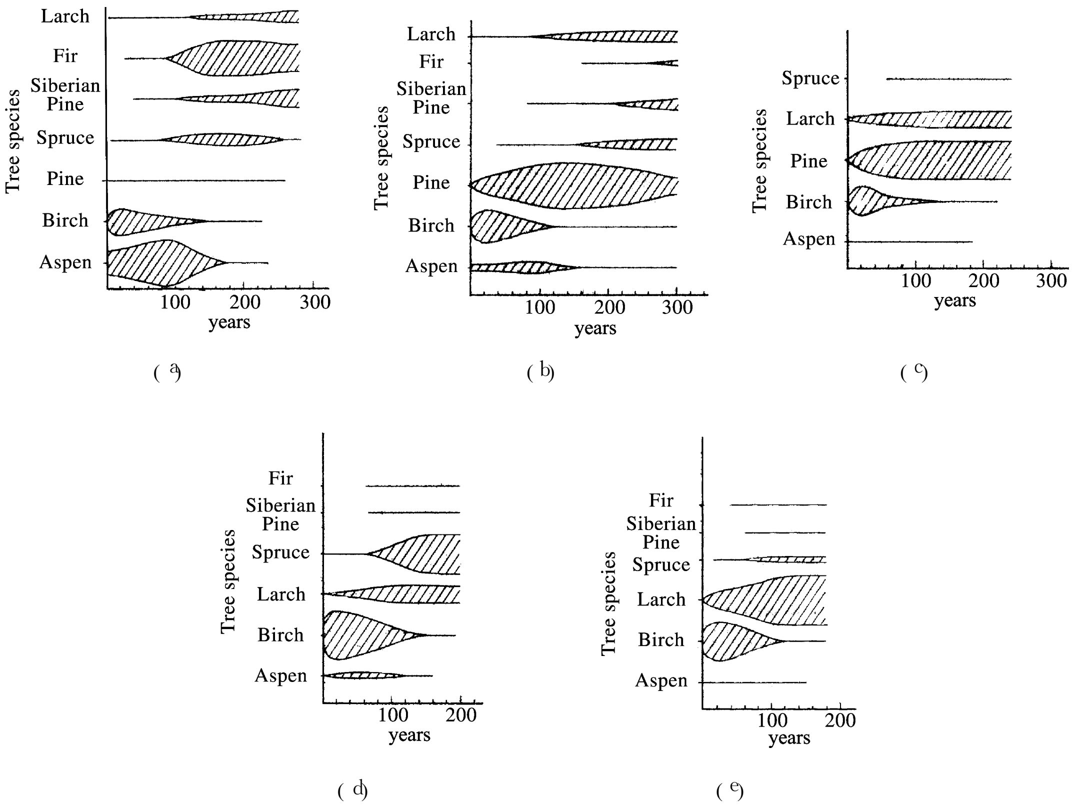

Fig 3 Dynamics diagrams of species composition of tree stands for progressive series
(a) II (b) III (c) VIII (d) IX (e) X

IV Series of pine stands on soddy-podzolic and podzolic soils of light mechanical composition.

V Series of pine stands on sandy podzolic soils of the watersheds and upper terraces of river valleys with intermittent ground fires.

VI Series of light coniferous forests on soddy-calcareous soils with long-lasting periods between fires.

VII Series of light coniferous forests on soddy-calcareous soils with frequent sweeping ground fires.

VIII Series of pine stands on soddy-podzolic and soddy-forest ferruginous and clayey soils of the northern part with intermittent fires.

IX Series of spruce stands of the lower part of the hillsides with soddy-podzolic and soddy-forest ferruginous soils.

X Series of larch stands on the hillsides with soddy-podzolic and soddy-forest ferruginous loamy and clayey soils.

XI Series of stone pine stands in low-lying watersheds with soddy-podzolic soils.

A classification of progressive series as suggested by L V Popov for the subzone of the Southern taiga of the Middle Siberia is largely similar to a classification of landscapes for this territory as identified by V B Sochava[4, 12]. For instance, the series of dark-coniferous taiga on medium-podzolic and soddy-forest ferruginous loamy soils of the drained watersheds and slopes is realized within the boundaries of the southern taiga dark-coniferous-forest class of facies of fixed elevations. The existing links of the facial structures of the territory with the dynamics of tree stands permit, on the one hand, landscapes on a terrain to be more easily identified, and, on the other, the forest dynamics to be inferred at a particular point of space from landscape mapping results.

3.3 Comparison of the landscape structure and progressive series of the forest type

Within the boundaries of each facies, the simplest variant of directional or fluctuational dynamics is realized. From start to finish, this process is evolving unidirectionally, and all elements involved fully reach their final state corresponding to a given facies. In this case, each of the dynamics stages characterizes the formation time of the community during which its composition is dominated by a definite forest-producer or a generation of a tree stand that has an edificatory and regulatory effect on the intracoenotic environment, and on biogeocoenotic processes[12].

Based on our research results, it was established that definite progressive series of the forest type correspond to different facies and progressive series of the key area(Table 1).

Table 1 Comparison of facies and progressive series for forest types

Landscape facies	Progressive series
Interfluve of elevated plains, fir-stone-pine with undergrowth of honey-sucke and juniper, grass-green moss, on soddy-taiga soils nterfluve of elevated plains	II
Dome-shaped tops of watersheds, fir-spruce-larch with undergrowth of honey-suckle, grass-green-moss, on soddy-taiga soils	II
Valley and floodplain spruce-fir large-grass on humus and humus-peaty soils combined with alluvial soddy	IX
Bottoms of creek valleys and narrow river valleys, fir (with stone pine and spruce), large-grass, on humus and humus-peaty soils, combined with alluvial soddy	IX
Bottoms of creek valleys and narrow river valleys, fir-spruce, fir, on humus and humus-peaty soils combined with alluvial soddy	IX
Slope footing, fir-stone pine with the involvement of larch, with mixed undergrowth, forbs, with patches of green mosses, on soddy-taiga soils	II
Gently sloping weakly dissected surfaces, dark-coniferous grass-green moss, on soddy-taiga soils	II
Slopes of moderate steepness, fir-spruce-larch grass-green-moss, on soddy-taiga soils	II
Slopes of moderate steepness dark-coniferous with the inclusion of larch, grass-shrubs, with patches of green mosses, with mixed undergrowth, on soddy-taiga soils	III
Steep slopes dark-coniferous with the inclusion of larch, grass-shrubs, with patches of green mosses, with mixed undergrowth, on soddy-taiga soils	III
Gently sloping weakly dissected surfaces pine with the inclusion of fir, forbs on soddy forest soils	III
Slopes of moderate steepness pine with the involvement of dark-coniferous species, forbs, with undergrowth of spiraea and mountain ash, on soddy-taiga soils	III
Leveled areas of watersheds aspen progressive series (with larch and stone pine as undergrowth) with mountain ash and alder as undergrowth, sedge-forbs, on soddy-taiga soils	II

Continue

Landscape facies	Progressive series
Flat weakly dissected surfaces birch progressive series (with fir and stone pine as undergrowth), shrub forbs on soddy forest soils	IX
Flat weakly dissected surfaces birch progressive series (with spruce and fir as undergrowth), large-grass, on soddy forest thick loamy and light-loamy soils	IX
Gently-sloping weakly dissected surfaces birch progressive series with the inclusion of dark-coniferous species shrubs forbs on soddy forest soils	IX
Bottoms of small creek and river valleys, birch (with stone pine and fir as undergrowth), forbs on soddy-forest soils combined with alluvial soddy	IX
Slopes of moderate steepness, birch progressive series (with fir and spruce as undergrowth), shrubs forbs on soddy forest soils	IX
Slopes of moderate steepness aspen progressive series (with fir and stone pine as undergrowth) with honey-suckle in undergrowth sedge-forbs on soddy forest soils	II
Leveled areas of watersheds pine foxberry-forbs with mixed undergrowth on soddy-taiga soils	VIII
Lowerings of watersheds and gentle nearwatershed slopes larch with spruce and fir, grass-shrub, with patches of green mosses on soddy-taiga soils	X
Gentle near valley slopes light coniferous with spruce and stone pine, grass-green moss, on heavy-loamy soddy-forest soils	VIII
Gently sloping of weakly dissected surfaces larch with the inclusion of pine, grass-moss, on soddy-taiga soils	VII
Gently sloping of weakly dissected surfaces larch shrub-moss on soddy-taiga soils	X
Slopes of moderate steepness pine sedge-forbs with mixed undergrowth on soddy taiga soils	VIII
Gently-sloping weakly dissected surfaces, pine foxberry-forbs, with sparse undergrowth of dog rose and alder, on light loamy soddy grey forest low-humic soils	VIII
Floodplain and terrace birch grass with patches of green mosses on floodplain-layered low-thickness soils	IX
Slopes of moderate steepness pine with larch with mixed undergrowth, forbs, on soddy grey forest soils	VIII
Slopes of moderate steepness pine foxberry-forbs on soddy-taiga soils	VIII
Gently-sloping weakly dissected surfaces, aspen progressive series with the inclusion of pine with undergrowth of alder and honey-suckle, forbs, on soddy forest soils	III
Gently-sloping weakly dissected surfaces birch progressive series with the inclusion of light coniferous, forbs, on soddy forest soils	X
Flat weakly dissected surfaces birch progressive series (with spruce and larch as undergrowth), forbs-grass, on soddy forest thick loamy and slightly loamy soils	X

3.4 Prognostic-dynamical maps of forest types

Based on the data for progressive series of forest types and on comparing them with the facial structure (see Table 1), the landscape map (see Fig.2), and forest assessment data, it was possible to create the map for the present state of forest types (Fig.4), and the prognostic-dynamical maps for forest types for a period of 50 and 100 years (Fig.5 and 6).

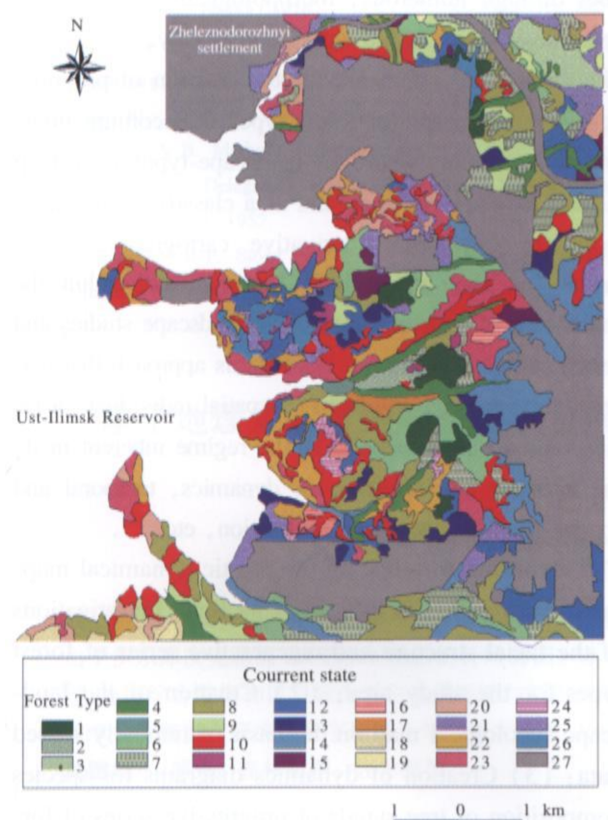

Fig.4 Map for forest types (present state)

1. Stone pine-fir stands with undergrowth of honey-suckle and juniper, grass-green moss; 2. Fir-spruce-larch with undergrowth of honey-suckle, grass-green moss; 3. Spruce-fir, large grass; 4. Fir (with stone pine and spruce), large grass; 5. Fir-spruce, fern; 6. Stone pine-fir with the involvement of larch with mixed undergrowth, forbs with patches of green mosses; 7. Dark-coniferous, grass-green moss; 8. Fir-spruce-larch, grass-green moss; 9. Dark coniferous with the inclusion of larch, grass-dwarf shrub, with patches of green mosses; 10. Pine stands with the involvement of dark-coniferous species, forbs; 11. Aspen-tree stands (with larch and stone pine as undergrowth) with mountain ash and alder as undergrowth, sedge-forbs; 12. Birch stands with the inclusion of dark-coniferous species, shrubs-forbs; 13. Birch stands (with stone pine and fir as undergrowth), forbs; 14. Birch stands (with fir and spruce as undergrowth), shrubs-forbs; 15. Aspen-tree stands (with fir and stone pine as undergrowth) with mountain ash as undergrowth, sedge-forbs; 16. Larch stands with spruce and fir, grass-shrubs, with patches of green mosses; 17. Light-coniferous with spruce and stone pine, grass-green moss; 18. Larch stands with the inclusion of pine, grass-moss; 19. Larch stands, shrubs-moss; 20. Pine stands, sedge-forbs, with mixed undergrowth; 21. Birch stands, grass, with patches of green mosses; 22. Pine stands with larch with mixed undergrowth, forbs; 23. Pine stands, foxberry-forbs; 24. Aspen tree stands with the inclusion of pine with undergrowth of alder and honey-suckle, forbs; 25. Birch stands with the inclusion of light-coniferous species, forbs; 26. Birch stands progressive series (with spruce and larch as undergrowth), forbs-grass; 27. Anthropogenic structures

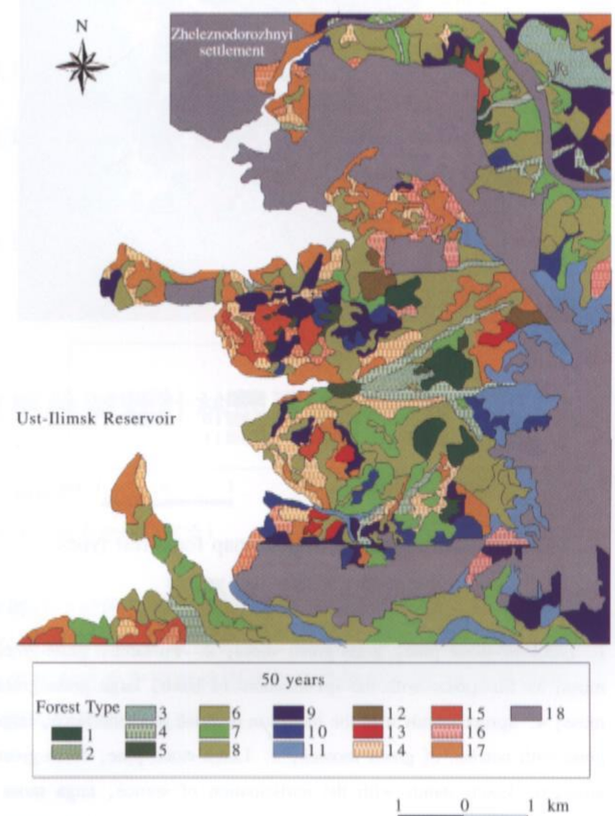

Fig.5 Prognostic-dynamical map for forest types (the state within 50 years)

1. Fir-stone pine with the involvement of larch, grass-green moss; 2. Fir larch stands with the involvement of spruce, grass-green moss; 3. Fir-spruce, large grass; 4. Spruce-fir with the inclusion of stone pine, large grass; 5. Larch-stone pine with the involvement of fir, forbs with patches of green mosses; 6. Stone pine-fir with the involvement of larch, forbs-green mass; 7. Spruce-larch, grass-green moss; 8. Spruce-stone pine-pine, forbs; 9. Birch stands with the inclusion of spruce and larch, green moss-large grass; 10. Birch stands with the inclusion of fir, green moss-large grass; 11. Birch stands with the inclusion of spruce and fir, green moss-large grass; 12. Stone pine-fir with the involvement of larch, forbs; 13. Larch stands with the inclusion of spruce and fir, grass-shrubs with patches of green mosses; 14. Pine stands with the involvement of larch, foxberry-forbs; 15. Larch stands with the inclusion of dark-coniferous species, green moss; 16. Larch

stands, green moss; 17. Pine stands, foxberry-green moss; 18. Anthropogenic structures.

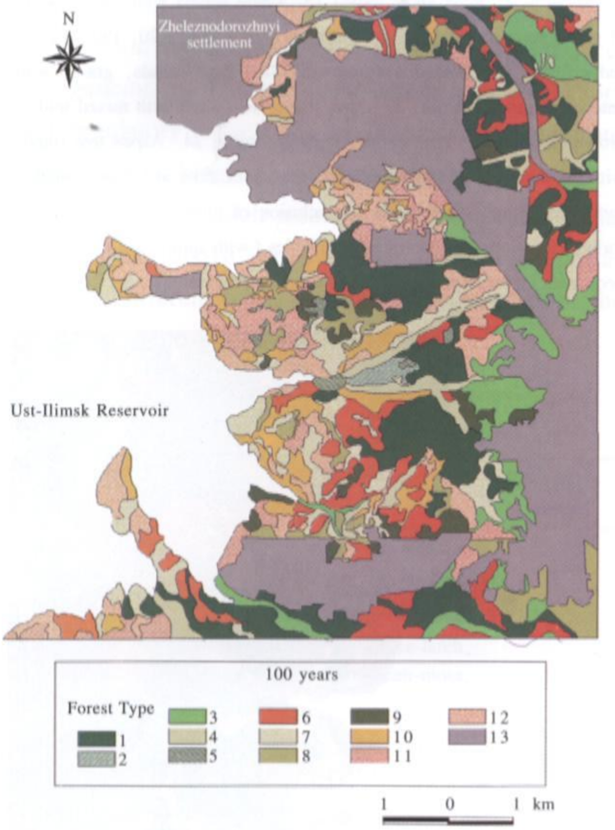

Fig. 6 Prognostic-dynamical map for forest types (the state within 100 years)

1. Larch-fir-stone pine, grass-green moss; 2. Fir-larch, grass-green moss; 3. Fir-spruce with the involvement of larch, large grass green moss; 4. Spruce stands with the inclusion of stone pine and larch, large grass with patches of green mosses; 5. Larch-stone pine, forbs-green moss; 6. Larch stands with the participation of spruce, taiga moss; 7. Spruce-stone pine-pine stands with the inclusion of larch herbaceous; 8. Spruce stands with the inclusion of birch and larch, green moss-large grass; 9. Stone pine-fir stands with the inclusion of larch, green moss-large grass; 10. Pine stands with the involvement of larch, foxberry; 11. Larch stands with the inclusion of dark-coniferous species, green moss; 12. Pine stands брусничные; 13. Anthropogenic structures.

4 DISCUSSION AND CONCLUSION

The comparison of the landscape structure and progressive series of forest types reported here does of course not reflect all possible variants of regenerative and age dynamics of forests. The characteristic property of the last of each facies is determined by ecological conditions of environment, and by the biological properties of the main and accompanying species composing the communities and maintaining a complicated interspecies linkage over the course of the entire cycle of progressive successions. The trend of the dynamics is often determined also by the intensity and recurrence of forest fires that are responsible for the duration of the stages, species composition, and for the appearance of the living surface cover. On the other hand, it has been established that in the process of formation within the boundaries of each facies the vegetation goes through numerous, morphologically similar, regenerative stages of the native community.

The theoretical framework for the creation of prognostic-dynamical maps for forest types is becoming interpretation mapping where the landscape-typological map is used as a contour map and as a classification framework for developing derivative cartographic documents[13]. This approach is best realized within the framework of structural-dynamical landscape studies and genetic silvics, because it is with this approach that it is possible to manage to identify a spatial individual (a facies and a biogeocoenoses), the regime inherent in it, the intensity and sequence of dynamics, temporal and spatial diversity, economic utilization, etc.[14].

The algorithm for creating prognostic-dynamical maps for forest types is as follows: (1) Field investigations of the facial structure and regenerative series of forest types for the study area; (2) Creation of the landscape-typological map on the basis of remotely sensed data; (3) Creation of dynamics diagrams for species composition of tree stands of progressive series of forest types; (4) Referencing of forest assessment data to the landscape-typological map; (5) Comparison of the facial structure and progressive series of the forest type, based on the data obtained as part of the analysis of forest assessment information and field observations; (6) Construction of the prediction of forest development on the basis of the landscape-typological map, and dynamics diagrams for natural composition of tree stands, and entering it into the database; and (7) Visualization of the prediction database in the GIS environment.

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基于地理知识与数学模型以及遥感数据检测针叶林的更新和龄级动态

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摘 要： 本文介绍一种利用高分辨率遥感数据与数学模型绘制针叶林的新方法, 适于处理空间影像数据。结果绘制出了伊尔库次克北部 Ust-Ilimsk地区的针叶林图。本文认为对景观判读绘制成图的 GIS技术需要包括信息调查程序、地图综合数据和以目标为导向的景观图与知识的阐释。应用新方法生产预测林型动态变化的分布图, 此方法使用数学分析模型在研究区数字地图上勾绘地表组成, 并根据直方图勾绘典型的地表组成。

关键词： 遥感；森林制图；数学模型