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New Approaches to Studies on the Dynamics of High-Mountain Tree Vegetation Using Repeated Landscape Photographs: The Example of the Polar Urals

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Abstract—A methodology for the analysis and presentation of repeated landscape photographs is described that has been used to evaluate the spatiotemporal dynamics of sparse tree stands in the upper timberline ecotone on the Rai-Iz mountain massif, the Polar Urals. It is intended to solve problems with the use of such photographs so as to help the researcher to gain an integral representation of the space under study, obtain additional information about the terrain, create and update descriptions to photographs, and construct thematic or schematic maps using repeated landscape photography.

Keywords: repeated landscape photographs, upper timberline ecotone, spatiotemporal dynamics, conventional symbols, schematic map, the Polar Urals

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Landscape photographs and digital images are relative inexpensive but spacious sources containing large amounts of information (Dahdouh-Guebas and Koedam, 2008). They are highly illustrative and provide objective data on the terrain. In recent years, repeated landscape photographs have been widely used in ecology and forestry to evaluate changes occurring over a certain period of time at the levels of landscapes, communities, populations, and organism (Hall, 2001; Nesterov and Sarychev, 2006; Sarychev, 2006; Fomin et al., 2007, 2008a; Shiyatov, 2009; Hendrick and Copenheadver, 2009; Webb et al., 2010; Fomin and Mikhailovich, 2011).

The systematic use of repeated landscape photography in geological and geoecological research dates from the late 19th to early 20th century (Hall, 2001; Sarychev and Nesterov, 2007). Analysis of relevant data shows that the method of ground-based photo monitoring (GBPM) is becoming increasingly popular in ecological studies (Hall, 2001; Hendrick and Copenheadver, 2009; Webb et al., 2010). However, this method has some serious drawbacks that restrict its application on a wider scale (Fomin et al., 2008b; Fomin and Mikhailovich, 2013).

One of them is accounted for by specific representation of spatial information in a photograph: it shows only the fragment of landscape that is visible from a given viewpoint at a certain camera angle, and the same fragment may be hardly recognizable in a photo made from a different viewpoint or angle. This feature makes it difficult for a researcher to gain an integral representation of the territory under study and comprehensively evaluate changes that have occurred throughout its expanse.

Moreover, the initial material for creating a GBPM system often consists of landscape photographs from the archives of scientists, tourists, and amateur photographers that have been taken not for the above purpose but only as a supplement to some other material. Until recently, the situation has been aggravated by the limitations that traditional photographic methods impose on the possibility to obtain a sufficiently large number of images.

Automated analysis of landscape photographs for quantitative characterization of the depicted objects is complicated because of the diversity of these objects and variation of scale values in an image and illumination level within a photo.

Summing up the aforesaid, several problems in working with landscape photographs can be noted, in particular:

—to compile a series of interrelated photographs allowing the researcher (user) to gain a comprehensive overview of the study region;

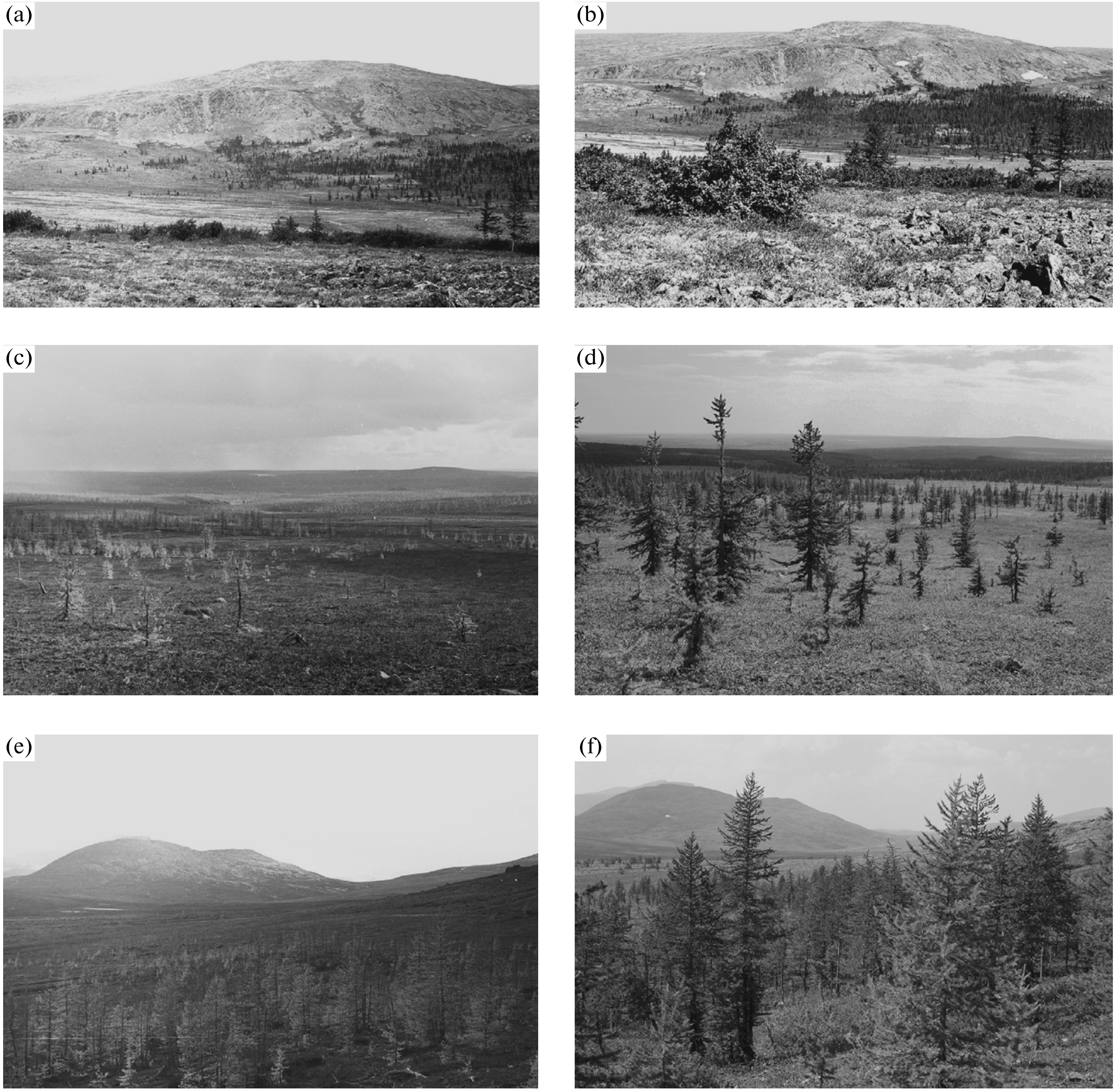

Fig. 1. The Rai-Iz massif and adjacent area: (a, b) the southeastern mesoslope photographed in (a) 1962 and (b) from viewpoint no. 54; (c–f) views on the lower part of the slope in (c) 1960 and (d) 2004 toward the southeast and in (e) 1977 and (f) 2004 toward the southwest from points nos. 247 and 248, respectively.

—to obtain additional data on the terrain shown in the photographs and to create and update textual descriptions and annotations to them;

—to construct thematic or schematic maps based on repeated landscape photographs;

—to quantitatively characterize the photographs and objects shown in them using automated methods and algorithms of image processing and analysis.

In this study, we describe an approach for analyzing the dynamics of mountain forest vegetation based on repeated landscape photographs, which is intended to solve the above described problems.

STUDY OBJECTS AND METHODS

The study is based on repeated landscape photographs from the archive of S.G. Shiyatov that were taken between 1962 and 2004 on the territory of monitoring range in the Rai-Iz mountain massif, the Polar Urals. Detailed characteristics of this area are described in our previous publications (Shiyatov et al., 2005; Fomin, 2009). The object of the study are sparse larch (*Larix sibirica* Ledeb.) stands in the upper timberline ecotone.

Three pairs of photographs in Fig. 1 were taken from viewpoints nos. 54, 247, and 248 and show the

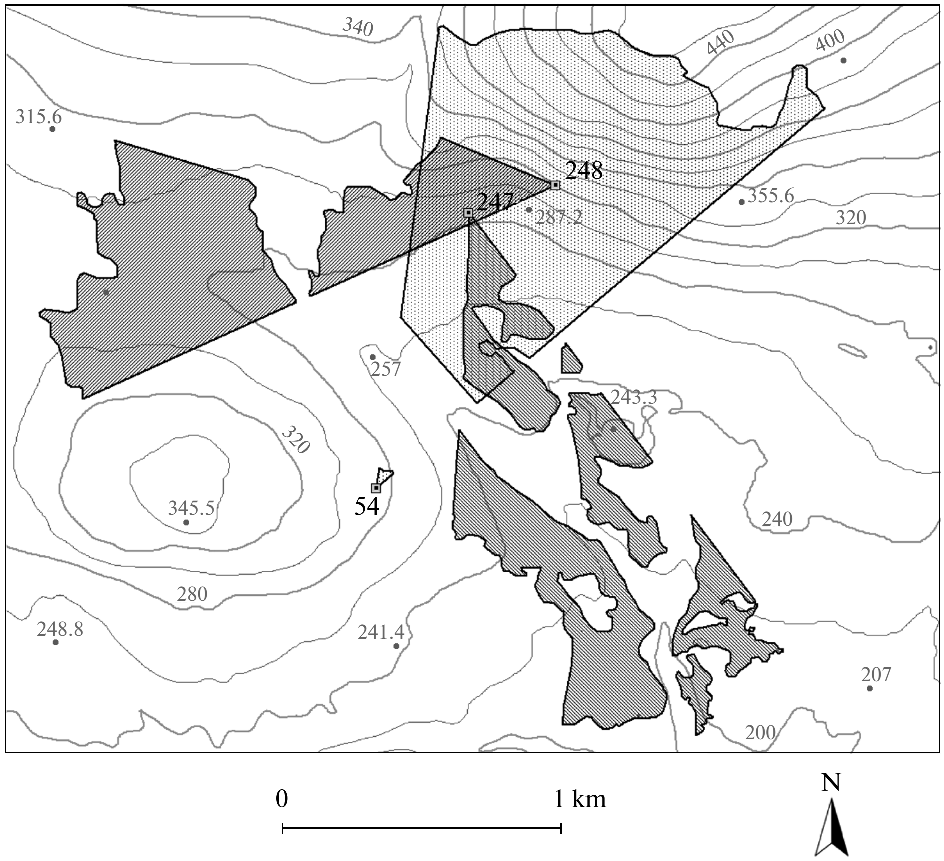

Fig. 2. Sectors with areas visible from viewpoints nos. 54, 247, and 248.

southeastern mesoslope of the Rai-Iz in 1962, 1977, and 204, respectively. However, it can hardly be inferred from these images that they pertain to the same terrain compartment, which is an illustration to the problem of gaining an integral representation of the study region from landscape photographs. The schematic map in Fig. 2 gives a closer look on the positions of viewpoints and camera angles. The areas shown in the photographs are represented in this map as sectors with areas visible from each viewpoint, referred to as viewsheds. The procedure for delimiting these areas was as follows.

Using a digital elevation model (DEM) of the study region in ARC/INFO (ESRI Inc., United States), polygonal vector layers (sectors) were generated for each photograph. Each sector was delimited by straight lines corresponding to the right and left edges of the image that extended from the viewpoint to the boundary of the study region. At the next stage, viewshed rasters based on the DEM were computed using ARC/INFO visibility analysis module. Overlaying these rasters with the sectors generated at the first stage, we obtained polygon layers displaying areas visible or invisible from a given point. Remote sites where tree vegetation was poorly distinguishable were deleted. Thus, a polygonal layer (viewshed) was assigned to each pair of photographs taken from the same point at the same camera angle.

It is a typical situation that landscape photography in the course of GBPM is performed using the equipment with different characteristics. Therefore, the size of the area reflected in photographs taken from a given point may also differ, e.g., depending on the camera's angle of view. If the difference is insignificant, it is safe to ignore it and use repeated photographs with the same (wider) field of view. If the difference is considerable, it is possible to cut off part of the photograph with the wider field of view. However, this procedure should be avoided, because in can result in the irreversible loss of information contained in the cut-off fragment.

The matching between the photographic image of an object and its position on the map is a tedious process, but in can be facilitated by dividing the image with vertical lines drawn at a specified interval, which in this study was equal to 10% of the width of the larger photograph. The corresponding sector in the map is also divided with radial lines extending from the viewpoint at an interval equal to 10% of its total angle, which are equivalent to the vertical lines on the photograph.

Additional data for performing comparative analysis of photographs and drafting textual descriptions can be obtained from geoinformation layers generated using GIS function and models. In this study, we used ARC/INFO functions for computing parameters of slope (the Slope and Aspect tools), generating the layer with concentric zones at specified distances from the photographic point (the Buffer tool), and calculating the compound topographic index (CTI routine) (Evans, 2003).

Geoinformation layers used as initial data for analysis and modeling were as follows: the DEM (raster layer with a spatial resolution of 10 m), vector layers with photographic points, line vector layer with elevation isolines, point vector layer with altimetric points, and linear vector layer for the river network. In addition, we used a high-resolution spectrozonal aerial photograph that was taken in 2004 and orthotransformed using the ERDAS Imagine program package (ERDAS Inc., United States). It served as a basis for generating a point vector layer where the points corresponded to locations of trees in 2004.

RESULTS AND DISCUSSION

The possibility to display the area shown in the photograph and the corresponding region on the map gives an opportunity to solve the problem of gaining an integral idea of the study region using landscape photographs (see Fig. 2). In addition to displaying viewpoints and allowing visual overlay of sectors corresponding to different photographs, GIS technologies offer the topology overlay that can be used to combine the characteristics of several layers onto one, in which new polygons are created by the intersection of the input polygon (sector) boundaries. In our case, each polygon of the output layer is characterized in the attribution table by data on the number of a given viewpoint, photographs taken from this point, and the date of photography. For example, if the polygon formed by the intersection of sectors 54 and 248 is addressed, the table will provide information that the part of the terrain represented by this polygon may be visible in photographs taken from the corresponding viewpoints.

Thus, such a polygon layer or a schematic map made on its basis can serve as an interface for searching and displaying photographs in information systems. This approach not only makes it possible to reveal connections between photographs but also opens up new possibilities for their comparative analysis.

Since a photograph shows parts of the terrain that lie at different distances from the viewpoint, the information that can be obtained using landscape photography pertains to different spatial scales. For example, the general tendencies of change in the distribution of tree vegetation that are well traceable in the background of photographs taken from point no. 54 (Figs, 1a, 1b) can be concretized using information derived from close-up views in the foreground of photographs taken from point 247 (Figs. 1c, 1d). Thus, the fact of shift in the upper timberline and change in tree stand density can be reflected in the background of one landscape photograph, while information from the foreground of another photograph can make it possible to estimate specific features of forest regeneration in a certain area (such as the species composition, abundance, and viability of young tree growth) and other aspects of processes taking place in the plant community.

This is illustrated by the following example. The photographs in Figs. 1a and 1b (taken from point 54) show a band of trees in the left part, and Fig. 1d shows a close-up view of adult and young trees in this band. It is seen that a segment of the stem in the upper part of the crown in adult trees is stripped of branches. Such a shape of the crown is explained by the fact that this forest band retains windblown snow in winter, which is piled up to the upper part of the stem. When the snow begins to melt in spring, it sags under its own weight, breaking the branches. An abundant accumulation of snow can result in suppression of young tree growth, because the snow disappears later in the spring and, hence, the growing period in the corresponding area is reduced.

Thus, the proposed approach to data presentation can help the researcher to solve the problem of gaining an integral representation of the study region from landscape photographs.

To obtain additional data on the terrain shown in the landscape photographs and to create and update textual descriptions and annotations to them, we propose to use spatial data and the results of GIS modeling and their subsequent overlay on the sector of visibility (viewshed) corresponding to a given photograph. Figure 3 shows two repeated landscape photographs taken from point no. 54 and divided into segments by vertical lines as described in Study Objects and Methods, and schematic maps with sets of geoinformation layers for the corresponding sector are presented in Fig. 4. In particular, Fig. 4a shows the isolines of elevation and distances from the photographic point and also the distribution of trees in 2004. This schematic map makes it possible to determine the altitudinal position of the upper timberline and the distance from the observed to the terrain compartment shown in the photographs.

Radial division of the sector overlaid with the slope layer (Fig. 4b) facilitates the task of comparing it with the photographs divided by vertical lines and matching the positions of the objects of interest in the photograph and in the map.

The slope aspect layer combined with data on the compound topographic index, which characterizes soil wetness, provide information indirectly characterizing the amount of direct solar radiation and hydrological regime in the study region (Fig. 3c). An overlay of spatial data on the sector of visibility allows one to obtain a set of quantitative characteristics of the ter-

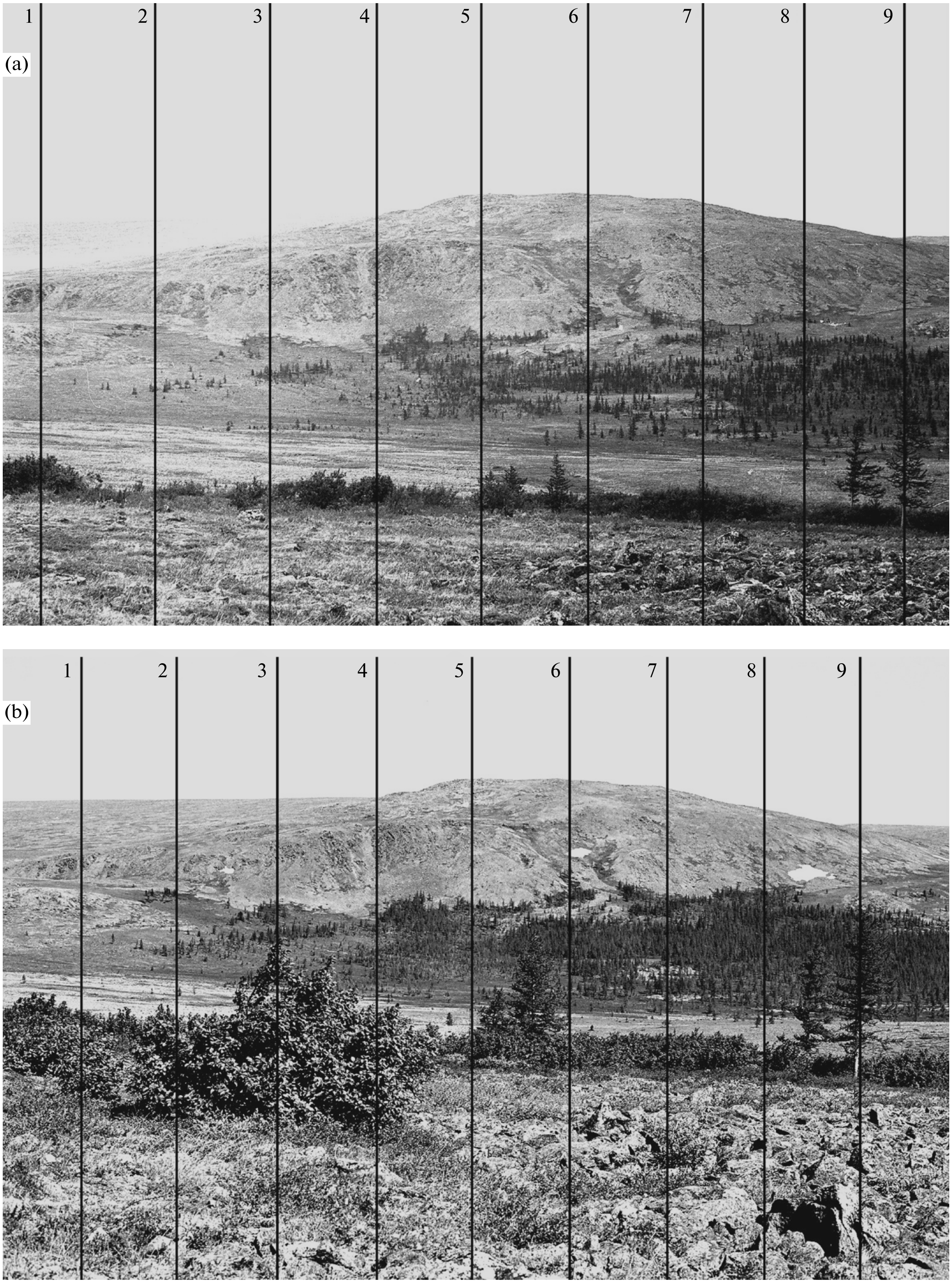

Fig. 3. Landscape photographs taken by S.G. Shiyatov from viewpoint no. 54 in (a) 1962 and (b) 2004. Vertical lines were drawn to facilitate identification of terrain and tree vegetation compartments.

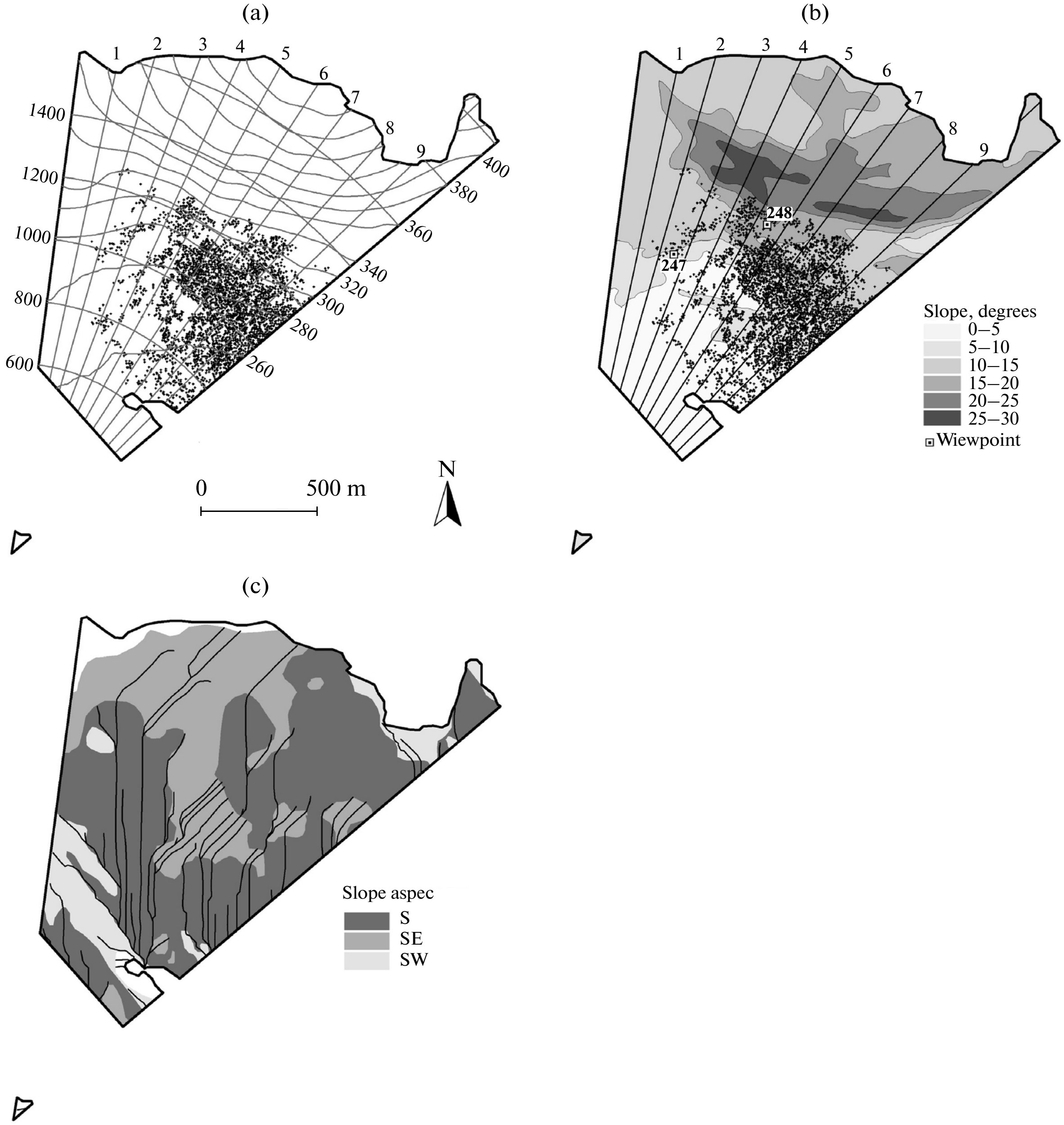

Fig. 4. Schematic maps of the sector with zones visible from viewpoint no. 54: (a) distribution pattern of tree vegetation in 2004, with elevation isolines and distances from viewpoint no. 54; (b) slope gradient and distribution pattern of tree vegetation; positions of viewpoints nos. 247 and 2/48 are indicated; (c) slope exposure and directions of surface water flows.

rain shown in landscape photographs and broadens the possibilities for making textual descriptions and annotations to them. This is illustrated by schematic maps shown in Fig. 4.

It should also be noted that the technology of overlaying the geoinformation layers and viewsheds within the sector corresponding to landscape photographs opens up possibilities for generation of descriptions and annotations based on preloaded textual templates that can be automatically filled with content such as certain values, their ranges, or phrases. This is especially important when the researcher deals with thousands of landscape photographs.

Integrated estimation of the spatiotemporal dynamics of tree vegetation throughout the study region (rather than in a single sector) on the basis of landscape photographs is a complex task because of several factors. They include difficulties in transferring information from the photograph to the map; relatively low accuracy of mapping, which interferes with some kinds of quantitative analysis; difficulties in generalizing data obtained from photographs on different

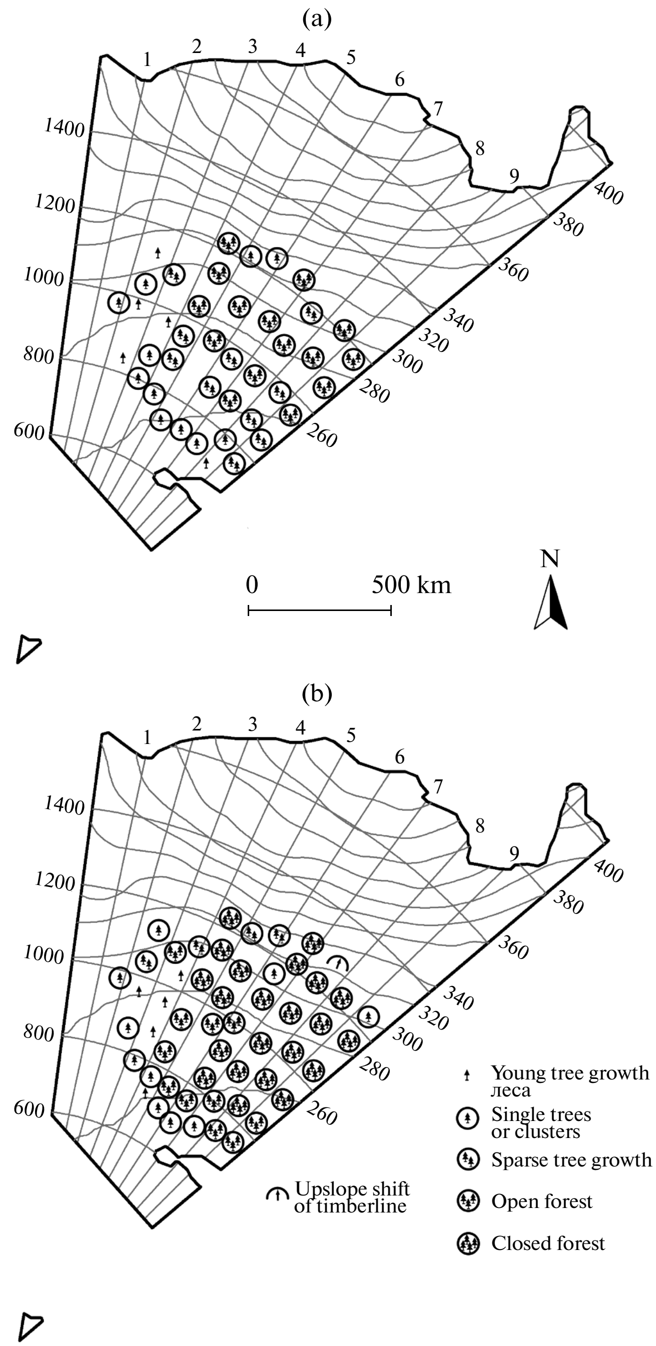

Fig. 5. Schematic maps characterizing tree vegetation pattern on the slope of the Rai-Iz massif in (a) 1962 and (b) 2004 in the area shown in photographs taken from viewpoint no. 54.

scales and in comparing changes in several pairs of repeated photographs taken at different time intervals. These difficulties can be resolved in part using the approach described below.

The schematic maps in Fig. 5 characterize basic changes that occurred in the area visible from photographic point no. 54 over the period from 1962 to 2004. They were constructed based on comparative analysis of the photographs shown in Fig. 3, and the transfer to the map was carried out using the spatial data shown in Fig. 4b (in should be noted that these maps were constructed simultaneously). After determining the position of an object in the photographs and on the map, conditional symbols were applied that characterized the area of interest with respect to the presence of absence of young tree growth, changes in the density of tree vegetation, and its upslope expansion. Schematic maps obtained in this way are the first element necessary for constructing thematic (schematic) maps for the entire study region based on analysis of repeated landscape photographs.

In this context, a need arises to revise current views on the content of identification cards for photographs used in the GBPM system (Nesterov and Sarychev, 2006). A set consisting of repeated landscape photographs, spatial data, and schematic maps shown in Figs. 3–5, along with other data available for a given sector, can serve as an important supplement to the coordinates of the photographic point included in the card.

Thus, the proposed methodology for the analysis and presentation of repeated ground-based landscape photographs contributes to the solution of problems associated with their use, making it less difficult for the researcher to gain an integral idea of the space under study, obtain additional information about the terrain, create and update descriptions to the photographs, and construct thematic or schematic maps based on repeated landscape photography.

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