Usage of GIS Technologies for Ecosystems Monitoring

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Abstract

Aiming to obtain an estimate of the changes in the position of the upper boundary of open spruce forests in the Zigal'ga mountain ridge (South Urals), we used a set of methods: a comparison of aerial photographs, satellite images, and repeated landscape photographs made at different times. A qualitative and quantitative assessment of these changes for the period from 1958 to 2012 was made. The results of the study show that tree vegetation has been actively expanding to higher elevations over the past 54 years. Altitudinal shift of upper boundaries of open forests along the median was 0.74 m/year, and horizontal shift was 0.20 m/year. Expanding open forests are explained by climate warming and increasing humidity, especially in the cold period of the year in the South Urals.

Introduction

At present, one of the major problems of ecology is the identification and quantitative assessment of the transformation of high-mountain ecosystems, and the significance of this problem is increasing with the background of the current climate change.

Climate warming causes the expansion of tree vegetation into alpine tundra, as well as an increase in the density and productivity of previously grown forest stands.

High-mountainous ecosystems are sensitive to changes in environmental conditions and therefore can be used as an indicator of such changes [Gorch85]. In recent decades, numerous facts of the advancement of woody vegetation to higher elevations have been established in many regions of the world. The results of such studies are summarized in articles [Harsch09] и [Myers11]. At the same time, there is a limited amount of material in the special literature on the quantitative assessment of the shift of the upper boundary of forests and open forests [Leon16; Mass16].

The aim of the work is to identify and quantify the changes in the position of the upper boundary of open spruce forests in the South Urals using a set of methods.

Materials and Methods

The key site is located in the northwestern part of the South Urals on one of the mountain peaks (N 54°39' E 58°39', Zigal'ga mountain ridge, mountain Poperechnaya). The present studies covered open spruce forests and thickets growing in the forest-tundra ecotone, which is considered a temperature sensitive transition zones that are expected to respond to climate warming by advancing beyond their current position [Harsch09].

We carried out a comparative analysis of aerial photographs of 1958 and a satellite image of 2012, covering the area of mountain Poperechnaya in order to obtain a quantitative estimate of the shifts of the upper limits (boundary) of the open forests (a line, with distances between trees from 7 to 30 m and total crown cover of 20–30% [Mois11]). Remote sensing data have been combined with a 10-m digital elevation model using a geographic information system ArcGIS, and then the upper limits of the open forests in 1958 and 2012 were mapped. Estimation of the area of open forest expansions was obtained using the Spatial Statistics module. Calculation of the horizontal shifts of the upper line of the open forests was made using the function of estimating the Euclidean distance from the line that describes the boundary of the open forests at the beginning of the study period, to the line of their current

spread. The vertical shifts of the upper line of the open forests was estimated by determining the medians from the values of the cells of the digital elevation model located on the lines delineating the open forest areas in 1958 and 2012. The most favorable conditions for the expansion of open forests into the alpine tundra were determined using histograms that represent the number of cells that belong to different classes by exposure, slope steepness, and stoniness for a raster limited by the area of shifting the boundary of the open forests.

Furthermore, the method of comparing historical and recent landscape photographs was used in assessing changes in forest areas and areas occupied by woody vegetation [Shiyat09]. In order to create a repeat landscape photograph, the researcher have found the exact location from which the original photograph was taken.

The climate assessment in the area of research was carried out according to instrumental measurements of the weather station Zlatoust (N 55°10'22.42", E 59°39'10.73", 532 m a.s.l.), which has the longest observational series for the region (from 1837 to 2014). The weather station is located 86 km from the object of study. The data on the average monthly air temperature and total monthly precipitation were separately analyzed for two periods: warm (June-August) and cold (November-March) seasons.

An inhomogeneity of long time series of precipitation was removed by the means of introduction of conversion factors from readings of the raingauge with Nipher shield to readings of the Tret'yakov precipitation gauge (in 1952) and by the exclusion of the moistening correction (since 1966), published in Handbook on the Climate of the USSR [Handb90]. Anomalies of the average air temperature and total amount of precipitation for warm and cold seasons of every year were calculated as the difference between a current value and an average one for the World Meteorological Organization standard period (1961–1990).

Results and Discussion

Analysis of changes in vegetation cover using remote methods (aerial and satellite images) made it possible to identify and assess the progress of the upper boundary of the open forests in the study area during the period from 1958 to 2012 (Fig. 1). The vertical shift of the continuous boundary of the open forests (excluding isolated islands) along the median was 40 m (from 1223 to 1263 m) for the period under study, and this was 0.74 m/year. The minimum value of the height of the position of the open forest above sea level changed by 19 m (from 1075 to 1094 m), the maximum value changed by 14 m (from 1293 to 1307 m). The horizontal shift of the continuous border of the open forests along the median was 11 m during the study period (0.20 m/year), the values of the horizontal shift were in the range from 0 to 508 m.

The total area of expansion of the open forests from 1958 to 2012 was 2.286 km^2.

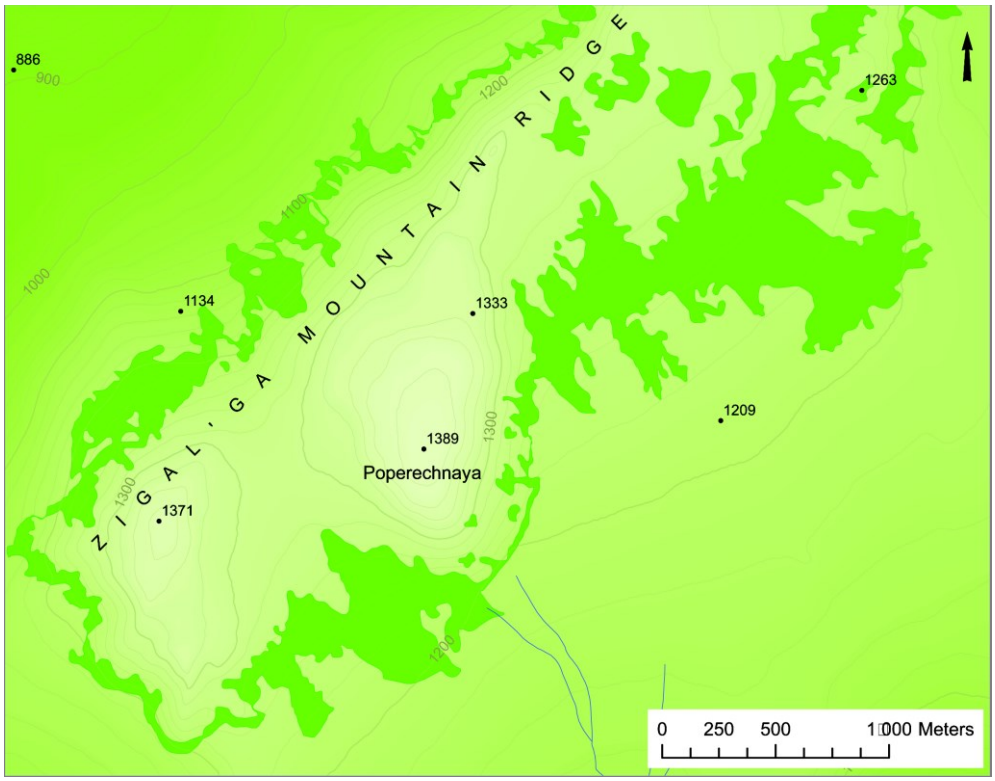

Figure 1: Shift of upper boundaries of open forests since 1958 to 2012 (mountain Poperechnaya, Zigal'ga mountain ridge, South Ural)

Traceable trends in the transformation of forest-tundra vegetation communities in the study area indicate the most significant expansion of open forests into the alpine tundra in the south-eastern slope (Fig. 2A), which is

explained not only by more favorable climatic conditions on this part of the slope, but also by more gentle slopes and less stoniness. The effect of the last two factors is confirmed by the analysis of histograms (Fig. 2B and 2C), which showed that the greatest progress in the expansion of open forest occurred on gentle slopes (steepness 0-5º) with the lowest stoniness (0-10%).

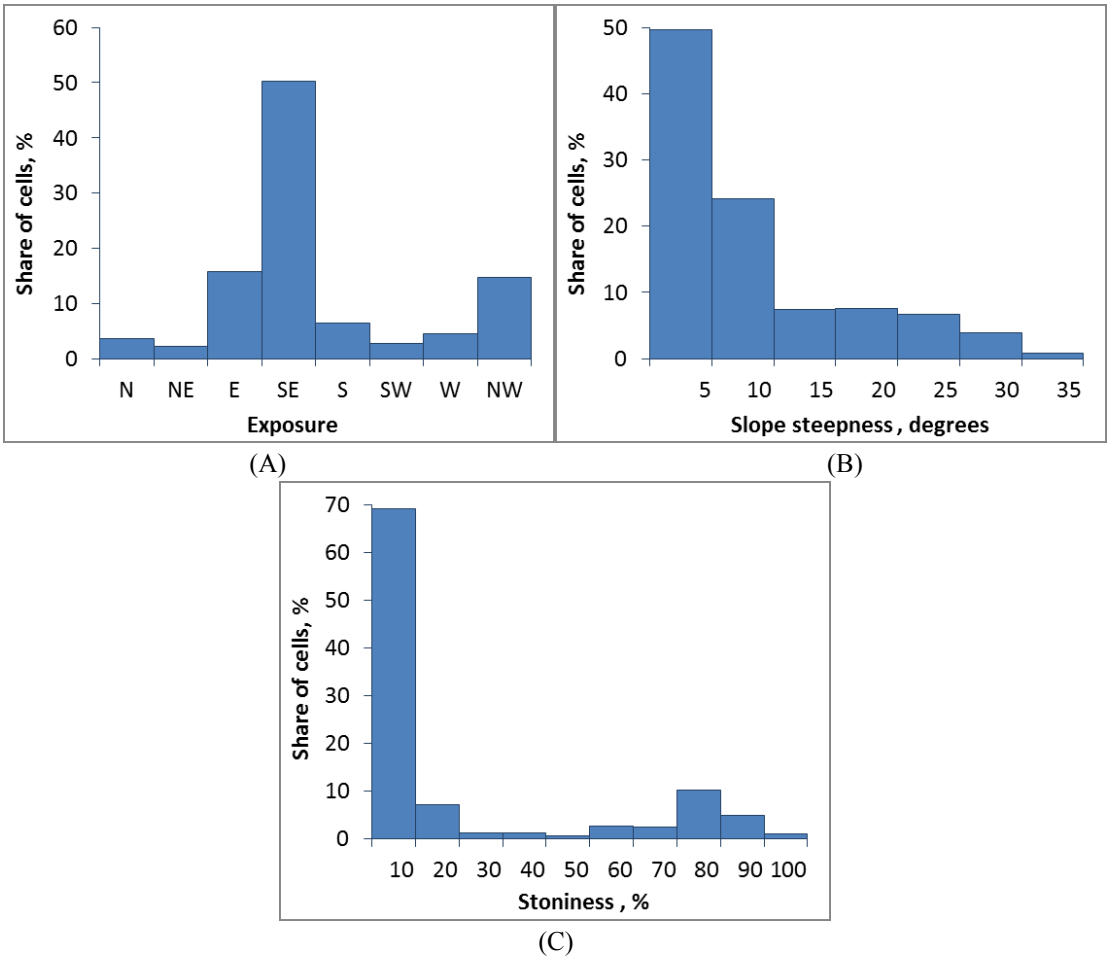

Figure 2: The histogram of the distribution of the raster cells belonging to the area of shift of the upper boundaries of open forests in 1958-2012, depending on the exposure (A), slope steepness (B), and stoniness (C); mountain Poperechnaya, Zigal'ga mountain ridge, South Ural

In addition, changes in the upper boundaries of woody vegetation can be clearly seen in repeated landscape photographs (Fig. 3). The historical photo shows that 80 years ago on the mountain terrace there were rare spruce trees whose height did not exceed 1-1.5 m. These trees have a multi-stemmed growth form, which is also known as krummholz or elfin wood. Currently, close spruce forest occupy a large part of the terrace. The height of the trunks reaches 5-6 m. Single spruces grow on stony areas located at a higher altitude.

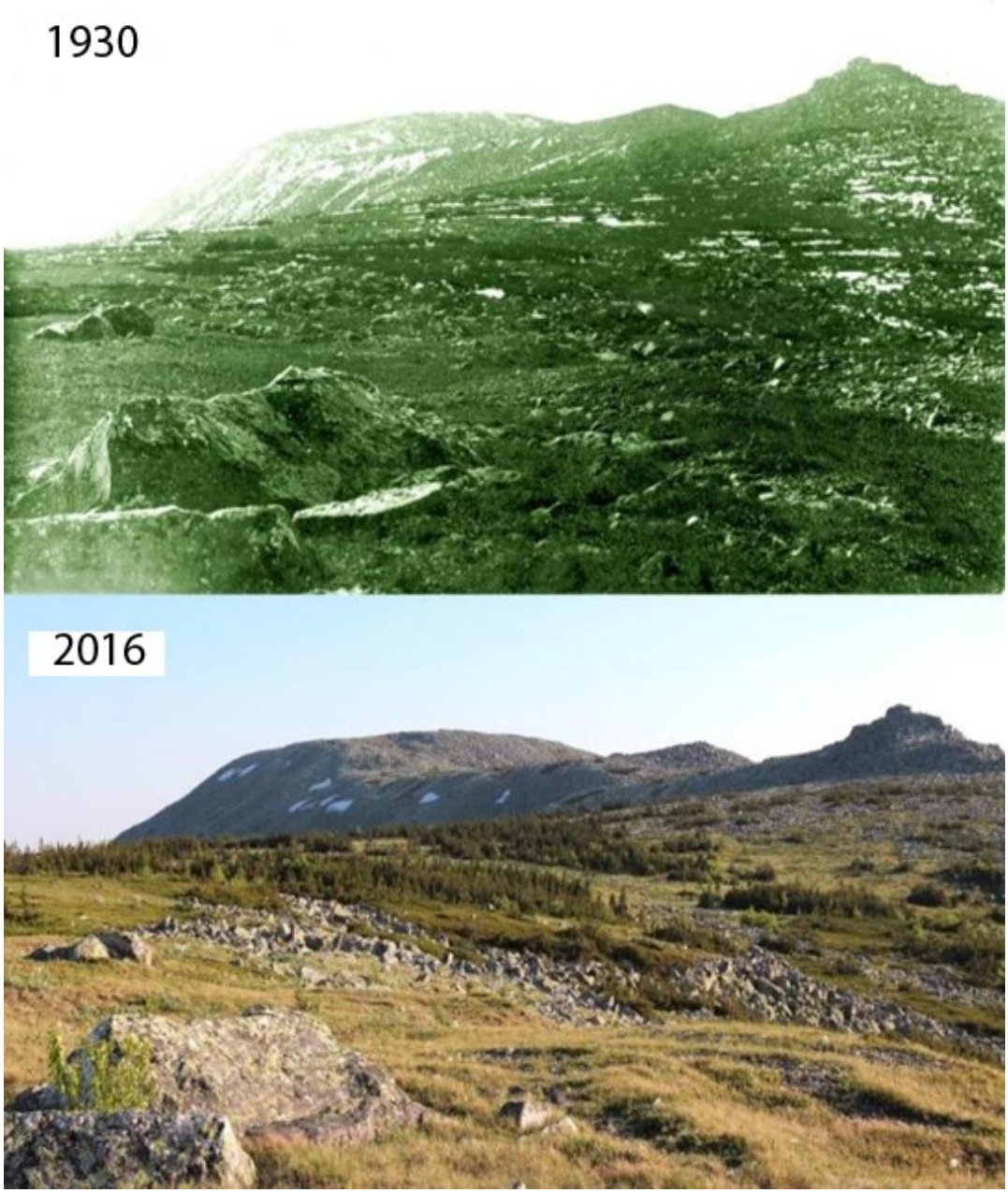

Figure 3: Repeat landscape photographs of mountain Poperechnaya, Zigal'ga mountain ridge, South Ural (N54º39.920', E 058º39.970', 1287 m a.s.l.). Photographs were made by L.N. Tyulina in 1930 and A.A. Grigoriev in 2016

Analysis of data from instrumental meteorological observations (Fig. 4) indicates that the climate has generally become warmer and wetter in our study region during the period from 1837 to 2014. The most significant change in the temperature regime and sedimentation regime occurred during the cold period of the year. Thus, the time series of mean air temperature anomalies in the cold period shows an increase in the linear trend by 1.7 ºC for 100 years, for anomalies of total precipitation the increase is 48.8 mm per 100 years. The reliable tendency according to linear trend of the anomalies of these climatic parameters in the warm period of the year is not revealed.

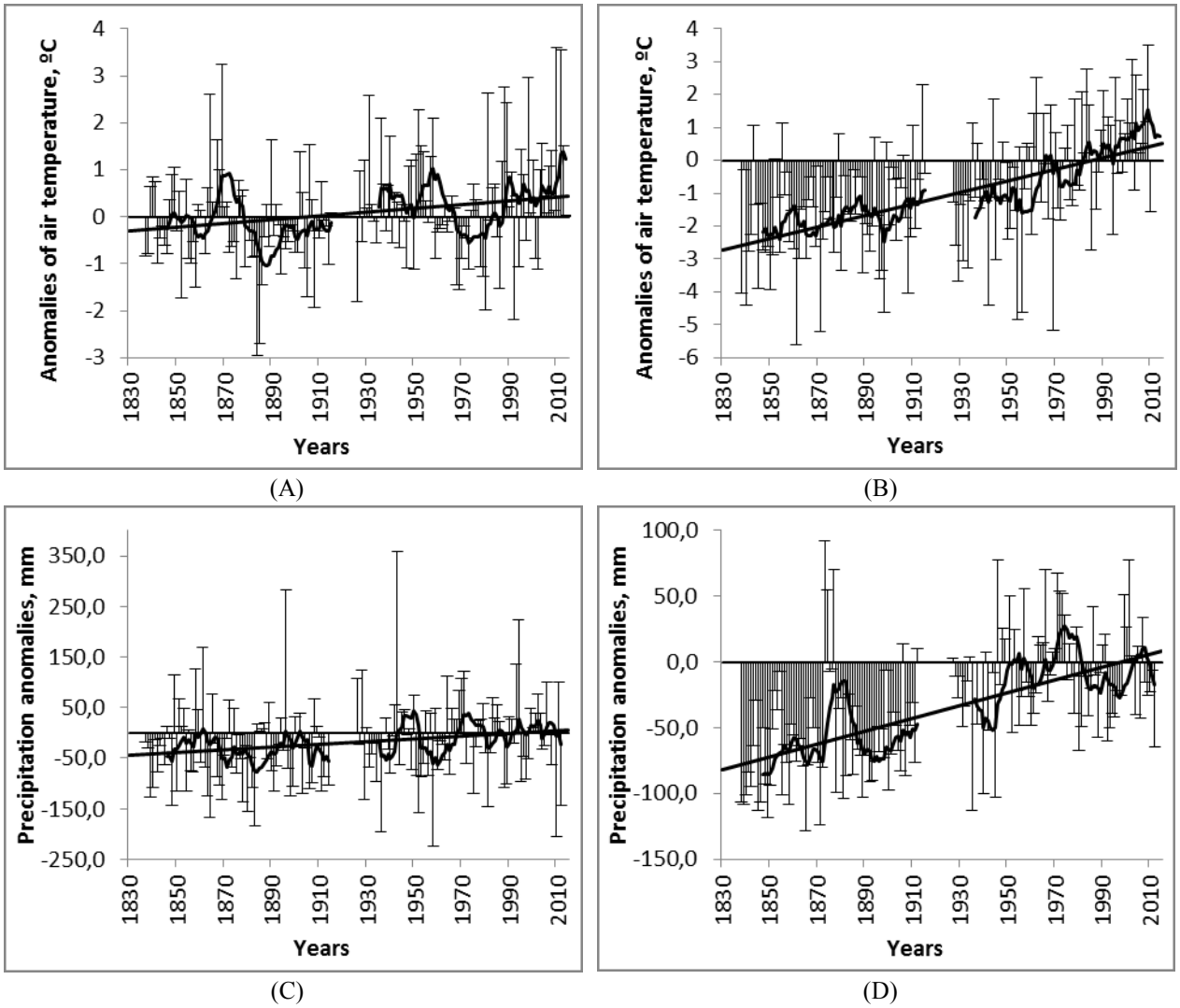

Figure 4: Time series of anomalies of the average air temperature (A, B) and total precipitation (C, D) for the warm (June-August) and cold (November-March) periods of the year, respectively, at the weather station Zlatoust. The period 1960–1990 is taken as standard. The heavy line indicates the linear trend, heavy curves show the moving average with ten-year period of smoothing.

Conclusion

In the last half century, the open spruce forests has been actively expanding to higher elevations on Zigal'ga mountain ridge (South Urals). We evaluated the changes of upper boundaries of open forests for the period from 1958 to 2012: altitudinal shift along the median was 0.74 m/year, and horizontal shift was 0.20 m/year. The most significant changes in the location of the boundaries of the forested areas occurred on relatively gentle slopes with the presence of fine earth and well-developed soil. This is confirmed by comparing aerial photographs, satellite images, and repeated landscape photographs made at different times.

Upper boundaries of open forests expanded upwards occurred against the backdrop of climate change. The climate has become warmer and wetter in the study area during the period from 1837 to 2014. The most significant change in the temperature regime and sedimentation regime occurred during the cold period of the year.

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