Relationship between stand and regeneration of *Picea obovata* Ledeb. and *Abies sibirica* Ledeb. in the primary and secondary forests of the Southern Ural Mountains

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Abstract. The aim of the research is to reveal the relationship between the age and composition of the forest stand and the regeneration of *Picea obovata* Ledeb. and *Abies sibirica Ledeb*. Null hypothesis: we can estimate young generations of *P. obovata* and *A. sibirica* under the forest canopy based on the composition and age of the forest stand. The studies conducted in the most widespread forest type of the South Ural Mountains confirmed our null hypothesis about the possibility of modelling the regeneration of *P. obovata* and *A. sibirica* by the structure of the stand. The number of young generations of *P. obovata* and *A. sibirica* showed high sensitivity to the age and composition of the stand. The graphical models developed by us can be used to combine with forest management data in order to obtain large-scale data on the regeneration of woody plants in the primary spruce small-grass-green mossy forests and secondary birch and aspen forests of the South Ural Mountains. In order to expand the scope of application of the developed models, it is planned to conduct additional studies for other forest types of the Urals.

1 Introduction

Understanding the biospheric role of forests, including for carbon storage and climate mitigation, places them at the centre of research [1, 2]. It is recognised that global climate change, wildfires and enormity of logging across countries have caused dramatic changes in the structure of forest ecosystems [3, 4]. A danger of primary (climax) forests extinction has emerged across all continents [5-7]. Biodiversity decrease, reduced community stability and loss of ability to provide ecosystem services are massively detected [8-10]. Forest degradation is reaching a global dimension and produces undesirable effects on human society and biosphere stability [3, 9, 11]. To reduce the impact of this process, an objective comprehensive assessment of forest vegetation condition and trends, development of objective methods to assess forest transformations are primarily required. Widespread satellite remote sensing methods provide a continuous flow of information about forests.

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However, this method is only excellent for forest stand surveys. The information about the subordinate layers is schematic and not sufficiently accurate [12]. It should be noted that the regeneration of woody plants is the most important characteristic of the forest plant community. The direction and pace of successions are directly dependent on the regeneration of woody plants. Therefore, a correct assessment of the regenerative potential of forest vegetation makes it possible to predict the rate of reforestation and plan sustainable forest management.

Our research was conducted in the South Ural Mountains. The ecosystem functions of the forests of this region are important not only for the adjacent territories, but also for the planet as a whole [13]. However, intensive forest management has led to the transformation of the structure and functions of these extremely important mountain ecosystems over large areas and this process is still ongoing [14]. Reforestation and restoration of ecological functions of forest ecosystems is an urgent problem in the South Ural region. Regeneration of woody plants in the mountain forests of the Southern Urals is described in numerous publications [15-18]. However, the relationship between the forest stand and the regeneration of woody plants is still insufficiently investigated. Only isolated examples of such studies can be given [19-21]. There is a catastrophic lack of information for the development of predictive models in order to obtain reliable information at the level of forest types and regions.

The aim of the research is to reveal the relationship between the age and composition of the forest stand and the regeneration of *Picea obovata* Ledeb. and *Abies sibirica* Ledeb. For use in forest inventory and management, develop models of these relationships.

Null hypothesis: we can estimate young generations of *Picea obovata* Ledeb. and *Abies sibirica* Ledeb under the forest canopy based on the composition and age of the forest stand.

2 Materials and methods

2.1 Study area

Study area is s located on the western mountain slope of the South Ural Mountains in the Chelyabinsk region between 54°33'- 54°40' N latitude and 57°48 '- 57°55' E longitude (Fig. 1). This territory belongs to Atlantic-continental region of the taiga zone. Dark coniferous small-grass-green mossy forests have been selected as research sites. This forest type is the most widespread and productive. These forests are confined to the lower parts of the gentle mountain slopes.

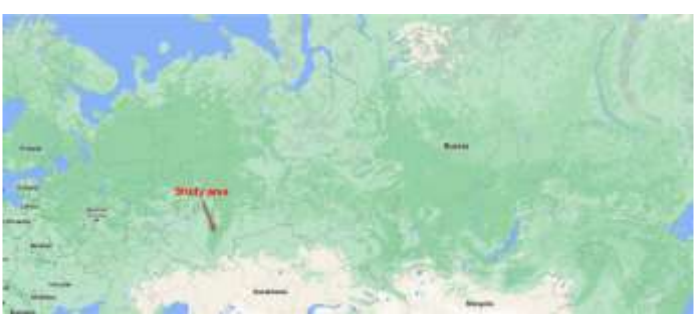

Fig. 1. Study area on the map: South Ural Mountains, Chelyabinsk region.

According to FAO [22], primary forests make up more than 50% in the Ural Mountains. However, an analysis of the forest reserve structure showed that within the conditions studied only 16% of dark coniferous forests have been remained out of the total forest area [23].

https://doi.org/10.1051/bioconf/20236703012

These are mainly logged spruce and fir forests, being at different stages of recovery-age transformations. They were formed from young spruce and fir generations preserved during logging, or after the natural decay of birch and aspen forests (less often on burning). Only 2% of old-growth dark coniferous forests are marked. Some of them are also disturbed by selective logging or wildfires [23].

2.2 Sampling and measurements

We used generally recognized research methods [24]. The research protocol is shown in Figure 2. Extensive analysis of literary and cartographic materials preceded the research in the Ural Mountains.

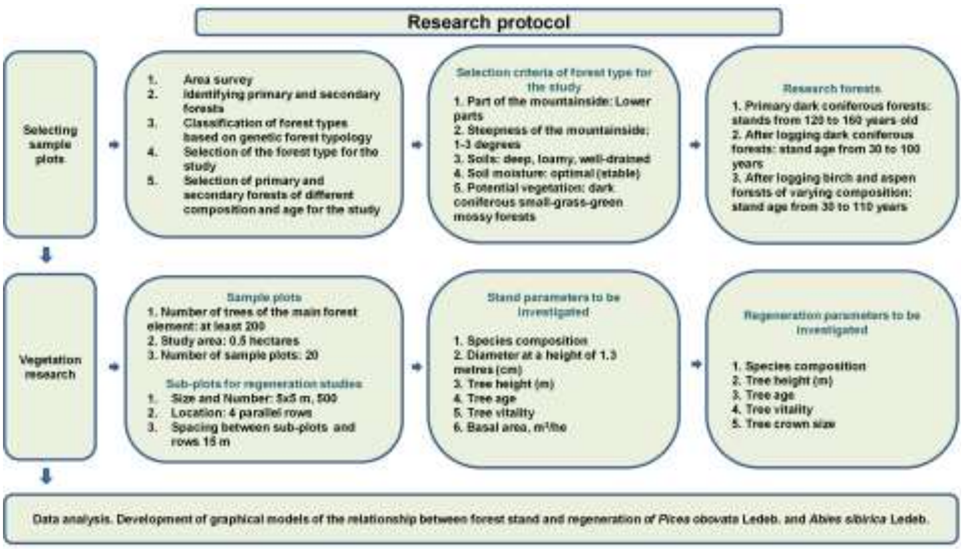

Fig. 2. Research protocol.

Data analysis was performed using Statistca 6.0 software. Exponential smoothing was used to develop three-dimensional graphical models. The forest stand on our joint sample plots was investigated by Georgy Andreev [23].

3 Results and discussion

The first forest typological scheme based on the principles of genetic forest classification was developed by Elena Filrose for the forests of the Ilmen Reserve in 1957 [25]. This classification began to be used in forest management as an ecological basis for the organization of forestry. Long-term wide-scale practical application of genetic forest typology has shown the prospects of this approach for forestry and nature conservation. We continued the forest typological studies of mountain forests initiated by Elena Filrose. For more than twenty years, we have received a lot of new results. A study of the processes of natural regeneration of *Picea obovata* Ledeb. and *Abies sibirica* Ledeb. and *Pinus sylvestris* L. under a tree canopy, in the territories of logging and burning in the prevailing habitats of the South Ural Mountains was carried out. Data on the number, vitality and age structure of young generations of these woody plants were obtained. Generalizing research results are shown in Figure 3.

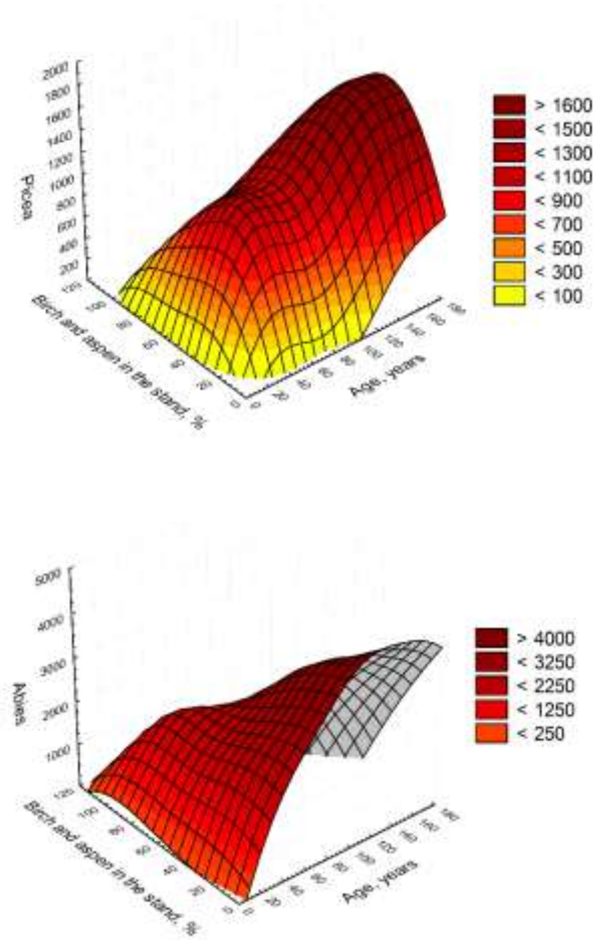

Fig. 3. Relationship between the forest stand and the regeneration of *Picea obovata* Ledeb. and *Abies sibirica* Ledeb. in the South Ural Mountains.

The research results are given in more detail in our earlier publications [7, 24, 26]. This report is generalizing. Here we tried to formalize the results we obtained earlier in the form of visual graphical models. Despite the fact that the development of these models required scrupulous long-term research, the practical application of our research results is not difficult.

The research results showed that *Abies sibirica* prevails in the regeneration of coniferous woody plants in the research area, and the undergrowth of *Pinus sylvestris* is rarest. The relationship between the forest stand and the regeneration of woody plants is quite clear (Fig. 3). The smallest numbers of saplings (both *Abies sibirica* and *Picea obovata*) are found in young forests, regardless of the composition of the forest stand. The maximum number of *Abies sibirica* is recorded in old-age primary dark coniferous forests. Spruce regeneration reaches the greatest number in old-age secondary spruce-birch and spruce-aspen forests. This feature confirms the success of the restoration of dark coniferous forests after logging with the preservation of young spruce generations. This indicates the preservation of the ability to self-repair the number and structure of coenopopulations of coniferous woody plants. Consequently, the ability to autoregulate the dynamics of the entire forest ecosystem is preserved, and its sustainable development is ensured.

The next important feature that our models show is the low intensity of *Abies sibirica* and *Picea obovata* regeneration in birch and aspen forests throughout the entire period of their existence. It indicates that the potential of natural regeneration is significantly undermined. As a result, the restoration of dark coniferous forests is stretched indefinitely. It is also a signal to pay attention to undesirable processes and to adjust forestry measures.

In general, the developed models give quite an optimistic forecast for the restoration of dark coniferous forests. However, it should be noted that birch and aspen forests in many respects exceed the area of distribution of dark coniferous, spruce-birch and spruce-aspen forests. Consequently, extremely low regeneration of *Abies sibirica* and *Picea obovata* is typical for large areas. Accordingly, the change of birch and aspen forests to dark coniferous forests is also difficult in large areas. Therefore, the revealed feature of extremely low regeneration of *Abies sibirica* and *Picea obovata* under the canopy of birch and aspen stands is of fundamental importance for forestry. Taking into account the potential of natural regeneration under the canopy of forest stands can help in choosing the optimal strategy for forestry in the South Ural Mountains. This will contribute to sustainable forest management and conservation of the natural potential of forest vegetation.

Fig. 4. Spruce-birch forest before logging.

Fig. 5. Spruce-birch forest after logging with maximum preservation of young spruce and fir generations.

The obtained results can serve as a basis for studying and regulating natural reforestation processes. The developed models should be used for planning the technology of logging and reforestation activities. In operational dark coniferous forests, it is recommended to use selective and gradual logging with maximum preservation of young *Abies sibirica* and *Picea obovata* generations. In the process of such logging, it is desirable to preserve the habitat, which will help prevent an undesirable change of coniferous forests to deciduous. An example of such an experience is shown in Figures 4 and 5.

4 Conclusions

Thus, the studies conducted in the most widespread forest type of the South Ural Mountains confirmed our null hypothesis about the possibility of modelling the regeneration of *Abies sibirica* and *Picea obovata* by the structure of the stand. The number of young generations of *Abies sibirica* and *Picea obovata* showed high sensitivity to the age and composition of the stand. The graphical models developed by us can be used to combine with forest management data in order to obtain large-scale data on the regeneration of woody plants in the primary spruce small-grass-green mossy forests and secondary birch and aspen forests of the South Ural Mountains. In order to expand the scope of application of the developed models, it is planned to conduct additional studies for other forest types of the Urals.

The work was carried out within the framework of the state task of the Institute Botanic Garden of the Ural branch of RAS

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