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Estimation of pine forest timber volume in the European part of Russia's Subarctic region: Evidence from the Kola Peninsula recovering from catastrophic disturbances

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Abstract. The study provides a comparative assessment of the volume of pine forests growing in the European part of the Subarctic region of the Russian Federation (the Kola Peninsula). This characteristic is one of the most important indicators in the forest inventory during the economic assessment of forest stands. The study considers forest communities at various stages of recovery after catastrophic disturbances with a special focus on forest cutting and forest fires. These catastrophic violations are of a different nature when exposed to elements of the forest ecosystem. Therefore, it can be assumed that different communities may experience differences in the estimated characteristics in the process of staged recovery. An alternative hypothesis of this study is the assumption that a comparative assessment of timber volume will vary between communities with different types of catastrophic disturbances (cutting and forest fire) at least in the early stages of recovery.

1. Introduction

Despite being part of the Subarctic climate zone (as, indeed, the greater part of Fennoscandia the Kola Peninsula has a high biocenotic diversity [1]. The biggest part of the Peninsula (except for tundra communities in the northernmost part of the region) is covered with forests. These plant communities also have a heterogeneous species and age structure. The main forest-forming species in the European part of the northern taiga is Scots pine (*Pinus sylvestris* L.), which, along with another fairly common species—Siberian spruce (*Picea obovata* Ledeb), forms extensive primary and secondary forests. The communities formed by common pine occupy about 50% of the total forested area and, therefore, shape the appearance of local landscapes [2]. The major threats to pine forests are cutting and periodic associated forest fires (either natural or human-induced). Having said that, it stands to reason that pine can be used as a model species to study long-term changes in the taiga forests of the European North (including those caused by anthropogenic factors). It should also be noted that the region is home to large industrial enterprises with the facilities for enrichment and smelting of non-ferrous metals having the biggest impact. Large-scale catastrophic disturbances of forest plant communities (clear cutting and associated fires) hit this region most in the 1930s and 1960s due to the active development of the territory resulting in clear cutting of vast tracts of land. Moreover, forest fires may be the result of anthropogenic activities (in light of this, the interval between anthropogenic disturbances in forest communities was reduced several times) [3]. Later, with a change in the political and social situation in the country, human activity in this region decreased significantly. The region features mosaic forests with coenopopulations at various stages of recovery.



Thus, the purpose of this study is to provide a comparative assessment of the timber volume for pine forests in the European part of Russia's Subarctic region. The evidence was obtained from the Kola Peninsula which is now at various stages of recovering from catastrophic disturbances (cutting, forest fires).

2. Materials and methods

The evidence for the study was obtained from the trial plots of the Apatity, Kovdorsky, Monchegorsky and Olenegorsky districts of the Murmansk Oblast. We considered a number of stages of recovery after disturbances (20, 40, 60, and 80 years,) and provided independent analysis for the recovery after cutting and recovery after a fire with at least 2 trial plots for each stage of recovery and for each type of disturbance. Trial areas complied with the basic rules and requirements [4]. The size of each area varied from 0.1 to 0.25 ha—depending on the number of trees belonging to the main forest-forming species (at least 200 individuals). The time passed after a disturbance and its nature was identified through the analysis of cuts and cores of living trees. The height of the trunk as well as its diameter was determined for each individual of the tree layer. It should be noted that the study covered all the individuals of the forest-forming species with a trunk diameter of 4 cm or more at a height of 1.3 m.

The estimation of timber volume was based on such indicators as the height of individuals and the sum of cross-sectional areas (diameters of tree trunks). The classical formula [5], [6] is:

$M_{1,0} = \Sigma G \cdot HF$, where:

$M_{1,0}$ — maximum timber volume, m³/ha;

ΣG — total cross-sectional area, m²/ha;

HF — average species height, m.

An alternative hypothesis of the study is an assumption that with an increase in the age of coenopopulation of Scots pine, timber volume may also increase. In addition, it can be assumed that timber volume in communities recovering from cutting and from fire will significantly differ [7].

3. Results

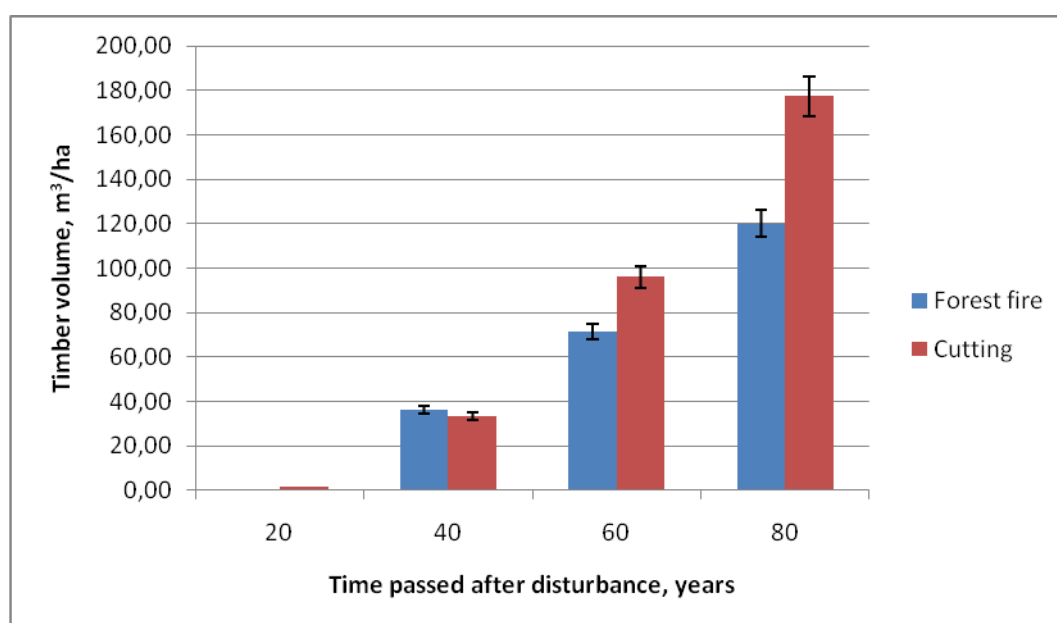
The study revealed a range of patterns. First of all, timber volume increases as the recovery reaches new stages and the community gets older. As regards timber volume in post-fire communities, in communities with a disturbance dating to 20 years ago, the average timber volume makes 0.05-0.1 m³/ha (here, the estimation was carried out for those individuals who satisfied the criteria for individuals in the tree layer or would do so in the short term). With a fire dating to 40 years ago, timber volume is around 36 m³/ha, while when a fire dates to 60 years ago, it accounts for about 71 m³/ha. As expected, the maximum values for this criterion (in the series under consideration) are observed in the communities facing a disturbance 80 years ago where they reach about 120 m³/ha. This happens despite the natural "thinning" of trees in the community due to intraspecific competition which effectively blocks the growth of some individuals or even leads to their death. This ultimately results in significant differentiation of trees in terms of their vitality. The upward trend in timber volume index is equally noticeable under a gradual increase in the total cross-sectional area index (from 0.5 m²/ha in 20-year-old communities to 17.5 m²/ha in 80-year-old communities) due to radial growth as well as an increase in the height of trees (from 0.5 m on average in 20-year-old communities to 13.5 m in 80-year-old communities) due to linear growth.

In communities that emerged after felling, timber volume is slightly higher than in post-fire communities. Communities formed 20 years after a disturbance have an average timber volume of 1.8 m³/ha. For a community with a felling age of 40 years, this value increases to 33 m²/ha, and for a community with a felling age of 60 years, it reaches 96 m²/ha. As well as for post-fire communities, the maximum value of timber volume (in the series under consideration) is observed in the communities facing a disturbance 80 years ago—an average of 177 m²/ha which is about 30% higher than in similar communities formed after a fire (Table 1).

Table 1. Average timber volumes for middle-aged pine forests recovering from catastrophic disturbances in the European part of Russia's Subarctic region, m³/ha

Type of disturbance	Time passed after disturbance, years			
	20	40	60	80
Forest fire	0,08	36,23	71,36	120,05
Cutting	1,78	33,22	96,11	177,39

At almost all stages of recovery to the stage of middle-aged pine forests, the timber volume in the communities formed after logging is significantly different from the timber volume in the post-fire communities at a similar recovery stage (except for the 40 year stage where the communities do not show significant differences in timber volume) (Figure 1).

**Figure 1.** Comparative dynamics of positive changes in timber volume for middle-aged pine forests recovering from catastrophic disturbances in the European part of Russia's Subarctic region

Thus, a pronounced tendency toward a more rapid renewal of timber volume in communities recovering after felling is revealed. This tendency is especially noticeable at the stage of 50 years (more precisely, between 40 and 60 years). After that the difference is getting even bigger (as mentioned above, it may reach 30% in 80-year-old communities). We have analyzed changes in timber volume over successive periods of time with middle-aged pine at the final stage. However, it can be assumed that in future, after a certain stage, the difference in timber volume in post-cutting and post-fire communities will begin to decline. Once the climax is reached (in 200 years or later), the difference will be minimal.

4. Conclusion

A possible reason for such a noticeable difference in timber volumes may be the fact that a fire (primarily a ground fire) to a greater or lesser extent damages the organogenic horizons of the soil. First of all, such damage affects the forest litter. For the Arctic and Subarctic regions, this set of organogenic horizons is usually combined into a common horizon A, which includes the forest litter A0 and the humus horizon A1. Such damage adversely affects subsequent renewal dynamics, especially in the early stages. In comparison with post-cutting plots, pine populates such spaces with

some delay. Apparently, differences in the time of settlement of pine habitats as well as different types of disturbances affect the formation rate of timber volume in the region.

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