Preserving complex pine forests in the taiga zone in conditions of science-based and sustainable forest management

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Abstract. The article presents the research of the content and structure of the formed young growth at the sites of alternate strip felling (ASF) in 2013-2015 in different types of forest growing conditions (FGC) in Medvedskiy Bor (the Kirov region): A1 (lichen pine forests), A2 (cowberry pine forests), B2 (beadruby-cowberry pine forests), B3 (beadruby-bilberry pine forests), C2 (mixed-grass pine forests). Circular discount areas of the size of 10 m^2 were made in accordance. Undergrowth complete enumeration was made at the areas, young growth taxation characteristics, as well as the age, biometric parameters and the state category of *Pinus sylvestris* L. were estimated. Undergrowth was distributed according to size categories – small, medium and large; according to the degree of viability – establishing (viable, healthy), doubtful (suppressed, injured), wilting (drying), dry (dead). Successful regeneration of *P. sylvestris* takes place at the expense of specimen of next generations. The number of large undergrowth almost 4 times exceeds the norm for artificial reforestation with bareroot tree seedlings (3500 sp./ha) at A1 felling places, 3 times – at A2 and B3, and 2 times – at B2 and C. As for containerized tree seedlings, with the norm of 2000 sp./ha, viable, establishing undergrowth 8 times exceeds the norm at felling places of A1 type, 6 times – at A2 and B3, 4 times – at B2 and C2. Grass-subshrub storey and moss-lichen storey regenerated at all the felling places. In order to preserve complex pine forests and to keep biodiversity in the region, special measures contributing to *P. sylvestris* natural regeneration and measures of forest care after ASF are offered.

1 Introduction

The Kirov region is situated in the north-east of the European part of Russia, the region stretches from north to south and it covers three natural sub-zones: middle and southern taiga, as well as sub-taiga (mixed coniferous-broad-leaved forests). The taiga zone is not marked by high biodiversity. Still, the main component of the Convention on Biological Diversity [1] consists in development of protected natural areas which form the basis for preserving biodiversity and providing sustainable use of bioresources. Nowadays it is

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evident that protective conditions do not always contribute to preserving species and communities [2–4].

In the south-eastern part of the Kirov region there are complex pine forests with rare steppe and nemoral species which have remained there since the previous geological ages. Many of them are natural monuments not subject to forestry activity. But in conditions of being protected, pine forests as intra-zonal communities gradually transform into zonal types (spruce forests), which leads to changing the conditions for rare species [5–6]. It was shown [7–8] that it is not possible to keep pine forests without human interference or without any negative natural factors.

The research aim is to ground forestry activity measures aiming at regeneration of steppificated forests and pine forests with *Convallaria majalis* L. in the natural monument "Medvedskiy Bor" (the Kirov region), as well as at preserving pine forests in this area on long-term conditions by means of analyzing *Pinus sylvestris* L. undergrowth in the sites of alternate strip felling with different types of forestry conditions.

2 Material and Methods

The research was made on the territory of the natural monument "Medvedskiy Bor". It is a relict pine forest on continental sand dunes with karst relief forms in the east of the sub-zone of mixed coniferous-broad-leaved forests. The dune relief caused diversity of phytocoenoses: a whole set of pine forest types is represented in the Bor (from lichen to sphagnum ones) surrounded by forests of the nemoral complex. On the comparatively small area of "Medvedskiy Bor" (6821.05 ha) 635 species of vascular plants were found [9], due to variety of ecotopes. There are 19 species which are included in the Red Data Book of the Kirov region [10], two of them are also included in the Red Data Book of the Russian Federation [11], some of the species found there earlier have not been found in the area any more.

On the territory of the natural monument there are three functional zones with a differentiated mode of forestry: 1) a specially protected zone is made for preserving sites with natural communities and for succession monitoring; 2) a recreational zone serves for organized tourism and recreation; 3) the zone of regulated forest management functions as an experimental ground and serves for remediation of wild-type communities [12].

The research was made in 2022 in the zone of regulated forest management. Regeneration of *P. sylvestris* in five types of forest growth conditions (FGC): A1 (lichen pine forests), A2 (cowberry pine forests), B2 (beadruby-cowberry pine forests), B3 (beadruby-bilberry pine forests), C2 (mixed-grass pine forests) was considered and analyzed at the felling places after alternate strip felling (ASF) of 2013-2015.

Model areas at pine forest felling places were determined with the help of mapping and forest managing data. Circular discount areas of the size of 10 m^2 were made in accordance with OST 56-69-83 [13]; undergrowth complete enumeration was made at the areas, young growth taxation characteristics, as well as the age and the state category of *P. sylvestris* were estimated.

Undergrowth was distributed according to size categories: those up to 0.5 m were attributed to small, of 0.6–1.5 m – to medium, over 1.5 m – to large [14]. To determine the total number of undergrowth the coefficients of calculating small and medium undergrowth into large one were used. Coefficient 0.5 was used for small undergrowth, 0.8 – for medium one, 1.0 – for large one.

According to the degree of viability the undergrowth was divided according to state categories: establishing (viable, healthy), doubtful (suppressed, injured), wilting (drying), dry (dead) [15]. This division was made taking into account a set of morphological features, such as: needles colour, dry prune share, crown form and crown stretch (sm), height

increment of axial and surculus shoots, having a terminal bud, the number of lateral buds of the terminal bud near, any injuries made by insects and fungi, etc. [16, 17]. After distributing the specimen according to state categories the viability index for *P. sylvestris* undergrowth was calculated according to the formula: L = (100n1+70n2+10n3)/N, with L – a relative living state of a coenopopulation; n1, n2, n3 – the number of healthy, doubtful, and wilting specimen for 1 ha accordingly; N – the total number of specimen, including dry ones, for 1 ha. With L = 80–100% undergrowth coenopopulation was considered healthy, 50–79% – weak, 20–49% – very weak, 0–19% – unviable.

3 Results and Discussion

The lichen group (A1 – lichen pine forests) accounts for 14.2% of the zone of regulated forest management. The green moss group (A2 – cowberry pine forests) prevails, it accounts for 28.9%; beadruby-cowberry pine forests (B2) take the second place in area, accounting for 26.9%. Beadruby-bilberry pine forests (B3) account for 11.7%. The mixed-grass group of forest types (C2 – mixed-grass pine forests) accounts for 6.2% of the area.

Undergrowth composition in felling places after ASF is represented in table 1. With FGC of A1, A2, B2, B3 *P. sylvestris* dominates, with C2 – the species of *P. sylvestris*, *Picea* A. Dietr., and *Betula* L. are represented in equal shares.

Table 1. Undergrowth composition after alternate strip fellings in forest conditions of different type.

TLU	A1	A2	B2	B3	C2
Undergrowth composition	9Pn1B sin. Pc	m. 9Pn1B sin. Pc	m. 8Pn2B sin. Pc Pt	m. 6Pn2B2Pc+Pt	5Pn2Pc3B sin. Q

Note. Pn – *Pinus sylvestris* L.; Pc – *Picea* A. Dietr.; B – *Betula* L.; Pt – *Populus tremula* L.; Q – *Quercus robur* L.; sin. – singly; m. – mean.

Almost in all the FGC the processes of natural regeneration run quite well, still in beadruby-bilberry pine forests (B3) they are less active, as compared with beadruby-cowberry pine forests (B2). In mixed-grass pine forests (C2) they are not quite effective, still rather sufficient (Table 2).

Table 2. *Pinus sylvestris* regeneration at felling places after alternate strip fellings in forest conditions of different type, sp./ha.

FGC	Undergrowth according to height categories			Total	Calculated as the large	Number of the viable
	small (to 0.5 m)	medium (0.6–1.5 m)	large (over 1.5 m)			
A1	6833	13333	833	21166	15000	11833
A2	14667	6917	584	22167	13833	13333
B2	8000	2333	3000	13333	8867	10000
B3	5834	5250	833	11917	7950	6417
C2	4667	6333	167	11167	7500	7000

More than a half (55.9–75.0 %) of pine undergrowth in all the FGC is considered establishing, healthy (Table 3).

Pine undergrowth at felling places of lichen, beadruby-cowberry, beadruby-bilberry and mixed-grass pine forests is healthy, while in felling places of cowberry pine forests it is weak (Table 4). Presumably, at felling places of cowberry pine forests not all the necessary tending measures were taken at the right time.

Table 3. Distribution of *Pinus sylvestris* according to state categories, %.

FGC	Undergrowth according to state categories			
	establishing	doubtful	wilting	dry
A1	55.9	39.4	3.9	0.8
A2	58.9	25.7	13.3	2.1
B2	75.0	20.0	5.0	0
B3	51.7	40.4	7.9	0
C2	62.7	29.9	7.5	0

Table 4. Assessment of *Pinus sylvestris* undergrowth state after alternate strip fellings in forest conditions of different type.

FGC	Index of relative viability, %	Assessment
A1	83.9	healthy
A2	78.3	weak
B2	89.5	healthy
B3	82.2	healthy
C2	84.3	healthy

The grass-subshrub storey and the moss-lichen storey regenerated at all the felling places. Best of all grasses and subshrubs regenerate in beadruby-cowberry and mixed-grass pine forests, mosses and lichens regenerate in lichen and cowberry pine forests, there are just very few bear spots of soil, if any. There are favourable conditions for rare meadow-steppe species of the grass-subshrub storey. Thus there is need in ASF in order to preserve pine forests and sustain biodiversity in the region.

The analysis of natural regeneration of *P. sylvestris* at felling places after ASF in 2013-2015 showed that the number of large pine undergrowth is almost 4 times higher than the norm accepted for artificial reforestation with bareroot tree seedlings (3500 sp./ha) [17] in felling places in lichen pine forests (A1), 3 times higher in cowberry pine forests (A2) and beadruby-bilberry pine forests (B3), 2 times higher in beadruby-cowberry (B2) and mixed-grass pine forests (C2). Viable (establishing) undergrowth is enough in all the FGC, it exceeds the norm 2-3 times. In case of artificial reforestation with containerized tree seedlings (2000 sp./ha), it is 8 times higher than the norm at felling places in lichen pine forests (A1), 6 times higher in cowberry (A2) and beadruby-bilberry pine forests (B3), 4 times higher in beadruby-cowberry (B2) and mixed-grass pine forests (C2); the amount of viable (establishing) undergrowth in all the FGC 4-6 times exceeds the norm.

In all the FGC viable undergrowth of *P. sylvestris* is either enough, or its amount exceeds the norms for 7-year-old young growth [17].

The analysis of *P. sylvestris* undergrowth according to height categories showed that in all the FGC the amount of large (over 1.5 m) undergrowth is 3–67 times less than that of small and medium ones. In all FGC regeneration takes place owing to pine undergrowth of the next generation. Remuneration increase at felling places, especially at mixed-grass pine forests, is possible only in case of keeping the undergrowth under trees.

The analysis of *P. sylvestris* undergrowth according to state categories in all the FGC showed that viable (establishing) undergrowth prevailed by more than 50%. There are reasonable grounds to believe that even undergrowth, which is doubtful, as for to one-two criteria, is able to form healthy forest stands in the future.

The processes of natural regeneration at felling places are mostly determined by the wild-type of a forest. At 7–9-year-old felling places the number of pine undergrowth varies from 7500 sp./ha in mixed-grass pine forests to 15000 sp./ha in lichen pine forests. On the whole, natural regeneration of *P. sylvestris* at felling places in lichen and cowberry-green-moss forests is more efficacious, mostly due to the next generation undergrowth.

There are not enough preconditions for drastic alternation of tree species at felling places in cowberry-green-moss, beadruby-cowberry, beadruby-bilberry pine forests. Still, if necessary forestation measures are not taken, in the future development of mixed coniferous-broad-leaved stands is possible at felling places. There are no grounds for alternation of tree species in felling places of lichen pine forests. Successful reforestation at felling places of mixed-grass pine forests is possible in case of keeping pine undergrowth under trees and in case of timely tending.

4 Conclusion

The research of natural regeneration of *P. sylvestris* at ASF places showed that it is not possible to preserve pine forests of the natural monument "Medvedskiy Bor" without taking specially planned forestation measures, as well as without preparing the area for reforestation and taking care of this area.

In order to facilitate natural reforestation certain measures should be taken. They are as follows.

- Logging forests stands.
- Soil surface mineralization with mechanical means at the areas serving for reforestation: making plowed furrows in lichen and cowberry pine forests; extraction (damage) of the live ground cover at the area of not less than 30 % soil cover of a felling place in beadruby-cowberry, beadruby-bilberry, and mixed-grass pine forests.
- Keeping to the maximum *P. sylvestris* undergrowth under trees during the felling, pruning away any sprouting, under bush and undergrowth of coniferous species, and *Picea,* making partial forest plantations with seedlings with the containerized root system at separate spots of fellings in order to enhance reforestation.
- Possibility of combined reforestation with partial cultures of *P. sylvestris* at felling places of beadruby-cowberry, beadruby-bilberry, and mixed-grass pine forests.

Forestry tending measures after ASF do not differ from the traditional ones, they consist in timely felling, in accordance with the stand age (admitting light, weeding, thinning out, increment felling). In FGC of C2, B3 tending should take place two times during a season: cutting and thinning the undergrowth (getting rid of the doubtful one). In order to keep pine forests with *P. sylvestris* monogenetic stand, as well as to decrease the competition, it is necessary to thin the undergrowth of *Betula*, *Populus tremula* L., and *Picea*. But for tending, there is a major risk that a felling place overgrows with broad-leaved species.

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