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# About the promotion of natural restoration of *Pinus sylvestris* L.

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The research was carried out in the pine forest of the specially protected natural areas "Medvedsky Bor" in the Nolinsky District of the Kirov Region. One can meet there both typical boron and boreal plant species and some representatives of broad-leaved forests and steppes. We researched the composition of vegetation and flora, as well as the state of *Pinus sylvestris* L. of the overgrown strip that had been formed after the gradual next-but-one belt logging, with contribution to renewal (mineralization) and care (clarification-logging with removal of non-target species). Green-moss and reed vegetation associations prevail there, as it was stated. Vascular plants are analyzed in relation both to humidity and the spectrum of ecologo-coenotic groups. Predominance of mesophilic and xeromesophilic groups was stated, which indicates moisture degree sufficient for seed germination of the xeromesophilic *P. sylvestris* species. Boreal, boron, as well as non-moral and steppe species prevail, which confirms conservation of biodiversity in these forests. The pine undergrowth was analyzed as for its number, vitality; vegetation influence on these indicators was stated. It was found out, per hectare there are 21 thousand young pine plants aged from 4 to16 years. This 84 times exceeds the required number of trees in the mature community (250 trees per hectare). The vitality of the pine undergrowth is estimated according to the original method, taking into account the age of the plants, their height, the length of last annual increment and the mean annual increment, deviation of lateral shoots from the major axis, presence of re-crowning and yellowed leaves. It is established that there are 17 600 young plants with a high degree of vitality per hectare. It 4.4 times exceeds the plants number required for artificial restoration of pine forests (4000 trees per hectare). These are the trees which can form pine forests with a high appraisal index in the future.

***Keywords:*** reforestation, logging, mineralization, undergrowth, real vitality, forest care, biodiversity.

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# О содействии естественному возобновлению *Pinus sylvestris* L.

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Исследования проведены в сосновых лесах особо охраняемой природной территории «Медведский бор» Нолинского района Кировской области, где наряду с типичными боровыми и бореальными видами растений встречаются представители широколиственных лесов и степей. Изучен состав растительности и флоры, состояние подроста *Pinus sylvestris* L. на зарастающей полосе, формирующейся после проведённой чересполосной постепенной рубки с последующим возобновлением, содействием возобновлению (минерализация) и уходом (рубки осветления). Установлено преобладание зеленомошниковых и вейниковых ассоциаций растительности; рассмотрены особенности естественного возобновления сосны в них. Выявлено преобладание мезофильной группы, бореальных и боровых растений; сохранение и восстановление степных и неморальных видов. С учётом возраста растений, высоты, длины последнего годового и среднегодового приростов, угла отхождения боковых побегов от главной оси, наличия перевершинивания и пожелтевшей хвои оценена реальная жизненность особей. Установлена эффективность мероприятий: пятикратное превышение численности подроста с высокой жизненностью в сравнении с нормой высадки сеянцев при искусственном восстановлении сосняков; возможность непрерывного интенсивного долговременного неистощительного лесопользования с сохранением экосистемных функций соснового леса и его биоразнообразия.

***Ключевые слова:*** лесовосстановление, рубки, минерализация, подрост, реальная жизненность, уход за лесом, биоразнообразие.

The growing demand in wood resources, as well as their constant decrease on the territories accessible by transport, are the reasons of shortening the time of growing technically ripe wood and increasing wood productivity, which would make using wood profitable [1–10]. Thus it is really topical nowadays to look for and research the ways of intensifying natural wood restoration, especially of coniferous forests. Pine forests are one of the main wood sources in Russia. Due to natural processes they eventually transform into zonal forests, mostly spruce ones. Original pine forests can be kept by means of special forestry practices.

It is especially important for specially protected natural areas (SPNA) where change of forest type leads to shortening biodiversity on all the levels. SPNA "Medvedsky Bor" in the Nolinsky District of the Kirov Region is situated on inland sand dunes on the second and third terraces above floodplain of the left bank of the Vyatka River. It contains the representatives of the first (southern) migration zone of pine which got there during Holocene from the Southern-Ural refugium [11]. These are forests of a high growth class and good technological qualities of high log grade.

One of the ways of protecting these pine forests consists in gradual next-but-one belt logging (NBL), when the forest stand of the same class is cut down in two-four stages on the belts with the length not exceeding the height of mature trees, the belts change each other in a certain order [7]. Unlike traditionally kept certain generative individuals on clean loggings, the trees of the belts are cross-pollinated enough and are more windfall-proof; also there appear viable seeds [12–15].

Research of this type of felling aiming at keeping pine forests of the Medvedsky Bor began with working out the methods of assessing vital capacity of the young growth and analyzing its state [16]. From 2013 on the research is being carried out according to the above-mentioned methods. The aim of this research is to assess efficiency of natural regeneration of *P. sylvestris* after NBL (winter 2006), soil mineralization (2007), and cleaning loggings (2015) with eliminating the trees of the untargeted species: birch, aspen, and spruce in the 30th unit of the 111th planning quarter. To achieve the goal a number of tasks were set: to analyze the influence of above-the-surface soil vegetation cover on development of pine young growth, to assess vitality of these plants and efficiency of natural *P. sylvestris* regeneration.

## Materials and methods

The field research was carried out in autumn 2017 on a bluejoint-cowberry-greenmoss logging. 18 sample areas of the size 4 $m^2$, with the gross area 72 $m^2$ were formed and researched. The areas were formed in different types of associations (with green moss, lichens, blue joint dominating). Vitality of *P. sylvestris* undergrowth was assessed on the basis of field research and cameral data treatment. In the field we assessed the age of the plant (B), its height (H), length of the latest annual increment (AI) and the branch union angle (A) was stated; the presence of re-crowning (R) during the whole life of the tree (dying off of the terminal bud which is followed by axis growing by means of one of the auxiliary buds) and yellowing of fir-needles on two-three summer shoots (X).

Taking into account all the indexes the general vitality (GV) of the trees was characterized that reflects the state of a certain tree this year, irrespective of its age. Good GV (1 point) is shown by the following indexes: no re-crowning; AG is over 5 cm; A is acute; absence of yellow needles; needles live over 3 years. Satisfactory GV (2 points): one re-crowning; AG is 3–5 cm; A is acute; absence of yellow needles; needles live not less than 3 years. Unsatisfactory GV (3 points): several re-crownings; AI is not less than 3 cm; A is oblique; there are either no yellow needles, or there are some on 3-year-old annual growths; needles live 1–2 years. If not all the features of a plant correspond to a certain point, GV was stated either according to the majority of three of them, or according to the most vitally important ones (A, R, AI).

During cameral treatment real vitality of the plants (Σ) was estimated in points: the state of each plant, taking into account its age. The following indexes were used: GV point; presence and number of re-crowning during the latest three years (1 point – not at all; 2 points – one; 3 points – two or more); the mean annual increment (MAI: height divided by age) and the length of the latest annual increment (AI). Individual plants of *P. sylvestris* different in age have different indexes of the latest AI, as well as of the MAI, thus they were assessed according to age periods of the plant [17]. The trees under 5 years: 1 point – increment is or over 5 cm; 2 points – increment is 3–5 cm; 3 points – increment is less than 3 cm. The trees from 5 to 20 years: 1 point – increment is or over 9 cm; 2 points – 5–9 cm; 3 – less than 5 cm.

Table 1

Vitality of individuals of the undergrowth of *Pinus sylvestris*

| The main parameters of the plants | | | | | | | | Real vitality, points | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | A, years | H, cm | R | A | AI, cm | AGav, cm | X | R | AIA | MAI | AI | Σ |
| 1 | 11 | 187 | – | acute | 36 | 27 | – | 1 | 1 | 1 | 1 | 4 |

The real vital power of a certain tree was assessed by means of summing up all the points. The less the number of points is, the better (Table 1).

This method was used to assess all the undergrowth individuals of *P. sylvestris* of the area.

## Results of the research

**Composition of vegetation and flora.** There are the following associations in the vegetation of the logging: with green mosses prevailing – greenmoss, lichen-greenmoss, cowberry-greenmoss, bluejoint-cowberry-greenmoss, sedge-greenmoss, clubmoss-bilberry-greenmoss-sphagnum, greenmoss-lichen, bluejoint-greenmoss; with bluejoint prevailing – greenmoss-bluejoint, blooming sally-bluejoint, cowberry-bluejoint, greenmoss-blooming sally with bluejoint.

Flora includes 75 plant species: 66 vascular (14 tree and shrubbery species, 52 subshrub and grass species) and 9 species of mosses and lichens. There were found 6 groups of vascular plants according to the hydric factor [18]. One species *Melampyrum sylvaticum* L. is hemiparasite. Mesophilic plants prevail (46 species); there are 11 xeromesophilic species, 4 hygromesophilic species, 2 hygrophilous species; there is also 1 mesoxerophilous species and 1 mesohygrophilou species. This indicates that logging sites are humid enough for pine seed germination, pine is a xeromesophilic species.

As for the content of ecological-coenotic groups (ECG), i. e. groups of plant species similar as for their reaction to a set of certain ecological factors typical for certain biotopes characterized by a high degree of association [19], the flora of the Medvedsky Bor is also diverse. All the species are represented in seven ECGs. Boreal species prevail (23 species). There is one oligotrophic species, there are 3 tall-grass species and 6 meadow-fringe-of-the forest species. In the Medvedsky Bor the typical boreal plant groups neighbor with coniferous, nemorose, and steppe plant groups. In monitoring it is topical to consider these groups separately, as they determine high bio-diversity of the SPNR "Medvedsky Bor". The coniferous group is represented by 20 species: *Calamagrostis epigejos* (L.) Roth., *C. arundinacea* (L.) Roth, *Veronica officinalis* L., *Lychnis flos-cuculi* L., *Chimaphila umbellata* (L.) W.P.C. Barton, *Campanula rotundifolia* L., *Antennaria dioica* (L.) Gaertn., *Polygonatum odoratum* (Mill.) Druce., *Juniperus communis* L., *Pteridium aquilinum* (L.) Kuhn, *Dactylorhiza maculata* (L.) Soo, *Pulsatilla patens* (L.) Mill., *Viscaria vulgaris* Bernh., *Pinus sylvestris* L., *Gnaphalium sylvaticum* L., *Arctostaphylos uva-ursi* (L.) Spreng., *Viola rupestris* F.W. Schmidt., *Rumex acetosella* L., *Hieracium umbellatum* L., *Hieracium vulgatum* Fries. Nemorose group contains 9 species: *Quercus robur* L., *Viburnum opulus* L., *Convallaria majalis* L., *Tilia cordata* Mill., *Platanthera bifolia* (L.) L.C. Rich., *Poa nemoralis* L., *Carex pilosa* Scop., *Carex digitata* L., *Aegopodium podagraria* L. There are 4 steppe species: *Astragalus arenarius* L., *Eremogone saxatilis* (L.) Ikonn., *Chamaecytisus ruthenicus* (Fisch. ex Wol.) Klask., *Trommsdorffia maculata* (L.) Bernh.

Thus the main specific ECGs of forest plants of the SPNA "Medvedsky Bor" are naturally preserved on the logging, and bio-diversity is sustained on the whole. Natural pine regeneration is provided by keeping the edificator of these forests on the territory under research.

**Undergrowth Characteristics.** All in all on the territory under research we found 158 young trees from 1 to 16 years old, they are quite equally spaced on the whole territory of the area, excluding waterlogged hollows, mostly with deadwater. The age of the undergrowth varies. 12–16 year-old plants are a surviving undergrowth of the original communities; 11 year-old plants appeared after NBL; 10 year-old and younger plants appeared after soil mineralization. Special attention was paid just to these age groups of plants which appeared there after different forest management activities.

The most plants have dark-green needles. There are very few yellowed needles. Side branch union angles are mostly acute. Growth of shoot system is unstable monopodial: at the beginning stages of development, usually more than once, re-crowning takes place. But this feature spoils life of just 29% individuals, and just a little bit. We think that in the future the undergrowth of this category will be able to live through all the ontogeny stages and form a timber stand of high quality.

The analysis of the undergrowth state, depending on the types of plant associations, showed the following results. On all the *greenmoss* areas of the logging there are many young *P. sylvestris* trees growing quite close to each other. There are 47 trees which are 8–16 years old (30% of all the trees under research). Separate 5–6 year-old plants trees die as a result of natural selection. The most trees are 11 years old. These are high (up to 360 cm) trees with a high AI (up to 60 cm) of an individual. 83% plants have the best indexes of real vitality (4–5 points), actually all 11 year-old plants are included here. The index of vitality of 3 trees is 6, of 2 trees – 7. Three 8-10 year-old trees have 9 points. These are stunted plants (16–28 cm), with the mean annual increment less than 3 cm, and they are most likely to naturally get lost from the wood stand.

On the areas with *greenmoss-lichnes and lichens-greenmoss cover* there are also quite many undergrowth individuals. Seedlings are few. There are 24 plants from 9 to 15 years old (15% of the total). 11–12 year-old individuals prevail. The index of real vitality is mostly 4–5 points (75%). Three individuals with one re-crowning have 6-point vitality, one individual – 7 points. There are just two individuals (9 and 12 year-olds which are 31 and 72 cm high) with low vitality (9 points).

On the areas with *sedge-greenmoss* and *clubmoss-bilberry-greenmoss-sphagnum* cover there are few undergrowth individuals. There are few plants younger than 10 years. There are 10 young plants 10–12 years old (6%). 11 year-old individuals prevail, they are all tall (up to 287 cm), with a high AI. 8 of them have a high degree of vitality (4–5 points); two – 6 and 7.

On the areas with *cowberry-greenmoss, bluejoint-greenmoss* and *greenmoss-blooming sally with bluejoint* types of vegetation 10–13-year-old plants prevail. On the sites under research there were found 35 3–14-year-old individuals (22%), mostly 11-year-olds; they are all tall (up to 276 cm), with the AI up to 57cm. Re-crowning mostly takes place at initial stages of development (at the age of 4–5) and it does not influence the index of real vitality so far. On these areas plants with high vitality prevail (91%).

Seed germination and undergrowth development suffer from negative influence of gramineous plants: *Poa nemoralis, Calamagrostis arundinacea* and *C. epigejos*. They afford sod, firm the forest litter and upper part of the soil layer with rootstock. Sandy-loam soils of the area under research contribute to their development. On some sites of the territory graneous plants form a kind of a mattress.

On the areas *with bluejoint* the undergrowth is thinned. Here 9–13-year-old individuals prevail. After mineralization on separate sites there are groups of germinated seedlings and of one-three-year-old plants. There are 42 individuals from 1 to 15 years old there (27% of the total number). 11-year-old plants prevail there: with AI over 60 cm, they are tall (up to 290 cm), with the best indexes of real vitality (69% plants have 4–5 points), at times with one-two re-crownings at the initial stages of development.

Per hectare the energy of natural regeneration in the greenmoss associations is 6 times higher than that of the necessary number of mature trees; in the areas with bluejoint it is 5 times higher. They appeared after pine felling and mineralization and they are about the same age; there are few younger individuals. Evidently, in course of time, increase of the degree of projective cover and herbaceous layer density leads to reduction of natural regeneration energy.

The analysis of one-three-year-old plants according to the given method showed that their indexes, because of their little annual and mean annual increment, are higher, and, consequently, their real vitality is less. Thus they are not that relevant at the analysis of undergrowth on the whole, alongside with older plants. So we calculated the vitality index of only 150 individuals from 4 to 16 years old (Table 2). Per hectare it is 21.000 individuals.

9–13-year-old plants prevail. 36% of the total is 11-year-olds. They are the tallest, with the best indexes of real vitality. They appeared as a result of a through-belt logging in 2006. 12–13-year old individuals account for 27%, at the moment of research their vitality indexes are high or the highest. There are 23% trees which are 9–10 years old, they appeared after soil mineralization.

The most plants have *the annual increment* from 16 to 25 cm, quite a few – from 26 to 36 cm. 8% individuals have maximum annual increment which is over 46 cm (some – up to 60 cm). Only 4% dwarf plants aged 9–10 and 12 from interdunal lowlands have annual increment which is less than 5 cm. Clearing logging with elimination of non-target wood species, which took place in 2015, had a positive influence on

**Table 2**

Indicators of real vitality of *Pinus sylvestris* plants of different ages

| Age, years | Number of plants | Real vitality, points | | | | |
|---|---|---|---|---|---|---|
| | | 4–5 | 6 | 7 | 8 | 9 |
| 4 | 3 | 1 | 2 | – | – | – |
| 5 | 1 | – | – | 1 | – | – |
| 6 | 1 | 1 | – | – | – | – |
| 8 | 5 | 2 | 1 | 1 | – | 1 |
| 9 | 10 | 5 | 2 | 1 | – | 2 |
| 10 | 25 | 21 | 2 | – | 1 | 1 |
| 11 | 54 | 53 | 1 | – | – | – |
| 12 | 27 | 23 | 2 | – | 1 | 1 |
| 13 | 14 | 11 | 2 | 1 | – | – |
| 14 | 6 | 6 | – | – | – | – |
| 15 | 3 | 3 | – | – | – | – |
| 16 | 1 | 1 | – | – | – | – |
| Total amount | 150 | 127 | 12 | 4 | 2 | 5 |
| % | | 85 | 8 | 3 | 1 | 3 |

*Note: "–" – plants with such indicators do not exist.*

forming AI, which considerably exceed the range of indexes stated by [17]. Increments of the latest two years of many plants are much higher than the previous ones; only 14% individuals have had a re-crowning. Actually all the auxiliary buds developed into surculus.

*Mean annual increment* of the most plants ranges from 6–15 to 16–25 cm. Maximum range of indexes here is 26–35 cm. 4% individuals have minimal increment (1–3 cm).

*Real vitality indexes* of 85% of 4–16 year-old plants are high on the territory under research. Per hectare it is 17.600 individuals. 9–13 year old individuals also have the best vitality index (Table 2). It is them which are to become sound mature trees in the future.

Thus efficiency of natural regeneration in conditions of these kinds of activity is high. According to the Forest Regeneration Rules of the Natural Resources Ministry of the RF it is necessary to plant not less than 4.000 pine plants per ha [20]. This number is considerably exaggerated due to natural die-off of young plants. The research results (21.000 individuals per ha) showed that this norm is more than five time increased in course of natural regeneration in conditions of NBL with the following contribution to natural regeneration and care.

According to the forest resource management indexes, normal state of pine forests requires 250 trees per ha [21]. Comparing this number with the data of the research it was stated that natural regeneration energy 84 times exceeds this number. Just one year can be required to provide natural forest stand regeneration in case of abundant seed production in conditions of NBL with the following measures of forest regeneration and care.

In course of forest management this type of logging can be used as one of possible ways of natural pine regeneration on the territory of the Medvedsky Bor, preserving the original forest communities and forests' eco-systematic functions.

## Conclusion

1. At greenmoss and bluejoint fellings natural pine regeneration after NBL in conditions of constant support of regeneration is sufficient (according to the norms for artificial planting).

2. Vitality of the undergrowth, which was formed during and after the measures taken, is stable and high.

3. In case of taking all the necessary measures of forest management, the formed undergrowth is able to form communities with a high appraisal index.

4. NBL provides keeping the specious and phytocoenotic bio-diversity.

Thus gradual next-but-one belt loggings with the following regeneration and complete elimination of the trees, soil mineralization measures, and clearance loggings are quite effective and can take place on the territory of the SPNA "Medvedsky Bor". In such conditions pine forests naturally regenerate. Alongside with different forest regeneration measures it provides continuous intensive long-term sustainable forest management.

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