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STRUCTURE OF A MIDDLE TAIGA VACCINIUM SPRUCE FOREST AFTER 40 YEARS SINCE AN INTENSIVE SELECTIVE CUT IN THE FISH SPAWNING PROTECTION ZONE OF LAKE ONEGA[1]

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Abstract. The condition and structure of the stand formed over 40 years after high-intensity, even, gradual logging in the fish spawning protection zone of Lake Onega were studied. In the test plots laid out in 1982 before logging in a relatively uneven-aged mixed spruce forest of the vaccinium type of forest of III–IV quality class with a wood stock of about 220 m^3 ha^{-1}, the proportion of spruce was 40%, and the density of medium and large spruce undergrowth was about 1 thousand trees ha^{-1}. As a result of logging, the reserve decreased by 50–70%, and the proportion of spruce in it was 60–65%. By 2023, stepped-closed mixed stands with a predominance of spruce and a total reserve of 250-300 m^3 ha^{-1} were formed on the logging site. Half of the available stock is concentrated in the lower part of the canopy, under which there are more than 3 thousand trees ha^{-1} of spruce undergrowth. The spatial variability of density, stock, species composition of the stand and natural regeneration in the context of ensuring the sustainability of the stand is studied. Data on the dynamics of increment, large woody debris, age structure of the stand and undergrowth are analysed. The role of the technological network in the formation of heterogeneity of the stock, increment, species composition and undergrowth was clarified. The species composition and projective cover of the living ground cover as an indicator and factor of the dynamics of the stand are studied. Statistical relationships between the structural elements of the phytocoenosis are revealed, contributing to the understanding of its development and stability. The correspondence of the stand formed after felling to the main criteria for identifying biologically valuable forests is shown. Based on the results of the analysis of the obtained data and literary sources, a conclusion was made about the prospects of continuing selective management in the interests of further growth and sustainability of the spruce forest and the performance of its protective functions.

Keywords: *Norway spruce, uneven-aged forest stand, composition, spatial structure, undergrowth, living ground cover, biodiversity, protective forests, selective cuts*

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In the forests of the Northwestern Federal District, which continue to be the raw material base of the woodworking and pulp and paper industries, the share of protective forests reaches 38 %. Management in them, with the main goal of maintaining ecological functionality, should also take into account socio-economic conditions (Forest Code, 2006; Zheldak et al., 2023). The need for scientific research in this direction is directly derived from the modern understanding of ecosystem services, which include, along with environment-forming, also raw material and social aspects of forest valuation (Lukina et al., 2015). The realization of protective functions of forests depends on their sustainability, largely determined by spatial and species diversity (Volkov et al., 2002; Storozhenko, 2007; Fedorchuk et al., 2012). Reduction of the latter requires special attention in the context of the implementation of the strategy of intensification of forest use and reproduction (Concept..., 2015). In this regard, the number of studies of biodiversity in forest areas with the introduction of intensive management elements is increasing (Burova et al., 2010; Belyaeva et al., 2012; Amosova, Ilyintsev, 2022). The concept of Variable Retention Forestry, or “conservation forestry”, has been formulated as one of the measures to prevent biodiversity loss (Gustaffson et al., 2012; Shorokhova et al., 2019; Kryshen et al., 2020). Some provisions of this concept have been introduced into forest management practices in the North-West of the Russian Federation over the last 20 years as part of forest certification programs (Rai et al., 2008; Identifying..., 2009).

In Karelia, about 80 % of protective forests are directly related to water bodies (Ananyev and Sinkevich, 2015). Therefore, maintaining the ecological functionality of protective forests should provide a level of total growth that effectively

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compensates for the excess of precipitation over evaporation. At the same time, it is necessary to form such a species and spatial structure of forest plantations, which would provide effective conversion of surface runoff into groundwater runoff (Pobedinsky, 2013). The urgency of these tasks increases especially in connection with the trend of increasing total precipitation and Rosgidromet's forecasts for its preservation in the near future (Report ..., 2018; Forest Plan ..., 2018).

The required level of growth can be achieved by having a sufficient number of actively growing trees or by selective logging where, due to the age structure of the forest fund, its ecological functionality decreases over time, both in the regional aspect (water-regulating) and in the global aspect (carbon storage) (Forest Code..., 2006; Sinkevich, Ananiev, 2020). The criterion of ecological functionality of protective forests that is accessible for determination in nature, in addition to the unconditional necessary species composition, should be the stock of stands sufficient to ensure the necessary level of growth, transpiration, water regulation and atmospheric carbon sequestration. At the same time, the sustainability of plantations, valuable from the ecological and economic point of view, largely depends on competitive relations in the phytocenosis, which also require attention.

OBJECTS AND METHODOLOGY

The object of the study is a relatively mixed-aged spruce forest located in the spawning protection zone of Lake Onega (60°36' N, 34°41' E), which was cut 40 years ago by uniform gradual cutting of high intensity. Mixed plantation of III—IV class of bonitet of the blueberry forest type was formed under the influence of selective logging of pine and spruce stands in the past (1860 and 1930). The site relief is flat, with a slight slope to the east, the soil is coarse humus strongly podzolic on the coastal abraded moraine. Two permanent sample plots of 80×80 m were established in 1982 before harvesting (Table 1), and one sample plot of 60×100 m on the same plot was established in the year of the survey. Felling was carried out according to the sorting technology with manual felling. The sample areas were placed so that their two sides were parallel to the planned technological corridors, the distance between which was 25 m.

On the sample plots (SP), divided into square sections of 10×10 m, a complete enumeration of the stand by 2-cm thickness steps separately by species, two age groups and condition categories, height measurements (230 trees), a complete count of viable undergrowth according to the generally accepted categories of size were carried out. Identification of floristic composition and projective cover of living ground cover (LFC) species was carried out at 25—30 sites systematically placed in each sample area; to assess floristic similarity and species diversity, the Jaccard coefficient (Kj) and H' — Shannon index were calculated (Pesenko, 1982; Methods..., 2002). To clarify the history, age structure and to assess the stand reaction to the harvesting, 180 cores were taken with a Pressler drill at a height of 1.3 m and 30 model plants of the undergrowth. Tree diameter, species, age category and location in relation to technological corridors were recorded during core sampling. To clarify age, cores were additionally taken at stump height from trees of different sizes and age categories. The width of all annual layers was measured with an accuracy of 0.01 mm on fresh cores after stripping and contrasting. The pre-cutting characteristics of the stand at PP 4, which was established in the year of the survey, were reconstructed on the basis of stump records and total growth over 40 years. The taxonomic characteristics of the stand were determined separately for 10× 10 m sections, which allowed us to assess the spatial variability of the studied parameters of the phytocenosis and to identify statistical relationships between them. To assess the heterogeneity of the horizontal structure of the plantation, in addition to the coefficient of variation, the Simpson index was calculated as an index of dominance and the Pilu index (normalized Shannon index) was calculated as a measure of similarity in the placement of objects of different classes (Magarran, 1992; Fedorchuk et al., 2009). Data processing and analysis were performed using MS Excel spreadsheet processor and Statistica 10 software package. Measurements were made using the scientific equipment of the Center for Collective Use of the FIC Karelian Research Center of the Russian Academy of Sciences.

RESULTS AND DISCUSSION

The stand stock as of the year of gradual harvesting averaged about 230 m^3ha^{-1}. Dry stands were represented by stunted spruce (*Picea abies*) and birch (*Betula pendula*) (15—35 pieces/ha) and overmature aspen (*Populus tremula* L.) (20 pieces/ha) with a total volume of 10—20 $m^3ha^{(-1)}$. As a result of harvesting, the stand stock in different parts of the section decreased by 49—70 % (Table 1).

Radial growth of trees after harvesting increased on average by 2 times, resulting in an average total change of 5.4 $m^3ha^{-1}year^{(-1)}$ for the stand as a whole, and 1.6 $m^3ha^{(-1)}$ $year^{(-1)}$ for spruce. After 40 years after harvesting, the stock exceeded the initial values by 28—40 % depending on species composition and growing conditions. The stock of the spruce part of the stand grew more efficiently at a higher intensity of harvesting, realized to a large extent at the expense of deciduous species (Fig. 1).

The accumulation of deadwood during the observation period (Table 1) was inversely proportional to the cutting intensity. The appearance of deadwood was a natural consequence of competition, and deadwood was formed from large trees. Common for all three sample plots is the presence of overmature aspen trees, which gradually lose stability due to the development of stem rots. Average volumes of deadwood trunks belonging to decomposition classes 2—4 (Storozhenko, 2012; Khimich and Shorokhova, 2018) are close in all sample plots (~0.35 m^3), and the same can be said

Table 1. Variation of plantation characteristics in sample plots PP 1, PP 2, PP 4

Average taxation	PP 1			PP 2			PP 4		
indicators	1982 before chopping	1982 after cutting	2022	1982 before chopping	1982 after cutting	2022	1982 before chopping	1982 after cutting	2022
Spruce diameter, cm	16.4	17.8	21.3	14.9	13.6	17.9	18.0	18.4	23.2
Stand height, m	14.7	15.5	18.5	13.7	12.7	16.0	15.5	14.5	23.7
Total stock, $m^3 ha^{-1}$									
- live trees	216	63	304	200	66	255	239	123	338
- deadwood	10		8	19		8	–		14
- valley	–		6	–		8	–		40
Stock selection,%	70			65			49		
Share of rocks in the composition									
spruce	4.1	6.2	5.0	4.2	6.0	5.3	4.9	5.3	4.3
birch	2.2	2.1	2.3	2.2	1.6	1.6	0.9	1.0	0.7
aspen	3.7	1.7	2.5	2.6	1.5	2.2	4.0	3.3	4.6
pine	0.1	+	+	1.0	0.9	0.7	0.2	0.3	0.2
alder, willow, mountain ash	–	–	0.2	–	–	0.1	+	0.1	0.2
Undergrowth, thousand pcs. ha^{-1}									
up to 0.5 m	0.27	–	2.3	0.09	–	1.4	–	–	1.1
0.5—1.5 м	0.29	–	1.6	0.21	–	1.8	–	–	0.9
over 1.5 m	0.62	–	0.4	0.72	–	0.4	–	–	0.9

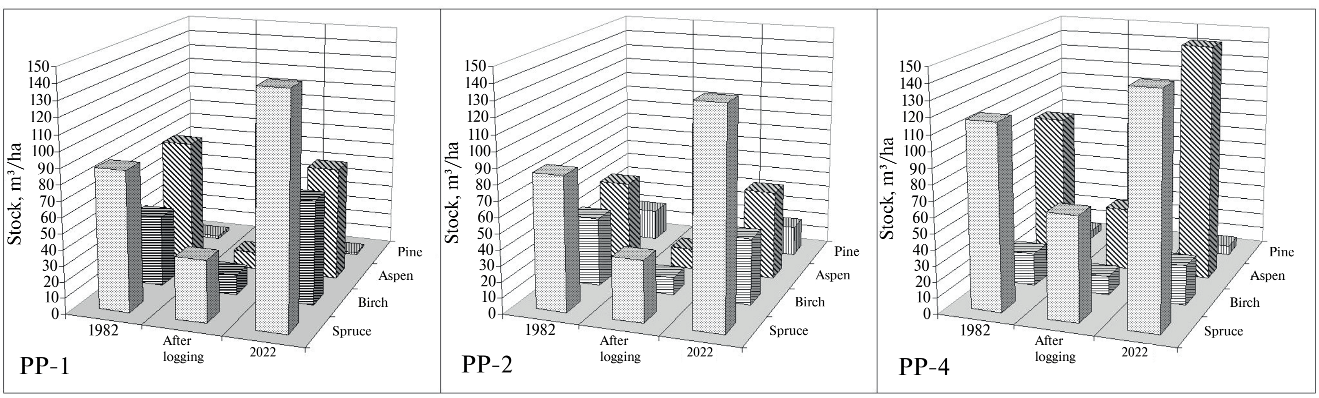

Fig. 1. Change in the stock of constituent rocks at the sample plots PP 1, PP 2, PP 4 for 40 years in a plot of intensive gradual harvesting in blueberry spruce forest.

about average trunk volumes of shrunken trees (0.2 m^3). Average annual rates of deadwood accumulation do not exceed 1 % of the stock left after high-intensity logging (PP 1 and PP 2) and are similar to results from selective logging and observations in mixed-age spruce forests of the Leningrad Region (Dekatov et al., 1985; Fedorchuk et al., 2010). Over the last decade, the amount of deadwood has significantly increased in the area with the lowest cutting intensity (PP 4), and half of the fallen trees were large-sized aspen and birch.

An important condition for the long-term existence of a forest area is its spatial heterogeneity (Drobyshev et al., 2003; Storozhenko, 2020). The integral indicator summarizing the effect of the causes that determine it is the total stock, which allows us to assess the suitability of the species composition and growing conditions of the plantation, taking into account the intended purpose of forests.

Local values of the total stock by sections are distributed according to the lognormal law and differ significantly from the average stock in the sample area (Fig. 2).

The reason for this is both the unevenness of sampling and the presence of individual large trees of the first tier. At the same time, the coefficients of variation of the total stock are 46—51 %, and there is no more than one case in each variant outside 3σ. ±

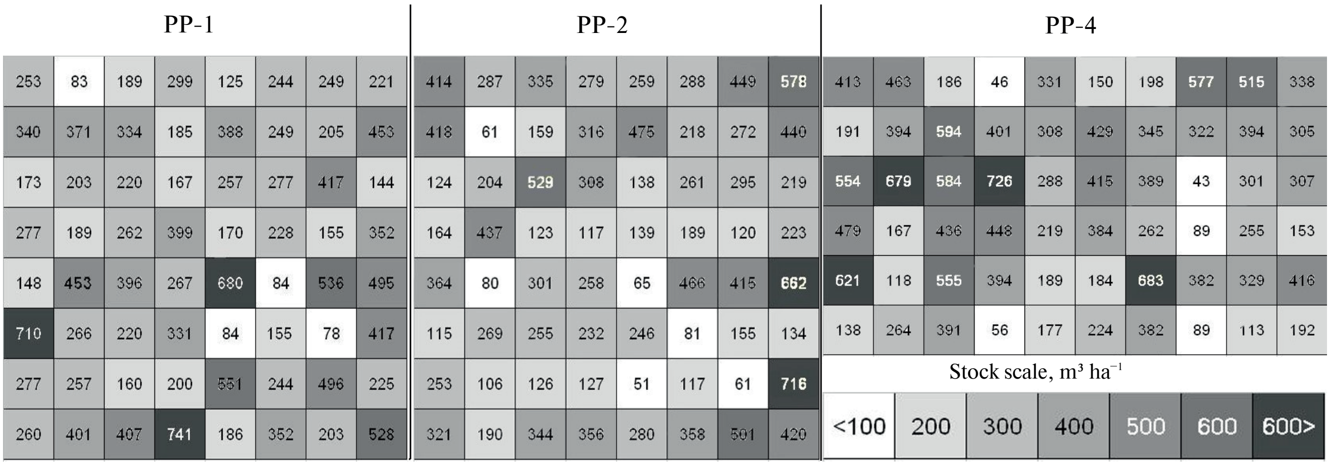

Fig. 2. Spatial variability of the total stockpile at 10× 10 m sections in blueberry spruce forest 40 years after gradual cutting.

The spatial uniformity of the stock, assessed by Simpson index, is very close in the variants with maximum cutting intensity (0.215 and 0.222) and is characterized by the dominance of sections with a stock of about 250 m^3ha^{-1}, while the stock uniformity, characterized by Pilu index in the case of maximum cutting intensity (PP 1), is slightly higher (0.417 and 0.406). For the variant with the lowest cutting intensity (PP 4), the values of Simpson and Pilu indices are 0.178 and 0.455, respectively, indicating the absence of dominance of any class and much better stock equitability.

On average across sections, two thirds (46 to 72 %) of the total stock is concentrated in Tier II, indicating prospects for maintaining the growth rate of the stand as a whole. No correlation between tier stocks was observed, largely due to the fact that 30 % (15 to 40 %) of the sections lacked upper tier trees.

The range of variability in the density of trees of the first tier (Table 2) is significantly higher than other taxation indices. The dominant trees are the reason for the increased variability of the tier stock, averaging 117 %. The trees of the subordinate II tier are distributed over the area much more evenly; at an average density of 1270 eq. $ha^{(-1)}$ (Table 2), the coefficient of variation in the number of trunks of enumeration size is 40 %, and in the stock — 55 %.

The diameter distribution of spruce and birch trees of enumeration size before harvesting and 40 years after it is characterized by a pronounced left asymmetry. The proportion of trunk number decreases exponentially (R^2 = 0.86—0.88) from 45—50 % in the 8 cm stage to a fraction of a percent in the 36—40 cm stages. Aspen is characterized by bimodality of diameter distribution with maxima in the area of 12 and 32 cm, especially manifested after cutting.

The stand species composition varies in space for the same reasons as the stock. The participation of spruce in the composition is important for preserving the functionality of coastal forests, whose purpose is to convert surface runoff into in-situ runoff (Pobedinsky, 2013). In the surveyed plantation, no preferential selection of spruce and deterioration of stand composition was observed (Table 1). Moreover, immediately after harvesting, the spruce proportion was on average one unit higher than at the end of the observation period. Sections with the share of spruce more than 4 units occupied 60—70 % of the plot area. The degree of variability of the spruce share in the composition formula of the plantation, amounting to 43 % at PP 1 and PP 2, indicates its even distribution. The dominance of sections with pure spruce stands and, accordingly, the least uniformity of the composition were observed at PP 2. The most uniform share of spruce in the variant with the lowest cutting intensity (PP 4), for which the Simpson and Pilu indices were 0.116 and 0.543, respectively.

As a result of intensive growth of aspen crowns after harvesting, the recovery of its stock was faster, and the share of spruce was replenished mainly due to second-tier trees and large undergrowth. As a result, the participation of spruce in the sections with the highest reserves is significantly lower,

Table 2. Mean values (M±m) of stand density and stocking rate by tiers on sample plots in bilberry spruce forest 40 years after high-intensity logging

Trial	Number of trees, pcs. ha^{-1}						Total stock, $m^3\,ha^{-1}$	
square	I tier	including spruce	tier I	II tier	including spruce	tier II	I tier	II tier
	total	old	young	total	old	young	total	total
PP 1	128 ± 16	51 ± 9	11 ± 4	1229 ± 64	172 ± 20	500 ± 41	138 ± 18	166 ± 9
PP 2	109 ± 14	38 ± 8	5 ± 2	1235 ± 82	398 ± 30	428 ± 39	101 ± 15	168 ± 11
PP 4	200 ± 17	73 ± 12	3 ± 2	1353 ± 68	167 ± 22	255 ± 25	205 ± 19	133 ± 12

which is characterized by the correlation coefficient from –0.30 to –0.58.

The resulting estimates of variability in stand stocking and composition and their dynamics indicate the need to intervene in the further development of the stand to reduce the likelihood of future windthrow.

The age structure of stands formed after harvesting was assessed during the enumeration visually with division into "old" and "young" categories (Table 2), taking into account tree size, bark and crown structure. More detailed information was obtained by counting annual layers on cores, during the selection of which diameter and external signs of tree age were also recorded (Dyrenkov, 1984; Volkov, 2003).

Based on the results of comparing the ages and diameters of 100 counted spruce trees with the enumeration data by thickness grades and age categories, an exponential decrease in the share of spruce trees of enumeration size from 66 to 1 % in the age range from 40 to 200 years can be stated. Thus, the largest share of the total spruce stock (32 %) is accounted for by trees aged 60—100 years. The previous and subsequent 40-year generations, as well as trees older than 140 years each account for 23 % of the spruce stock. For birch and aspen trees in the main canopy, the age range of 80—100 years is predominant, and up to 20 % of specimens up to 200 years old are also present.

According to the representation of different generations of spruce, the surveyed stand can be classified as relatively mixed-aged (Dyrenkov, 1984; Volkov, 2003), which is one of the signs of biologically valuable forests (Identification..., 2009). Resilience to the intensive thinning of 1982 was facilitated by logging conducted in the past, which formed a step-compact canopy of the plantation, thus creating prerequisites for the continuation of selective management (Alekseev and Molchanov, 1954; Sinkevich, 1980). The probable loss in economic productivity (Valyaev, 1989) is compensated in protective forests by the preservation of their ecological functionality.

Growth dynamics is a mandatory element of meaningful silvicultural assessment of the accumulated tree stock for 40 years after harvesting. The main role in the ecological functionality of the plantation in this case is played by spruce, the dynamics of radial growth of which is shown in Fig. 3. 3.

Trees representing the two main generations in terms of stocking rate and having an average age of 70 and 150 years at the time of the survey responded similarly to the 1982 cutting with a 2—4 fold increase in growth; the response of the older generation was naturally weaker.

The increase in growth of trees of both generations immediately adjacent to the technological corridor is significantly lower than at a distance of 5 m from it. This difference, although smoothed out a few years after cutting, continued to manifest itself for at least 20 years.

In the depth of inter-corridor spaces the reaction was significantly weaker and was manifested for up to 20 years, and in older generations — not more than 10 years. Taking into account the number of trees of different generations and their spatial location, the duration of the period of active increase in radial growth due to cutting can be estimated at 25 years. After this period, another commercially profitable cutting aimed at maintaining the protective properties of the plantation is possible.

Undergrowth is a necessary condition for maintaining stability and functionality of forest stands (Storozhenko, 2022) and their restoration after exogenous disturbances. Before the gradual cutting in 1982, the number of mainly medium and large undergrowth amounted to 1.1 thousand units ha$^{(-1)}$ (Table 1). This number was clearly insufficient as a restoration reserve.

After 40 years after harvesting, the total number of undergrowth increased 3—4 times, and the average density was directly proportional to the intensity of harvesting. The share of small undergrowth in the size structure of regeneration increased to 40—50 %. Its predominance after intensive thinning in spruce forests was noted by foresters earlier (Alekseev

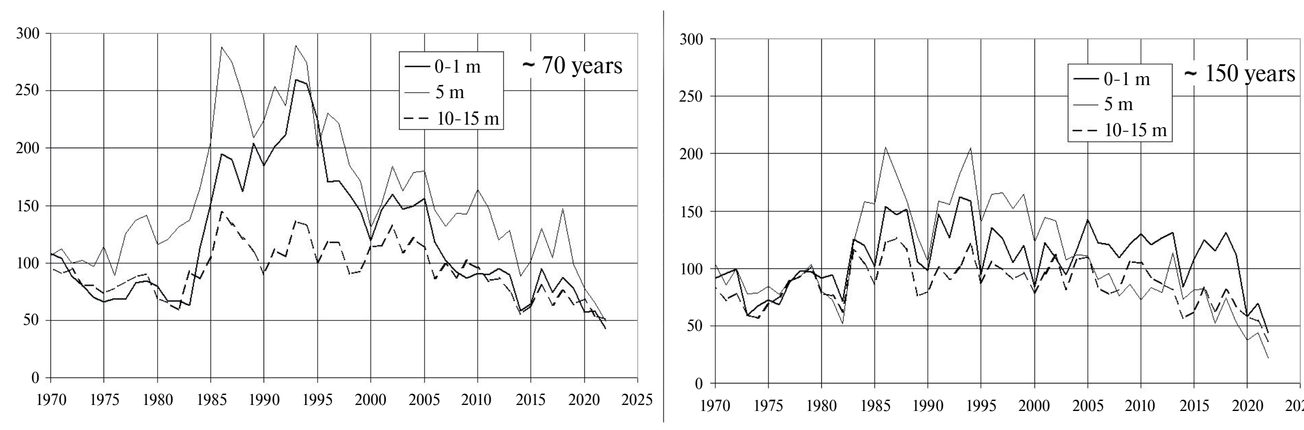

Fig. 3. Dynamics of annual ring widths (mm-10^{-2}) of two generations of spruce trees of average age 70 and 150 years located at different distances (0—1m, 5m and 10—15m) from the technology corridors.

and Molchanov, 1954; Latyshev et al., 2010). Taking into account the generally accepted correction factors for undergrowth size, its total number in terms of large undergrowth over 40 years reached 2.2—2.8 thousand pcs. ha^{-1}.

Spatial variability of the total number of spruce undergrowth at sufficiently sparse canopy of the mother stand (PP 1, PP 2) is 52 % and is determined mainly by the grouping of small specimens (V=88 %) confined to the places of anthropogenic damage of forest litter and old windthrow complexes. Unevenness of the number of medium and large undergrowth is characterized by the coefficient of variation 56—60 %. In the variant of the lowest cutting intensity (PP 4) the variability of undergrowth density is 20 % higher for all size categories.

The age structure of the undergrowth is determined by the age of the last harvest and the presence of seed years that followed it. Analysis of model specimens of undergrowth showed that in the height range of 0.3—0.8 m the age of spruce varies from 15 to 30 years, after which up to the height of 4 m it does not exceed 35 years. This regularity is approximated by a hyperbola equation with correlation coefficient R = 0.88. Specimens older than this age occurring in apiaries make up 10 % of the total number and have a pre-cutting suppression period of about 10 years. The height of such spruces can be from 0.8 to 2.5 m. At the same time, the age at the time of the beginning of the sharp increase in growth (year of cutting), which ranged from 7 to 20 years, does not correlate with the height reached by the end of the observation period. The age of undergrowth located directly in the technological corridors has the same range of variability and type of relationship with height as in the whole data set. The age of younger specimens appearing later is linearly related to their height.

The presence of assumed dependencies of spruce undergrowth abundance on the taxonomic parameters of the parent stand was investigated by means of correlation analysis at the level of 10×10 m sections for each category of undergrowth size. The total stock, density of I and II stands, as well as the shares of spruce, birch and aspen in the composition of the upper stand were considered as influence factors. The number of small undergrowth decreases weakly but significantly with increasing total stand stock (R=0.25—0.30). In a similar way, large undergrowth depends on the density of the second story. The influence of specific species at the highest cutting intensity (PP 2 and PP 4) could not be detected, but at PP 4 a significant positive influence (R=0.47) of birch canopy mainly on small undergrowth was observed.

Live ground cover (LFC) is an indicator of the level and diversity of growing conditions and, at the same time, a factor limiting the emergence and development of tree species seedlings. Its general characterization at the study site is given in Table 3. A total of 24 species of vascular plants and 7 species of mosses were recorded in the LNP of the surveyed stands. In the epiphytic layer, a significant distribution of the protected lichen (Red Data Book..., 2020; Order..., 2023) *Lobaria* pulmonaria (L. *pulmonaria* (L.) Hoffm.) was observed, mainly on aspen trees, but also on spruce undergrowth.

The number of species of the herbaceous-shrub layer (HSL) in plots with different cutting intensity varies from 16 to 20, and the species composition is characteristic of the indigenous forest types of the Spruce Formation (Kazimirov, 1971; Kryshen et al., 2021). In the herbaceous-shrub layer, irrespective of the cutting intensity of stands, the total projective cover (TPC) of 10 to 30 % prevails; increased occurrence of higher TPC values was noted only at PP 2.

Insignificant values of projective cover in the plot as a whole make it difficult to compare variants, therefore it is reasonable to use also the indicator of species occurrence at the survey sites. This makes it possible to obtain contrastingly different indirect assessments of light conditions, which took place earlier, and to judge more reasonably about effective fertility.

Bilberry (*Vaccinium myrtillus* L.) is the absolute dominant TCN in all sample plots, the share of other species does not exceed 2—3 %. The projective cover of bilberry is maximum in the variant with the highest cutting intensity (PP 1), where it can reach 40 % and more. In other cases, values of 10—20 % absolutely prevail. At the lowest cutting intensity (PP 4) the presence of *shade-tolerant* species characteristic of bilberry spruce — sagebrush (*Oxalis acetosella* L.) and mayberry (*Maianthemum bifolium*) — is more pronounced. The high occurrence of sagebrush, mayberry, some ferns (*Dryopteris* carthusiana, *Gymnocarpium dryopteris*) and the presence of non-moral species (*Lathyrus vernus, Maianthemum bi*folium) also indicate increased soil fertility, which is also confirmed by a significantly higher tree stock. Conversely, the lower occurrence (or absence) of these species on PP 1 and PP 2, together with a significantly higher projective cover of the moss-lichen layer (MLL), indicates lower fertility.

High occurrence of 4 loose-leaved grasses (*Avenella flexuosa, Calamagrostis arundinacea*), creeping shrub *Linnaea borealis* L., long- and pseudo-rooted ferns at PP 4 indicates that they had high projective cover after felling in the recent past, which caused the lowest number of spruce undergrowth.

The moss-lichen layer contains 7 species of mosses typical for spruce stands of the middle taiga subzone. The dominant species in terms of both projective coverage and occurrence are *Hylocomium splendens*, *Pleurozium schreberi*, *Rhytidiadelphus triquetrus*. The highest average moss cover was observed in the variant with the lowest tree stock (PP 2). In contrast to the herbaceous-shrub layer, moss cover can reach 90 %, but its values of 5—20 % absolutely dominate.

In general, the coefficient of variation of the total projective cover of LNP is small and amounts to 20—30 %, which is significantly less than its values for the stand and undergrowth. Comparison of the level of TKJA diversity according to the Shannon index (H') showed the identity of PP 1 and PP 2 (H' = 0.56—0.60) and a significant

Table 3. Average projective cover and occurrence of species of living ground cover on sample plots in bilberry spruce forest 40 years after harvesting

Tiers and species	Projective coverage,%			Occurrence,%		
	PP 1	PP 2	PP 4	PP 1	PP 2	PP 4
Grass and shrub layer:	18.0	13.9	16.6	-	-	-
Athyrium filix-femina (L.) Roth	<1	–	–	4	–	–
Avenella flexuosa (L.) Drej.	<1	<1	<1	4	36	15
Calamagrostis arundinacea (L.) Roth	<1	<1	<1	14	21	75
Carex globularis L.	<1	<1	<1	11	4	5
Dryopteris carthusiana(Vill.)H.P.Fuchs	<1	<1	<1	4	11	15
Equisetum sylvaticum L.	<1	<1	–	18	4	–
Fragaria vesca L.	<1	–	–	4	–	–
Gymnocarpium dryopteris (L.) Newm.	<1	–	<1	43	–	50
Goodyera repens (L.) R. Br.	<1	<1	–	4	7	–
Lathyrus vernus (L.) Bernh.	–	–	<1	–	–	5
Linnaea borealis L.	<1	<1	<1	39	43	70
Luzula pilosa (L.) Willd.	–	<1	<1	–	18	25
Maianthemum bifolium (L.) F.W. Schmidt	<1	<1	2.7	64	18	90
Melampyrum pratense L.	<1	<1	<1	18	50	70
Orthilia secunda (L.) House	<1	<1	<1	39	61	25
Oxalis acetosella L.	<1	<1	3.2	50	14	90
Platanthera bifolia (L.) Rich.	–	–	<1	–	–	5
Pyrola rotundifolia L.	–	–	<1	–	–	5
Rubus arcticus L.	–	–	<1	–	–	10
Rubus saxatilis L.	<1	<1	<1	14	7	20
Solidago virgaurea L.	<1	–	<1	25	–	35
Trientalis europaea L.	<1	<1	<1	32	29	70
Vaccinium myrtillus L.	16.5	12.5	10.3	96	96	90
Vaccinium vitis-idaea L.	1.3	2.2	1.9	86	93	90
Total species in the tier	19	16	20	–	–	–
Moss-lichen layer	20.0	40.0	18.6	–	–	–
Dicranum scoparium Hedw.	<1	<1	<1	21	32	25
Hylocomium splendens (Hedw.) Shimp.	3.7	14.9	3.5	75	96	80
Plagiomnium cuspidatum (Hedw.) T.J. Kop	–	–	<1	–	–	5
Pleurozium schreberi (Brid.) Mitt.	1.0	13.8	4.3	43	89	45
Polytrichum commune Hedw.	–	1.0	<1	–	18	5
Rhytidiadelphus triquetrus(Hedw.) Warnst.	15.9	5.6	5.8	86	50	75
Sphagnum girgensohnii Russow	<1	5.2	<1	4	18	10
Total species in the tier	5	6	7	–	–	–
Total projective coverage,%	31.0	50.0	28.5	–	–	–

difference between PP 4 (H' = 1.08). At the same time, the latter is identical to PP 1 in moss cover diversity (H = 0.30—0.33), but both are significantly behind PP 2 (H' = 0.59). According to Jaccard's coefficient, the floras of LDNPs of the sites with the highest cutting intensity (PP 1 and PP 2) are also similar to each other (K_j = 0.80) and less close to the flora of the minimum cutting intensity variant (PP 4) — K_j = 0.60 (PP 1 and PP 4), K_j = 0.68 (PP 2 and PP 4). Close values of floristic similarity with the Jaccard control (0.56—0.72) were observed in the experiment with full and partial removal of stands in the middle taiga spruce-grass forest (Rai et al., 2012).

The technological network is a significant factor affecting the diversity of composition and structure of forest phytocenoses under management impact. Technological corridors (up to 5 m wide), serving as its basis, can occupy up to 25% of the total area, where the whole complex of forest environment conditions is significantly transformed. At the research site under conditions of manual felling and skidding on strongly stony soil, these changes are limited mainly by the increase in light and precipitation.

The total stand stock in sections with technological corridors is naturally and reliably lower than in the inter-corridor space (in apiaries) by 25—40 %, while the share of spruce is higher by 1—2 units of composition. On all sample plots in the corridor zone there was a reliable decrease in the number of trees of the I tier by 2 times compared to apiaries, and the density of the II tier is the same or differs insignificantly. The total density of spruce undergrowth is 1.5—2 times higher in the zone of technological corridors due to increased illumination. This corresponds to the data on the influence of skidder trails on the spatial distribution of undergrowth in different-aged spruce forests of the Arkhangelsk region (Torbik and Feklistov, 2014).

Species diversity of living ground cover on the sample plots with maximum cutting intensity (PP 1, PP 2) both in apiaries and in technological corridors is practically identical — 21—22 species of vascular plants, 5—6 species of mosses (Table 4). The average values of SRF at the survey sites located in the corridors or in close proximity to them were significantly higher by 1.5 times than in the inter-corridor spaces (Table 4) mainly due to bilberry and cowberry (*Vaccinium vitis-idaea* L.), as well as some other species (*Carthusian* shield (*Dryopteris carthusiana*), forest strawberry (*Fragaria vesca* L.), *Orthilia secunda*).

The slight increase in the projective cover of grasses is negligible, but a comparison of their occurrence in the technological corridors and in apiaries indicates that in the first years after harvesting they could form a continuous cover,

Table 4. Influence of technological corridors on the development of living ground cover in the plot of 40-year old gradual harvesting in blueberry spruce forests

Tiers and species	Projective coverage,%				Occurrence,%			
	PP 1		PP 2		PP 1		PP 2	
	pase-ki	corydorses	pase-ki	corydorses	pase-ki	corydorses	pase-ki	corydorses
Grass-shrub	17.5	27.2*	11.5	30.8*	–	–	–	–
Athyrium	<1	–	–	–	4	–	–	–
Avenella	–	<1	<1	1.8	–	13	21	70
Calamagrostis	<1	<1	<1	<1	13	31	26	10
Carex	<1	–	<1	–	13	–	5	–
Dryopteris	–	2.2	<1	<1	–	31	11	5
Equisetum	<1	<1	<1	–	17	6	5	–
Fragaria vesca	–	<1	–	–	–	6	–	–
Gymnocarpium	<1	<1	–	<1	46	25	–	5
Goodyera	<1	–	<1	<1	4	–	5	10
Linnaea	<1	<1	<1	<1	46	19	47	25
Luzula	–	–	<1	<1	–	–	5	40
Maianthemum	<1	1.0	<1	<1	67	63	21	15
Melampyrum	<1	<1	<1	<1	17	6	47	35
Orthilia	<1	1.6	<1	1.9	42	44	58	55
Oxalis acetosella	<1	<1	<1	<1	50	44	16	10
Rubus	<1	<1	<1	–	17	19	11	–
Solidago	<1	1.9	–	<1	25	44	–	5
Trientalis	<1	<1	<1	<1	25	38	5	45
Vaccinium	16.3	18.3	10.5	21.2*	96	88	100	90
Vaccinium	1.1	1.5	1.9	6.0*	83	69	95	80
Moss-lichen	19.4	19.4	33.5	48.1	–	–	–	–
Dicranum	<1	<1	<1	<1	17	19	37	15
Hylocomium	3.6	3.4	14.3	16.0	71	50	95	50
Pleurozium	1.1	2.0	15.2	8.0	38	38	89	65
Polytrichum	–	<1	<1	4.3	–	13	5	45
Rhytidiadelphus	15.3	18.1	6.3	13.1	88	69	47	65
Sphagnum .	<1	<1	<1	14.2	4	6	5	30
RPF	30.5	44.1*	42.1	74.7*	–	–	–	–

** — differences between corridor and apiary zones are significant.*

which was later eliminated due to the growth of hardwoods. Species such as saddlebush (*Trientalis europaea* L.), oleaster (Luzula *pilosa* (L.) Willd.), ferns and forest horsetail (*Equisetum sylvaticum* L.) within the study area participate insignificantly in the formation of projective cover of TKJA, but their occurrence in technological corridors, as a rule, is 2—3 times higher than in apiaries.

Changes in the moss layer of the study site in the technological corridors are common to the study site and are associated with a slight increase in the projective cover of Rhytidiadelphus triangularis, cuckoo flax (*Polytrichum commune* Hedw.) and *Sphagnum girgensohnii* Russow. Locations of the latter are confined to depressions in the nano-relief but do not occur universally as there is no rutting in the corridors within the site. The level of diversity of TKJA, as assessed by the Shannon index, does not differ significantly between process corridors and apiaries, while the moss layer shows an average increase of 20 % in process corridors.

Correlation analysis of relationships between general stand parameters and some characteristics of the living ground cover was performed to identify the presumed influence of woody vegetation on species composition and development of the living ground cover (Table 5).

The influence of the total stock of the tree layer on the SRB is predominantly negative. The projective cover of mosses decreases with increasing woody stock in all cases, and the herbaceous-shrub layer responds weakly positively. Similar, but less reliable was the influence of the number of trees of the I tier, which largely determines its stock.

The influence of the proportion of spruce in the stand composition has an unambiguous positive effect on the SRB, which is provided mainly through the moss layer. The presence of birch in the stand composition has a negative effect

Table 5. Correlations of living ground cover characteristics with parameters of woody vegetation of bilberry spruce 40 years after logging (bold is significant at $p < 0.0500$, italics is significant at $p < 0.1000$)

Elements of the WNP description	General	Share of participation of breeds			Number of trees		Teenager
	stockpile	spruces	birches	aspens	tier I	tier II	
Projective coverage,%			PP 1				
–general	0.11	0.08	-0.39	-0.32	-0.10	0.13	-0.19
– TCJA	0.28	0.02	-0.12	**-0.50**	0.34	-0.04	-0.20
– moss layer	-0.06	0.23	*-0.44*	-0.17	-0.27	0.21	-0.15
Vaccinium myrtillys	0.41	-0.04	-0.05	**-0.56**	0.41	0.01	-0.32
Vaccinium vitis–idaea	0.01	0.16	-0.05	0.13	0.05	-0.03	0.01
Rhytydiadelphus triquetrus	0.10	0.36	*-0.44*	-0.28	-0.03	0.25	-0.08
Hylocomium splendens	-0.30	-0.14	-0.01	0.20	-0.42	-0.05	-0.08
Number of grass species	0.03	0.33	0.05	-0.16	0.13	0.16	-0.03
Total number of species	0.11	0.38	0.05	-0.19	0.16	0.18	0.07
Projective coverage,%			PP 2				
– general	**-0.58**	**0.69**	-0.24	**-0.66**	**-0.44**	-0.38	0.24
– TCJA	0.14	0.04	*0.33*	-0.21	0.02	0.12	0.00
– moss layer	**-0.66**	**0.72**	*-0.34*	**-0.66**	**-0.50**	**-0.42**	0.27
Vaccinium myrtillys	0.17	-0.03	*0.35*	-0.13	0.03	0.20	0.05
Vaccinium vitis–idaea	-0.10	0.11	0.07	-0.07	-0.25	0.17	0.33
Pleurozium schreberi	*-0.36*	*0.43*	-0.33	*-0.35*	-0.20	-0.27	0.16
Hylocomium splendens	-0.23	0.30	-0.16	-0.26	-0.21	-0.12	0.28
Number of grass species	*-0.34*	**0.45**	*-0.35*	**-0.43**	-0.14	-0.14	-0.13
Total number of species	-0.31	*0.39*	-0.21	**-0.41**	-0.15	-0.06	-0.10
Projective coverage,%			PP 4				
– general	-0.33	**0.70**	-0.18	**-0.67**	-0.03	**-0.46**	**-0.46**
– TCJA	-0.03	*0.39*	-0.13	-0.36	0.11	-0.31	-0.31
– moss layer	*-0.42*	**0.69**	-0.07	**-0.70**	-0.14	*-0.41*	*-0.41*
Vaccinium myrtillys	-0.19	**0.53**	-0.04	**-0.55**	-0.01	**-0.46**	**-0.46**
Oxalis acetosella	0.16	-0.25	0.17	0.19	0.10	0.14	0.14
Maianthemum bifolium	0.09	-0.33	0.15	0.29	0.02	0.06	0.06
Number of grass species	0.09	-0.19	0.16	0.15	-0.09	0.24	0.24
Total number of species	-0.04	0.01	0.09	-0.04	-0.04	0.07	0.07

on the moss cover and, accordingly, on the total projective cover; its influence on the herbaceous-shrub layer in general is ambiguous. The presence of aspen as part of the tree canopy has an unconditional negative effect on the total projective cover and development of the main tiers of the LNP. The presence of the second tier, usually formed by spruce, also in most cases turned out to be a negative factor in the development of LNP; the influence of the total density of spruce undergrowth was also similar.

In terms of projective cover of individual, most frequently occurring species, unambiguous results could not be obtained due to differences in edaphic conditions in the sample plots. The average number of species was positively related to the proportion of spruce in the stand and negatively related to the proportion of aspen.

A study of species diversity and spatial structure of living ground cover did not reveal consistent trends in the distribution of plant species that could inhibit regeneration of target species or worsen conditions for conversion of surface runoff to in-ground runoff.

CONCLUSION

Uniform gradual cutting with selection of up to 70 % of the stock in a relatively mixed-aged mixed stand of bilberry spruce does not lead to irreversible transformation of the structure and stability of the plantation. A comprehensive study of the main constituent elements of the forest phytocenosis formed over 40 years after high-intensity thinning did not reveal any signs of reduction of protective properties.

Recovery of the initial stock after intensive thinning in mature spruce forest of III—IV class of bonitet is completed in 25—30 years, after which, in order to maintain ecological functionality, it is possible and necessary to carry out the next cutting with selection of mainly large-sized trees.

According to the parameters of the age and spatial structure of the stand, the presence of large wood remnants, the specifics of the living ground cover corresponding to the native spruce forests, the surveyed plantation meets the criteria of biologically valuable forests.

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