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REGENERATION OF PINE STANDS AFTER SHELTERWOOD CUTTING IN FOREST ZONE OF UKRAINE

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Abstract

Features of regeneration of Scots pine (*Pinus sylvestris* L.) after shelterwood cutting in mature pine stands of Eastern Polissya of Ukraine (Chernihiv region) were studied. After the first stage of cutting, the density of stocking of pine stands of certain forest types was reduced to 0.2–0.6, and the natural regeneration of pine was supported by various methods of soil mineralization and seed sowing. Self-sown seedlings and young growth of tree species were recorded on accounting sites in strips on 2–5 % of the plot area. The most successful natural regeneration of Scots pine was found at fresh and humid oak-pine relatively poor forest types, with the density of stocking 0.4. The density of 3–4-year pine young growth was 9–34 thousand plants per ha, which corresponded to a successful regeneration rate. In the final stage of shelterwood cutting, more than 70 % of Scots pine and other species seedlings were preserved, which is sufficient for the formation of valuable stands of natural origin. Shelterwood cutting is an important system of measures for close-to-nature forestry.

Key words: regeneration success rate, Scots pine, self-sown seedling, young growth.

Introduction

Shelterwood cutting is carried out in mature stands to preserve the young growth of the main species and ensure the regeneration of valuable accompanying tree species. The gradual and selective cutting in forest stands is consistent with the European forest management strategy, which aims to preserve continuous forest cover (Mason et al. 2021).

In Ukraine, shelterwood cutting in pine stands was used for first time at the beginning of the twentieth century (Alekseev 1927, Pogrebniak 1968, Zhezhkun 2021). The vast majority of it in previous years was carried out in pine stands for the natural regeneration of Scots pine (*Pinus sylvestris* L.) (Megalinskiy and Nakonechniy 1965, Romashov 1971, Zhukovskyi et al. 2021). After shelterwood cutting, a satisfactory natural regeneration of English oak (*Quercus robur* L.) (Tikhonov 2018) and small-leaved linden (*Tilia cordata* Mill.) occurs (Zakamskii 2019).

Shelterwood cutting should not be carried out in the case of low wind resistance of stands (Brown et al. 2015), weak seed yield in low-yielding years.

Clear-cuttings, compared with other logging systems, have higher efficiency: a high income from the sale of wood from 1 ha of the forest stand, in the case of rapid reproduction of the natural forest stand due to natural regeneration and high growth rates of self-sown seedling on the cutting area and remove of derived stands and exotic crops, the regeneration of which is not desirable (Brown et al. 2015).

The use of shelterwood cutting has environmental advantages over clear-cuttings, namely: regeneration of native indigenous stands of natural origin, absence of need to create forest plantations, reduction of the regeneration period, preservation of soil fertility, protecting and environmental functions of forests. According to its economic feasibility, an increase in the yield of wood per unit area, an increase in forest productivity, but, at the same time, an increase in the cost of 1 m^3 harvested wood (by 15–20 %) compared to clear-cutting, damage to trees left until the next cutting stage, grass cover growth. A considerable amount of young growth is damaged and destroyed during subsequent shelterwood cutting techniques. Therefore, it is not widely used, and the main method of final felling is clear-cuttings with the subsequent creation of forest crops at the clear-cuts (Gordienko et al. 2002). However, artificial stands and monocultures have low biotic resistance, which leads in modern conditions on the background of global climate change to a decrease and cessation of growth processes, weakening and mortality of pine stands (Gilliam 2016, Meshkova and Borysenko 2018, Hlasny et al. 2019, Reyna et al. 2019, Klein 2020, Zhezhkun and Porochniach 2020). In many sites, shelterwood cutting was not completed, as they were not sufficiently reforested with Scots pine and other valuable tree species.

So, various authors have obtained controversial results of the success of the natural regeneration of Scots pine and the feasibility of using shelterwood cutting for final felling. Therefore, it requires clarification and coverage of this problem in our article.

The aim of the research is to study the features of regeneration of Scots pine stands after shelterwood cutting.

Material and Methods

The research was carried out in Eastern Polissya of Ukraine, located on the left bank of the Dnieper River within the northern part of Chernihiv, Kyiv and Sumy regions. The climate of the region is temperate-continental. The average annual temperature is 6.6 °C, the average annual precipitation is 501–600 mm. The forest cover of the region is 25.6 %. As of 01.01.2011, the forest fund occupies 697,000 ha (6.7 % of the forest area of Ukraine). Stands with predominance of Scots pine cover 66.4 % of the forested land, English oak stands – 11.3 %, silver birch (*Betula pendula* Roth.) – 10.4 %. Pine stands are mostly of artificial origin (81.9 %), dominated by V–VIII age classes (50–80 years). The share of pines over 81 years is 19.7 % (Zhezhkun 2021).

Regeneration of tree species was studied in pine stands in which shelterwood cutting was planned. Pine stands were mainly of artificial origin, monocultures, or with an admixture of other species, with a density of stocking of 0.6–0.9. Permanent sample plots (PSP) were laid following the requirements (MAPU 2006). Estimation of evaluation indicators was carried out using regulatory reference materials (Kashpor and Strochynskyi 2013). Alekseyev-Pogrebnyak typology was used to classify forest types (Ostapenko and Tkach 2002). The research was carried out in two forest types: fresh relatively poor oak-pine type (B_2-dC) and wet relatively poor oak-pine type (B_3-dC).

Shelterwood cutting was carried out in two stages. At the first stage, dead-standing, trees with dead tops and other defects of all species, silver birch (*Betula pendula*), aspen (*Populus tremula* L.), goat willow (*Salix caprea* L.) trees were assigned to the felling, which regeneration was not desirable. Among trees of Scots pine, those with a crown length less than 1/3 of the height, as well as wide-crowned trees with a slope of trunks and other defects were assigned to cutting. In the final stage, all trees were cut. The technology of cutting operations provided for preliminary cutting of young growth, removal of dangerous trees. Felling of trees, pruning of branches in lines with a width of 50 m was carried out with chainsaws; skidding of tree trunks or their parts along technological corridors with a width of 5 m to the upper log yard was carried out by using wheeled tractors with a skidding device. Felling debris were placed in small piles and burned after a fire-prone period.

During the skidding of wood, the litter was removed and the soil was mineralised (up to 30 % of the site area). Measures to support natural regeneration also included: loosening the soil with disk cultivators, laying plow furrows, sowing pine seeds.

After the final stages of shelterwood cutting, the following categories of damage to the pine young growth were identified: top and branch breakage; stem slope of more than 20 ^{o}; bark peeling; crown damage.

Assessment of pine seeds under the canopy of thinned pine forests was carried out by the method of seed meters (Molotkov et al. 1993). In years with low seed yields, pine seeds were sown (1 kg·ha^{-1}) on cutting areas.

Assessment of self-sown seedling (1–2 years old) and young growth (older than 3 years) was carried out at sample sites according to the method of Pasternak (1990), in strips 20 m long and 2.5–4.0 m wide. The total area taken for assessment was 2–5 % of the cutting area. During assessment of young growth and self-sown seedling, its species composition, origin, age, viability, density, total assessed area and share of the site area were estimated. Surveys were performed separately for the mineralised and non-mineralised parts of cutting sites.

Regarding the criteria for assessing the progress of natural renewal, the success of renewal was determined according to the method of Pasternak, 1990 with our additions taking into account the number of viable undergrowth of Scotch pine, depending on age (Zhezhkun 2014, 2021). That is, at each site of uniformly gradual felling, the amount of pine undergrowth was taken into account and its progress was determined on an evaluation scale.

The data were verified, and a regression analysis of the amount of pine undergrowth was carried out depending on the density of pine forests in wet relatively poor oak-pine type (B_3-dC) using the standard Microsoft Excel software package.

Results

In the mature pine stands of State forestry enterprises of Chernihiv region of Ukraine, shelterwood cutting was carried out in 2013–2014 on an area of over 400 ha (Zhezhkun 2021). After the first cutting stage, the number of trees in pine stands was 130–336 plants·ha^{-1}, basal area 9.9–30.3 m^2·ha^{-1}, the density of stocking – 0.2–0.6 (Table 1). For the first stage, from 91 (PSP 2-Brs) to 262 m^3·ha^{-1} of wood (PSP 1-Tpch) were removed. The intensity of felling varied from 24 % (PSP 4-Rdk) to 67 % (PSP 8-Krh) of growing stock. Experimental variants of shelterwood cutting exceeded the current standards (SFCU 2010). After the first stage in 2013, pine stands with a density of stocking 0.5 prevailed, and in 2014 – 0.4.

After the first stage of shelterwood cutting, up to 2–5 Scots pine trees per ha remained damaged (peeling of bark, or bark and wood), which made 1.3–2.4 % of the total number of remaining trees. About 3 thousands plants·ha^{-1} (91–95 %) of 3–5-year Scots pine regeneration were assessed at some sites.

After measures to support natural regeneration in the autumn of the cutting year or in the spring of the next year, the share of soil mineralisation was 50–60 % of the of the sample plot.

The number of young growth and self-sown seedling of Scots pine for 3–4 years after the first stage under the pine canopy was noticeably different (Table 2).

Table 1. Forestry and evaluation indicators after the first stage of shelterwood cutting.

PSP	Species composition*	Age, years	Average height, m	Average DBH, cm	Density of stocking		Number trees·ha^{-1}	Growing stock, m^3·ha^{-1}	Forest type**
					Absolute, m^2·ha^{-1}	Relative			
8-Krh	10Pinsyl + Betpen	87	21.9	27.9	9.94	0.22	162	96	B_3-dC
1-Bat	10Pinsyl + Betpen, Querob	82	29.0	35.9	16.41	0.35	228	207	B_3-dC
1-Brs	10Pinsyl	82	25.5	30.0	18.71	0.39	263	215	B_2-dC
2-Brs	10Pinsyl + Querob	82	26.4	33.7	23.26	0.49	274	228	B_2-dC
1-Tpch	10Pinsyl	84	29.9	40.3	16.60	0.33	130	218	B_3-dC
2-Tpch	10Pinsyl + Poptre	84	30.2	42.9	23.00	0.45	155	290	B_3-dC
3-Tpch	10Pinsyl + Querob	84	29.3	37.2	25.56	0.52	236	330	B_3-dC
1-Blsh	10Pinsyl + Querob	88	28.8	35.0	23.65	0.47	263	287	B_3-dC
2-Blsh	10Pinsyl + Querob	88	29.5	36.6	15.70	0.31	172	209	B_3-dC
4-Rdk	10Pinsyl	86	26.2	34.3	30.29	0.63	336	351	B_2-dC

Notes: * Pinsyl – *Pinus sylvestris*, Poptre – *Populus tremula*, Querob – *Quercus robur*, Betpen – *Betula pendula*; ** B_2-dC – fresh oak-pine relatively poor forest type; B_3-dC – humid oak-pine relatively poor forest type.

Discussion

In 2014, the seed production of Scots pine was low to medium (the number of seeds in seed collectors was 86–130 thousands seeds·ha^{-1}). With a sufficient number of pine seeds that fall on the mineralised soil after the first stage of shelterwood cutting, the emergence, survival, and growth of self-sown seedlings depended on the hereditary properties of plants, climatic, edaphic conditions under the canopy of sparse pine stands of certain forest types.

During January–March 2014, the pre-

Table 2. The abundance of young growth and self-sown seedling for 3–4 years after the first stage of shelterwood cutting.

PSPs	Number of natural Scots pine regeneration, thousand plants ha^{-1} by age groups				Regeneration success rate
	Self-sown seedling 1 year	Self-sown seedling 2 years	Young growth 3–10 years old	Total	
8-Krh	1.20	2.50	21.66	25.36	Good
1-Bat	1.34	2.42	8.98	12.74	Good
1-Brs	8.80	7.76	0.92	17.48	Satisfactory
2-Brs	2.30	6.40	0.50	9.20	Satisfactory
1-Tpch	-	5.33	10.17	16.5	Good
2-Tpch	0.83	3.96	26.87	31.66	Good
3-Tpch	2.08	6.12	6.50	14.70	Satisfactory
1-Blsh	0.78	2.94	26.60	30.32	Good
2-Blsh	1.16	1.66	30.60	33.42	Good
4-Rdk	2.40	1.20	1.80	5.40	Insufficient

cipitation was almost half of the long-term average for this period. Precipitation in April (31.1 mm) and May (47.9 mm) almost reached the annual average levels. According to surveys in the third decade of May 2014, Scots pine seedlings were found at all sites of shelterwood cutting, mainly in furrows, on the soil mineralised by disk cultivators and during skidding, and much less – at the plots with the intact forest litter.

In the absence of precipitation in June and exposure to high air temperatures (up to +32 °C) in some plots of shelterwood cutting, especially in fresh pine and oak-pine relatively poor forest type, pine self-sown seedling dieback was observed due to lack of moisture and damage caused by larvae of cockchafers. The increase in the temperature in July was regulated by an increase in precipitation (116.3 mm), which contributed to an improvement in the growth conditions of self-sown pine seedlings. In the future, the overlap of a period of high air temperatures in August and a decrease in precipitation (in August – 10.2 mm, in September – 33.8 mm, in October – 6.2 mm) determined critical conditions for the survival and growth of pine self-sown seedlings.

The next year after the first stage of shelterwood cutting in 2013, successful natural regeneration of pine took place at the sites with a total area of 44.6 ha (20.8 %). The most successful was found in the pine forests of the humid oak-pine relatively poor forest type with thinned to 0.4 of the density of stocking and furrowing: as of 09.10.2014, the density of 1-year self-sown seedling of pine was 24.3–58.3 thousand plants·ha^{-1}. It should be noted that there was no significant difference in the number of 1-year self-sown seedling of pine trees between the options with and without additional sowing in 2014.

Within 3–4 years after the first stage of shelterwood cutting in 2013, most of the Scots pine young growth was preserved and the density of regeneration was replenished by self-seeding. In the pine forests of the humid oak-pine relatively poor forest type, successful regeneration was found at the plots with a total area of 69.4 ha (66.2 %), which is twice as much as in the first year after cutting. In pine stands with a density of stocking of 0.4, good and satisfactory pine regeneration was determined at 7 sample plots (77.8 %), with an area of 33.8 ha (88.3 %). At two plots (4.5 ha), poor and insufficient Scots pine regeneration in this forest type is explained by the suppression of regeneration by *Calamagrostis epigeios* (L.) Roth and damage by larvae of cockchafers (*Melolontha melolontha* L.). In Scots pine stand, with a density of stocking 0.31, 3 years after the 1st stage of shelterwood cutting 30.6 thousand plants·ha^{-1} (20 %) of 3-year-old pine young growth were preserved and natural regeneration in an amount 1.7 thousand plants·ha^{-1} 2-year-old and 1.2 thousand plants·ha^{-1} 1-year-old self-sown seedlings were revealed (Table 2). Therefore, it is advisable to reduce the density of stocking of pine forests to 0.3–0.4, which is consistent with the data (Karaziya 1982), provided that the wind resistance of thinned pine stands is preserved (Brown et al. 2015).

The process of accompanying pine regeneration in pine forests at fresh oak-pine relatively poor forest type is low due to insufficient soil moisture during seed germination and self-sown seedling growth, damage by cockchafer larvae, and competition with the grass cover. After the first stage of shelterwood cutting in 2013 with a decrease in density of stocking of 0.5 or more and soil mineralisation for 3–4 years, the natural regeneration success rate of pine was estimated as 'insufficient'. The number of 3–4 years old pine young growth is 2.0–6.3 thousand plants·ha^{-1}, 1–2-year-old self-seedings – 0.1–9.8 thousand plants·ha^{-1}. In pine forests with a density of stocking of 0.4, the regeneration success rate is satisfactory (PSP 1-Baht, PSP 1-Brs). Dryness of the soil and air were the highest in areas bordering cutting area, opened forest plantations, young forest stands which were one of the obstacles for the successful regeneration of pine, which is consistent with the data (Alekseev 1927).

In pine forests of fresh poor forest type, thinned out to a density of stocking of 0.5 without the support of regeneration at the first year of cutting and subsequent 3–4 years, the success rate of natural pine regeneration was unsatisfactory. The placement of pine young growth is uneven (the occurrence is 46–60 %).

Insufficient pine regeneration was determined under the canopy in most pine stands thinned to a density of stocking of 0.5 or more (PSP 4-Krh), as well as a result of grass cover growth in areas without natural regeneration support. In pine stands, with a second layer formed by *Robinia pseudoacacia* L., dense undergrowth of *Corylus avellana* L., abundant grass cover formed by *Calamagrostis epigeios*, pine regeneration is unsatisfactory. Therefore, in general, in pine stands thinned at the first stage of experimental shelterwood cutting in 2013, successful natural regeneration within 3–4 years occurred on 19 plots (32.2 %), with a total area of 76.3 ha (35.5 %).

In winter, the snow cover protects self-sown seedling from low temperatures, but in some years pine trees were affected by snow/needle blight (caused by the pathogen *Phacidium infestans* Karst.). During December 2014 – January 2015, the amount of precipitation was less than normal (snow cover melted in the second half of January), in February there was no precipitation at all, in March (20.2 mm) and April (20.4 mm) precipitation was low. A decrease in precipitation and an increase in air temperature in April – May contributed to the opening of pine cones. In 2015, with a high yield, from 540 to 1046 thousand plants·ha^{-1} of pine seeds fell under the canopy of pine forests thinned out by the first stage of shelterwood cutting.

Under a favourable hydrological regime in May 2015 (precipitation – 145.7 mm or more than 3 times more than in previous years), seeds sprouted and the first pine shoots appeared on May 21. In June–July, precipitation (187.7 m) exceeded the long–term average by 75–100 mm. These conditions probably ensured the safety of self-sown seedling of pine trees during August (there was no rain) and in September, when only 20.2 mm of precipitation fell, and the sum of active temperatures for this month exceeded the long-term average. The dry period continued in October 2015 (14.9 mm of precipitation). In general, during 2015, the sum of active temperatures (2973 °C) was 1.3 % less, and the amount of precipitation (522.9 mm) was 39.5 % higher compared to the previous year. Therefore, better pine seed yield and favourable weather conditions in 2015 should have contributed to successful natural regeneration.

In pine stands of fresh oak-pine relatively poor forest type after the first stage of shelterwood cutting (2014) with a decrease in density of stocking to 0.30–0.32 and furrowing in March, as of 29.10.2015, from 19.1 to 24.0 thousand plants·ha^{-1} of 1-year-old self-sown seedlings of pine trees were registered. For 3 years, 8.1–17.6 thousand plants·ha^{-1} (42.4–73.3 %) of pine growth were preserved and its number was replenished by 3.5–7.0 thousand plants·ha^{-1} of 1–2-year-old self-sown seedling, which is sufficient under such conditions to complete shelterwood cutting.

In the pine forests of fresh oak-pine relatively poor forest type after the first stage (2014) of the shelterwood cutting with a decrease in density of stocking to 0.4 and satisfactory pine regeneration in the first year, the next two years the number of viable young growth, up to 0.5 m high (8.5–17.9 thousand plant·ha^{-1}) exceeds the standard (8 thousand plants·ha^{-1}), it has a uniform placement, which allows you to assign the final stage. After thinning the pine forests to a density of stocking of 0.5, for 3 to 4 years, the success rate of natural pine regeneration was satisfactory only in one third of the plots. Therefore, in the pine forests of fresh oak-pine relatively poor forest type, at the first stage of shelterwood cutting, it is more expedient to reduce the density of stocking to 0.4 and implement measures to support natural regeneration.

In pine stands at humid oak-pine relatively poor forest type, after the first stage of shelterwood cutting (2014), with a decrease in density of stocking to 0.3–0.4, preservation of young growth and soil mineralisation, a satisfactory regeneration of pine occurs. This is confirmed by the results of studies on shelterwood cutting sites in 2013. The density of 3–4-year-old pine young growth in pine forests with a density of stocking of 0.4 was 8.8–34.7 thousand plants·ha^{-1}, and with a density of stocking 0.3–9.1–11.3 thousand plants·ha^{-1} (Fig. 1). However, without measures to support regeneration, the amount of young growth and self-sown seedling of pine trees did not reach the standard and was 1.8–4 times less than in areas with soil mineralization. Therefore, even in the seed year after the first stage, it is desirable to carry out soil mineralisation.

In pine stands at humid oak-pine relatively poor forest type after the 1st stage of shelterwood cutting (2014) with a decrease in density of stocking to 0.5 and soil mineralisation, during the first year, a satisfactory accompanying regeneration of Scots pine occurred only in one PSP, and for the next 2–3 years – in

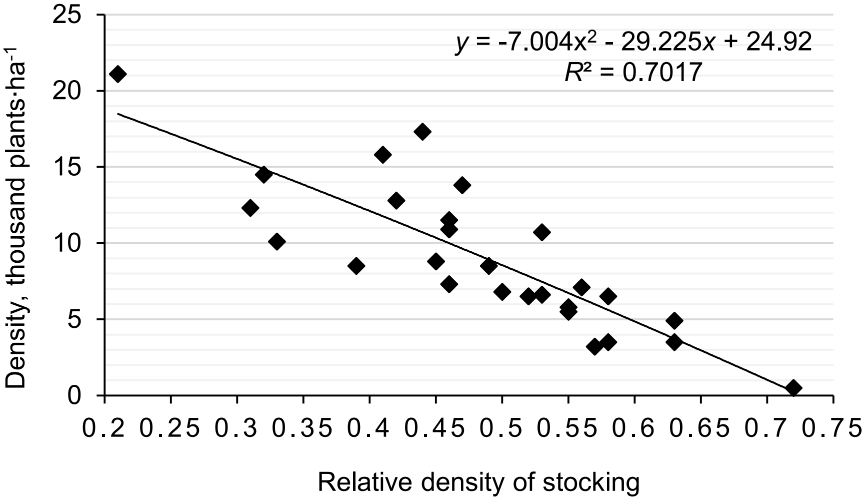

Fig. 1. Dependence of the density of young growth on the relative density of pine stands.

most areas, which is consistent with the results obtained in the cutting areas of 2013. The density of 3–4 – year young growth of Scots pine is 7.7–28.5 thousand plants·ha^{-1}, self-sown seedling – 2.2–20.2 thousand plants·ha^{-1}, young growth of English oak of seed origin – 0.3–3.3 thousand plants·ha^{-1}, of English oak of coppice origin – 0.6–1.1 thousand plants·ha^{-1}. The final stage can be assigned after 4 to 5 years from the start of cutting.

Satisfactory natural regeneration was determined in sites with preserved pine young growth (2.7–3.2 thousand plants·ha^{-1}) after thinning of pine stands of fresh and humid oak-pine relatively poor forest type with the first stage of shelterwood cutting to a density of stocking of 0.4–0.5 and replenishment with accompanying regeneration.

In pine stands, with the presence of the second layer of *Robinia pseudoacacia*, dense Hazel undergrowth, abundant grass cover from *Calamagrostis epigeios* after the first stage, the accompanying regeneration of pine similar to the previous year was unsatisfactory so, in general, in pine stands thinned out by the first stage of shelterwood cutting in 2014 for 3–4 years, good and satisfactory natural regeneration occurred on 20 plots (42.6 %), with a total area of 65.1 ha (35.5 %).

Thus, in mature pine stands, after the first stage carried out in 2013–2014, the process of natural regeneration of valuable species occurred noticeably differently. The most successful regeneration took place in the pine forests of fresh and humid oak-pine relatively poor forest type with sufficient seed production, after thinning to a density of stocking of 0.4 and measures to support natural regeneration.

In sites where a satisfactory natural regeneration of pine and other valuable species for 4–5 years occurred, the final stage of shelterwood cutting was carried out. The yield of industrial wood was 85–89 % of merchantable wood. During the final stage of cutting, from 9.1 to 26.8 thousand plants·ha^{-1} (71.3–96.2 %) of pine young growth were preserved (Table 3). The most common damage to the young

Table 3. Preservation of pine young growth after the final stage of shelterwood cutting.

PSPs	Number of pine young growth							
	After cutting	Without damage	Types of damage					
			Top break	Breaking branches	Slope > 20 °	Peeling of the bark	Crown damage	Total
8-Krh	16.46 / 100	3.80 / 23.1	1.68 / 10.2	3.62 / 22.0	2.50 / 15.2	0.52 / 3.1	4.34 / 26.4	12.66 / 76.9
1-Bat	9.08 / 100	0.22 / 2.4	2.30 / 25.3	0.52 / 5.7	5.04 / 55.5	0.36 / 4.0	0.64 / 7.0	8.86 / 97.6
1-Blsh	25.6 / 100	9.40 / 36.7	1.10 / 4.3	4.00 / 15.6	2.60 / 10.2	- / -	8.50 / 33.2	16.2 / 63.3
2-Blsh	26.80 / 100	9.70 / 36.2	1.00 / 3.7	5.10 / 19.0	5.20 / 19.4	- / -	5.80 / 21.7	17.10 / 63.8

Note: in the numerator are thousands of plants·ha^{-1}, in the denominator, %.

growth was crown damage and stem slope of more than 20 ^{o} from the vertical. To reduce damage to the young growth, skidding of wood should be carried out only along the technological corridor.

After the final stage of shelterwood cutting, the young growth of English oak (0.1–0.8 thousand plants·ha^{-1}) and silver birch (0.1–1.7 thousand plants·ha^{-1}) are also preserved. The frequency of occurrence of young growth of economically valuable species is 75–90 %, including 73–84 % of Scots pine. During the first year after the final stage of the cutting, a viable young growth of Scots pine prevails, aged 5 years, with an average height of 0.6–1.0 m. At PSP 1-Bat, the current annual growth in height of 5-year-old pine trees (18.2 ±1.02 cm) is more than 3 times greater than that of 3-year-old trees (5.3 ±0.48 cm). Plow furrows have been laid in the technological corridors and upper log yard to facilitate the subsequent regeneration of pine trees.

So, after carrying out two stages of shelterwood cutting in fresh and humid oak-pine relatively poor forest type in mature pine forests, successful natural regeneration and preservation of Scots pine young growth are ensured. Thinnings here in the future should form stable oak-pine stands.

Based on the results of shelterwood cutting, stands of mixed composition and natural origin are formed. After carrying out it in pine stands the diversity of tree species increases, structural diversity increases, the genetic intraspecific variability of trees is maintained and increases, and the resistance of trees to adverse biotic and abiotic factors increases, which corresponds to the principles of close-to-nature silviculture (Brang et al. 2014, Krynytskiy and Chernyavsky 2016).

Conclusions

As a result of the research, the following conclusions were obtained:

For the reproduction of stable pine stands of natural origin, shelterwood cutting is used, aimed at using the natural regeneration of Scots pine and valuable accompanying tree species. It is an important system of measures for close-to-nature forestry.

In pine stands of fresh oak-pine relatively poor forest type after the first stage of shelterwood cutting with a decrease in density of stocking up to 0.5, the natural regeneration of Scots pine is mainly unsatisfactory. After reducing the relative density of the stocking of pine stands to 0.4–0.3 and implementing soil mineralisation on the eve of the seed year, the natural regeneration of pine trees is satisfactory. The number of 3–4-year-old young growth of Scots pine is 8.1–18.0 thousand plants·ha^{-1}. It is evenly distributed at the site and has a height of up to 0.5 m. Under such conditions, the final stage of cutting should be scheduled 4 to 5 years after the first stag.

In Scots pine stands at humid oak-pine relatively poor forest type after the 1st stage of shelterwood cutting with a decrease in relative density of stocking to 0.5 and soil mineralisation, during the first year, satisfactory regeneration of Scots pine occurs only at some sites, and for the next 2–3 years – at most sites. The largest amount of Scots pine young growth accumulates under the canopy of pine stands, thinned out to a relative density of stocking 0.4 (8.8–34.7 thousand young growth plants·ha^{-1}) and up to 0.3 (9.1–11.3 thousand plants·ha^{-1}). In some sites, poor and insufficient pine regeneration is explained by the suppression of self-sown seedlings by *Calamagrostis epigeios* and damage by cockchafer larvae.

Good and satisfactory natural regeneration was assessed at the sites with preserved pine young growth (2.7–3.2 thousand plants·ha^{-1}) after thinning the pine forests of fresh and humid oak – pine relatively poor forest type in the first stage of shelterwood cutting to a density of stocking of 0.4–0.5 and replenishment with individuals of accompanying regeneration.

During the final stage of shelterwood cutting, from 9.1 to 26.8 thousand plants·ha^{-1} (71.3–96.2 %) of Scots pine young growth trees are stored, 0.1–0.8 thousand plants·ha^{-1} of English oak, 0.1–1.7 thousand plants·ha^{-1} of silver birch. The frequency of occurrence of young growth of economically valuable species is 75–90 %, including pine – 73–84 %. During the first year after the final stage viable pine young growth aged 5 years prevails, with an average height of 0.6–1.0 m. In the future, it is necessary to form stable pine stands of mixed composition and natural origin.

It is necessary to assign shelterwood cutting in mature pine stands of fresh and humid oak-pine relatively poor forest types in case of undergrowth layer relative density below 0.3, and absence of grass cover. The first stage and measures to support the natural regeneration of Scots pine and other species should be carried out in the seed year before the start of opening cones. The share of soil mineralisation should be more than 60 % of the site area. In the presence of self-sown seedlings and young growth of pine trees under the canopy, it is necessary to ensure its maximum safety. In the final cutting stage, it is necessary to ensure the safety of more than 70 % of the young growth of Scots pine and other valuable species.

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