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Experimental Felling in Assistance to Natural Forest Regeneration in Kyiv Region

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Abstract. Forest management in Ukraine should be conducted considering climate change, as well as degradation and mass drying of forests. It also must follow the principles of preserving the conditions for the reproduction of biologically stable, highly productive tree stands and rational and sustainable use of forest resources. Therefore, one of the main tasks of forest management is to maximize the use of the natural seed potential of forest stands. Felling corresponds to this principle, being aimed at maximizing the use of natural seed regeneration of the forest, and as a methodological basis for creating highly productive, biologically stable forest stands. The purpose of this study is to develop a felling method that promotes natural forest regeneration and offers organizational and technical indicators for its implementation. Accounting of natural forest regeneration was performed per the A.V. Pobedynskyi's method; the natural forest regeneration was estimated according to V.G. Nesterov's scale; the projective cover of the forest ground vegetation was figured out on the Brown-Blanquet scale; the dryness of the climate was figured out according to the De Martonne's aridity index; the humidification conditions at the experimental site were investigated using G.T. Selyaninov's hydrothermal coefficient; the sum of active temperatures was figured out according to the method of the Ukrainian Hydrometeorological Centre. The regulatory framework for felling to form and sanitise forests was analysed. It was found that the current rules do not make provision for felling that would be most favourable for the natural renewal of economically valuable tree species in forests of any category, age, composition, and structure. The results of accounting and evaluation of natural forest regeneration in felled circular areas are presented. It was found that under the condition of average (3 points) and higher points of seed bearing (fruiting) and sufficient moisture on circular plots with a diameter of 1.5 of the average height of the stand (H_{avg}), there was a very dense, healthy, evenly distributed natural forest regeneration. Dense understorey and significant sodding of the soil surface (over 50% of the area) with forest ground vegetation negatively impact the natural forest regeneration in the first year of life. Otherwise, special tillage is ineffective. In 2020, despite the decade-long droughts in March-April, as well as in August-September, favourable conditions for natural forest regeneration developed. In May and June, there was an increase in precipitation compared to the previous and subsequent months after the emergence of seedlings, which positively affected their rooting and growth. Feeling that contributes to the natural forest regeneration should be classified as felling for the formation and sanitation of forests, and the proposed organizational and technical indicators should be set up for it. The conclusions of this study will serve as a methodological framework for the introduction of a new method of felling in forest stands, which would be as favourable as possible for a sufficient amount of high-quality, viable natural regeneration of economically valuable tree species

Keywords: climatic indicators, stand, circular area, seedlings, viability of understorey, natural forest regeneration

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Introduction

Forests cover approximately 31% of the planet's land area and 35% of Europe's area [1; 2]. The important role of forests in terms of ecological, economic, social, and aesthetic values, as well as the source of natural resources, ecosystem services, and functionality, including protection of watersheds, prevention of soil erosion, and mitigation of climate change [3; 4], makes forest management crucial, and the topic of natural forest regeneration – extremely relevant [1; 5].

It is known that forest stands of natural seed origin are characterized by high biological stability. Given the current soil degradation [6] and massive drying of forests [7], increasing the biological stability of forest stands is an extremely urgent issue for the forests of Ukraine. In this context, natural forest regeneration is of particular importance, which contributes to the formation of biologically stable forest cenoses compared to artificial stands [4].

Over the past decades, an area with naturally restored forests in Europe has increased substantially [1]. Studies have shown that between 2018 and 2019, more than half (66%) of European forests were restored naturally [1; 5]. In 2010-2020, France, Spain, Portugal, and Italy experienced an increase in the share of naturally reproduced forests from 2,600 (Portugal) to 52,700 hectares per year (Italy) [5]. However, during 2005-2015, Europe's share of natural forests substantially decreased [1]. According to official data of the State Agency for Forest Resources of Ukraine, the share of natural forests is about 40% [8]. During 2003-2021, the share of natural forests stayed consistently low at 9.0-13.0 thousand ha/year, which is about a third of the annual reforestation area [8]. Therefore, in the context of climate change, an important task for foresters in different countries is to increase the share of natural forests by developing approaches and tools for versatile assistance to natural forest regeneration [9].

The purpose of this study is to develop a felling method that contributes to the natural forest regeneration and organizational and technical indicators for its implementation. To fulfill this purpose, it was planned to perform the following tasks: to analyse the results of scientific research of natural forest regeneration by scientists-foresters of Ukraine and other countries; to investigate the influence of environmental factors on natural forest regeneration; to set up quantitative and qualitative indicators of natural forest regeneration; to analyse felling for the formation and sanitation of forests to promote natural forest regeneration in forest stands; to develop organizational and technical indicators for the proposed method of felling that contributes to natural forest regeneration.

Literature Review

Successful natural renewal of forest stands in Ukraine occurs in many types of forest. In general, for natural seed forest renewal, more favourable conditions are formed in the forest natural zone, which is characterized by an increased amount of precipitation, low evaporation, and moderate development of understorey and forest ground vegetation in forest stands [10]. Forest stands of seed renewal, in contrast to vegetative ones, are characterized by greater durability, long growth in height and volume, high technical qualities of wood, accumulation of the most valuable varieties and a larger mass of wood before the age of ripeness [1; 4].

It is known that forest stands of natural seed origin are characterized by high biological stability [4; 11]. Given the current soil degradation and massive drying of forests, increasing the biological stability of forest stands is an extremely urgent issue for the forests of Ukraine. In this context, natural forest regeneration is of particular importance, which contributes to the formation of biologically stable forest cenoses compared to artificial stands [4; 12; 13]. Forest management should be based on an understanding of the processes of formation and development of natural forest ecosystems. Therefore, foresters should apply in practice the approaches of close to nature forestry, as one of the tools of forestry management.

At the stage of germination, the younger generation of the forest often suffers from insufficient moisture in the soil, which leads to its drying out. Seedlings of woody species can withstand some lack of light, and over time, having turned into understorey, they need it more. For normal growth and development of understorey, illumination and fertility of the upper soil horizon corresponding to the tree species are necessary. This stage of seed renewal is characterized by gradual adaptation of the understorey to the environmental conditions under the stand canopy. With age, the understorey becomes more suppressed, its demand for light increases. Therefore, from the very first years of life, it is characterized by the improvement of the adaptations inherent in each tree species and the acquisition of new adaptive features. Understorey usually suffers from a lack of light and soil moisture. This is confirmed by a small height increment, underdeveloped leaves or needles, weak foliage or entanglement of branches, presence of ascomycete fungi, disease lesions, etc. If the fastidiousness of a tree species to light and nutrients, which increases with age, is not satisfied, then the least adapted specimens die off [4; 6; 7].

Thus, the preservation, growth, and development of self-seeding and understorey of common oak under the canopy of parent stands is most affected by Illumination. Under the canopy of high (0.8-1.0) relative density oak-hornbeam stands, it is 0.5-3.0% of full illumination, which leads to the gradual death of the young generation of common oak in the second or third year of life [14]. Under the canopy of medium (0.6-0.7) and high (0.8-1.0) relative density stands (aged 41-111 years) of fresh and moist hornbeam oakery, the age of understorey of common oak did not exceed three years. At an older age, its shade endurance decreases, and plants eventually die [15; 16].

In Scots pine stands of fresh and moist fairly poor soil conditions (B_2, B_3) as part of the natural forest regeneration, Scots pine has the largest share, and in wet fairly rich soil conditions (C_3) – common oak. The intensity of natural forest regeneration depends on the degree of soil moisture. Thus, in fresh fairly poor soil conditions of self-seeding and understorey, there were 0.3-0.7 thousand pcs·ha^{-1}; in transitional conditions of soil moisture content from fresh to wet – 0.2-4.8 thousand pcs·ha^{-1}; in wet fairly poor soil conditions – 0.6-12.4 thousand pcs·ha^{-1}. In wet fairly rich soil conditions, where the forest ground vegetation develops intensively, the smallest amount of natural forest regeneration is observed – 0.2-0.5 thousand pcs·ha^{-1}. All stands are dominated by 3-10-year-old Scots pine understorey. In a smaller number, Scots pine understorey is observed at the age of 10-20 years and younger. Natural regeneration of Scots pine is most often observed in forest stands with a stand's relative density of 0.6-0.8. In high (0.8-1.0) stand's relative density, the natural regeneration of Scots pine is limited by insufficient lighting and a thick layer of forest floor, and in low (0.4-0.5) stand's relative density – by intensive development of herbaceous plants [17; 18].

The age-class composition of natural regeneration of common oak under the canopy of forest stands (forest type – fresh and rich maple-linden oakery soil conditions) is dominated by seedlings (46.1%), 2-3-year regeneration is 29.8%, 4-8-year-old – 22.7%, 9-15-year-old – 1.4%. As the relative density of the stand grows, the density of common oak shoots increases, and the density of 4-8-year-old oak understorey decreases due to insufficient lighting or competition from other plants [19]. The total growth of common oak in open space conditions (on timber blockings) up to the age of three increases almost twice with each subsequent year. While under the canopy of a stand with a completely felled second storey of hornbeam, this indicator has a negative trend [14].

Preserving and increasing the natural regeneration of Scots pine under the canopy of parent stands is possible if complex felling methods are used and measures are taken to promote natural forest regeneration [20].

According to the research of A.M. Zhezhkun [21], in square-shaped spaces with a side length of 1.5-2.0 H_{avg} of the stand (the ratio of side lengths is 1:1) and in rounded spaces with a diameter of 1.0-1.5 H_{avg} of the stands, as well as in rounded gaps with a diameter of 1.0-1.5 $H_{avg.}$ in the forest stand with uniform thinning in the strip around the gaps, there were 22.9-26.2 thousand pcs.·ha^{-1} of self-seeding, of which common oak – 0.6-1.1 thousand pcs.·ha^{-1}, Scots pine – 7.4-11.6 thousand pcs·ha^{-1}.

The natural regeneration of pine occurs worst in stands with uniform thinning of the stand to a relative density of 0.5, and best of all – in gaps of rounded shape, created on the principle of group-gradual felling. On rounded gaps with a diameter of 1.0 H_{avg}, in a stand with furrows, the natural regeneration of pine in the age group of 4-8 years is 12-21 thousand pcs·ha^{-1}, and in the variant with soil loosening with a disk tiller – 11-12 thousand pcs·ha^{-1} [22].

Suppression of 2-5-year-old understorey of common oak is observed at 15-20% of the illumination of an open space. The best growth and development of the younger generation of common oak is observed in circular areas with a diameter of 1.5 H_{avg} of the stand, where there is more light during the day and there is no suppression of common oak growth from 10 to 16 hours (23.5-68.0% of the illumination of an open space). This is confirmed by the higher average height (1.8 m) of five-year-old oak in these areas, compared to the average height (0.9 m) of five-year-old oak in circular areas with a diameter of 1.0 H_{avg} of the stand. On circular plots with a diameter of 0.5 H_{avg} in the stand, where the lowest illumination and greatest suppression of common oak is observed during the day, mass drying of the younger generation of common oak occurred at the age of three years [23].

Under favourable conditions (the presence of seed years, a sufficient amount of soil moisture, light, the absence of dense understorey and dense forest ground vegetation, a thick layer of forest floor, etc.), a sufficient amount of understorey of economically valuable species can accumulate under the canopy of the stand to regenerate the plot naturally. Without the above conditions, frequent cases are the presence of signs of suppression in the understorey – a small increase in height, underdevelopment of leaves or needles, the presence of ascomycete fungi, etc. Therefore, the issue of obtaining high-quality, viable natural regeneration of economically valuable species to the age of maturity of the stand, which is characterized by high biological stability, and also better corresponds to particular forest vegetation conditions from a genetic and ecological standpoint, is relevant.

To create favourable conditions for natural forest regeneration in forest stands, it is necessary to carry out appropriate economic measures. One of such measures to promote natural forest regeneration is the use of felling, which contributes to the emergence and preservation of the younger generation of the forest.

The rules for improving the qualitative composition of forests [24] do not make provision for felling that would be most favourable for the natural renewal of economically valuable species. Maintenance felling only to some extent solves this issue, especially for the natural regeneration of light-demanding tree species. Starting from the age of cleaning and older, maintenance felling involves the uniform placement of trees on the plot, which are left for further growth. Such placement of trees in medium (0.6-0.7) and high (0.8-1.0) stands relative density mainly adversely affects the safety and normal growth and development of the younger generation of the forest under the canopy of the parent stand.

Re-formation felling considers the bioecological properties of tree species to a greater extent than maintenance felling for their successful natural regeneration. According to the rules for improving the qualitative composition of forests [24], re-formation felling is aimed at gradually turning same-age pure forest stands into mixed multi-storeyed forest stands of different ages. They combine the simultaneous felling of individual trees or their groups and the promotion of natural forest regeneration, provided that the forest exists continuously. Such felling is performed to form a target stand when the composition and structure of the stand do not correspond to optimal parameters close to the natural state. According to the same principles, felling is also performed in foreign countries. Thus, German foresters in recent decades have widely used re-formation felling in Scots pine forests, which makes provision for gradual reproduction on the plot instead of a pure single-storeyed pine stand of indigenous, mixed, multi-age, and multi-storeyed stands [4; 8; 25].

Therefore, if the stand corresponds to the management of the forestry and its composition and structure are optimal, then felling is not carried out, and natural forest regeneration occurs mainly under the above-mentioned adverse factors.

Felling is associated with the reconstruction of low-value young and derived stands, is performed to replace low-value and derived young stands with targeted ones and is combined with the implementation of measures related to artificial forest regeneration. Reforestation felling is performed in mature and over-mature multi-storeyed stands of different ages and stands of simple structure to restore valuable tree species in forests where principal felling is forbidden [7]. Landscape felling is performed to form forest-park landscapes and increase their aesthetic, health-improving value and sustainability in recreational and health-improving forests, forests with historical and cultural purposes, as well as in recreational areas of national natural and regional parks.

Materials and Methods

To fulfill the purpose of this study, in 2020, an experimental site was laid in a monodominant pine stand of the Plesetskyi Forestry of the Separate Subdivision of the National University of Life and Environmental Science of Ukraine "Boiarka Forest Research Station" (SS NULES of Ukraine "Boiarka FRS") (Fig. 1, Table 1).

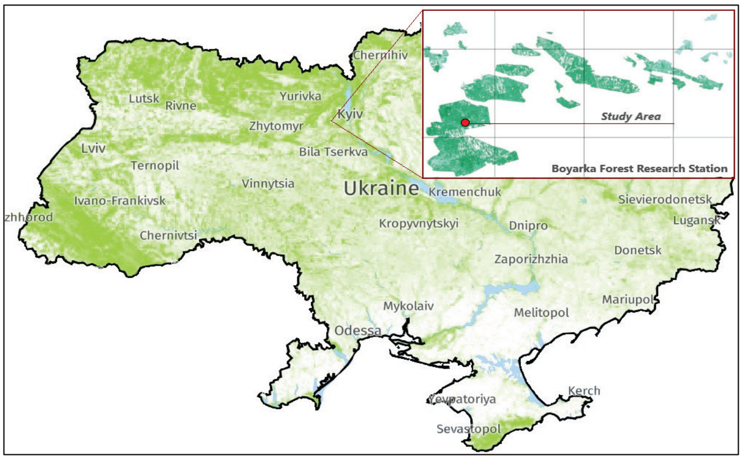

Figure 1. Experimental site in Plesetskyi Forestry of the SS NULES of Ukraine "Boiarka FRS", Kyiv region

Accounting for natural forest regeneration was performed according to A.V. Pobedinsky's method [26] on accounting plots measuring 1.0x1.0 m, which were laid on cut-down circular areas in two mutually perpendicular directions. In terms of quality, the younger generation of the forest was divided into: dry – dead specimens; doubtful – suppressed, with signs of drying out of aboveground parts, mechanical damage, etc., which is still capable of further life; healthy – reliable, without mechanical damage and signs of disease and suppression [26]. In terms of height, natural forest regeneration was divided into: shallow – up to 0.50 m, medium – 0.51-1.50 m, high – above 1.50 m [27].

Table 1. Forest inventory indicators of the stand before felling

Enterprise, forestry, quarter, allotment	Forest category	S, ha	Stand	Site index class	A, years	P	Average		M $m^3 \cdot ha^{-1}$
							H, m	D, cm	
SS NULES of Ukraine "Boiarka FRS", Plesetske, 393, 1	Recreational	6.0	10Ps	I^a	77	0.60	27.0	30.0	360

Source: [28]

The V.G. Nesterov's scale was used to estimate natural forest regeneration [29]. Simultaneously with the study of natural forest regeneration on circular plots, the projected coverage of forest ground vegetation was evaluated on the Brown-Blanquet scale [30]. The experimental site is used during all-Ukrainian research-to-practice seminars and training practices for students of bachelor's and master's degrees with specialties in forestry.

To investigate climate indicators, the authors used archival weather data of the Ukrainian Hydrometeorological Institute of the State Emergency Service of Ukraine and the National Academy of Sciences of Ukraine [31].

The degree of dryness (aridity) of the climate for 2019-2021 was investigated using the De Martonne's aridity index [7], which is calculated according to the following formula:

$$IA = \frac{(12 \cdot R)}{(T+10)}, \tag{1}$$

where *IA* – De Martonne's aridity index; *R* – monthly average precipitation, mm; *T* – monthly average air temperature, °C.

Humidification conditions at the experimental site were investigated using the G.T. Selyaninov's hydrothermal moisture coefficient (HTC) [32]. HTC is a universal indicator of the humidity of the territory, which is used by the Ukrainian Hydrometeorological Centre. It is set as the ratio of the amount of precipitation in mm for a period with average daily air temperatures above 10°C to the sum of temperatures for the same period, reduced by 10 times. The HTC is calculated according to the following formula:

$$HTC = \frac{R}{(0,1 \cdot \Sigma T)}, \tag{2}$$

where *HTC* is the G.T. Selyaninov's hydrothermal moisture coefficient [32]; *R* is the precipitation for the period with temperatures above 10°C, mm; ΣT is the sum of active temperatures >10°C, °C.

To estimate the moisture content of the territory, the HTC assessment scale was used based on the obtained value, with the HTC indicator <0.4 – very severe drought, 0.4-0.5 – severe drought, 0.6-0.7 – average drought, 0.8-0.9 – weak drought, 1.0-1.5 – sufficient humidity, and >1.5 – excessive humidity.

The demand of plants for heat during the growing season is characterized by the sum of active temperatures [33]. Accordingly, average daily temperatures exceeding 10°C are called active. The sum of active temperatures for 2019-2021 was calculated according to the following formula:

$$\Sigma t_{act} = t_{avg} \cdot n, \quad (3)$$

where Σt_{act} is the sum of active air temperatures for a given period, °C; t_{avg} is the average active air temperature for a given period, °C; n is the number of days in the period.

The age of principal felling for pine stands of the forestry part of the green zone of the SS NULES of Ukraine "Boiarka FRS" is 101 years or more. By this age, pine stands can already be subjected to selective sanitary felling several times, which is an indicator of their low biological resistance. By the age of 100, mainly suppressed natural regeneration of pine trees accumulates under the canopy of such stands. Therefore, to set up optimal conditions for natural forest regeneration at the experimental site (Table 1), trees were cut down partially on six circular plots with a diameter of 1.5 H_{avg} of the stand – 40.5 m (0.13 ha per each plot). This will provide normal conditions for the emergence and preservation of natural forest regeneration (Fig. 2). The circular plots were placed on the experimental site considering the available forest glades and rare (up to 3 thousand units·ha^{-1}), medium (0.5-1.5 m), suppressed natural regeneration of Scots pine.

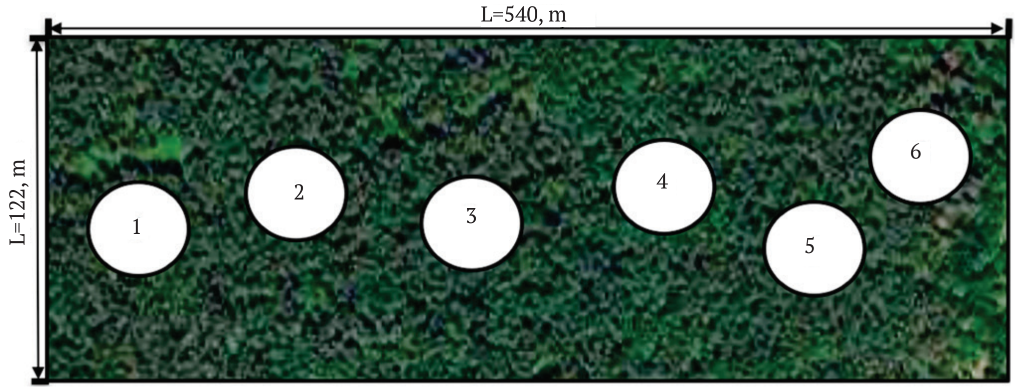

Figure 2. Placement of circular plots in the Scots pine stand of the Plesetske Forestry of the SS NULES of Ukraine "Boiarka FRS" (q. 393, al. 1)

For rational use of the average seed year (3 points) in a pine stand, felling on circular plots was performed in early spring (March) 2020 before the mass discharge of seeds from pinecones. The reserve of felled wood per 1 ha is 46 m^3. This accounted for 13% of the stock of stands before felling. Felling remains were stacked in piles and burned on circular plots.

To find the best conditions for the germination of Scots pine seeds after felling (March) on circular plots No. 2, 6, the surface of the soil was loosened with a disc harrow BDN–1.8 in two tracks, and on circular plots No. 3, 4 the surface of the soil was not processed. At circular site No. 5, after felling (March), the soil surface was loosened with a BDN–1.8-disc harrow in two tracks and Scots pine seeds were manually sown. To remove sodding of the soil surface by bushgrass (*Calamagrostis epigejos* (L.) Roth.) at circular site No. 1, furrows were cut with a PKL–70 plough, considering the existing understorey of Scots pine. Annual seedlings of Scots pine and common oak were planted at the bottom of the furrow.

Results and Discussion

Analysis of climate indicators. Perennial and seasonal fluctuations in climate indicators directly affect the preservation and viability of natural forest regeneration after its emergence [1; 8]. Among the limiting weather indicators, we can distinguish the temperature and humidity of the air, the sum of active temperatures, precipitation, as well as their number and frequency [3; 34]. At the experimental site, the mass emergence of natural regeneration of Scots pine was noted during the spring of 2020, which was preceded by the seed year. To investigate the weather parameters before and after the emergence of natural forest regeneration, the climate indicators for 2019-2021 were analysed.

Statistical characteristics of the climatic indicators of the region under study for 2019-2021 are presented in Table 2. The following conventions are used: T_{avg} – average monthly value of air temperature, °C; U_{avg} – average monthly value of air humidity, %; R – average monthly rainfall, mm; N_{dp} – average monthly value of the number of days with precipitation, days; *IA* is the average monthly value of De Martonne's aridity index; n – number of months; M – arithmetic mean; *Me* is the median; σ – standard deviation; v – coefficient of variation; *As* – coefficient of asymmetry; *Es* is the kurtosis coefficient.

Table 2. Descriptive statistics of weather parameters by year

Indicators	Year	n	M	M_e	min	max	σ	ν	As	Es
T_{avg}, °C	2019	12	10.5	10.8	-4.5	23.6	8.95	84	-0.13	-1.17
	2020		10.9	11.2	-0.5	22.4	8.42	77	0.10	-1.58
	2021		9.2	8.2	-4.5	24.6	9.90	108	0.18	-1.25
U_{avg}, %	2019		70.4	68.0	54.0	87.0	11.60	16	0.28	-1.46
	2020		69.2	67.5	41.0	92.0	15.15	22	-0.15	-0.68
	2021		71.6	67.5	61.0	88.0	9.41	13	0.74	-0.98
R, mm	2019		43.4	40.5	14.0	82.0	21.52	50	0.48	-0.59
	2020		50.3	42.5	15.0	123.0	35.05	70	1.59	1.62
	2021		45.0	53.5	1.6	77.0	24.41	54	-0.42	-1.25
N_{dp}	2019		14.8	15.5	9.0	25.0	5.43	37	0.50	-0.72
	2020		13.5	13.0	6.0	24.0	5.90	44	0.49	-0.77
	2021		15.7	14.5	4.0	27.0	5.87	37	0.04	0.92
IA	2019		31.0	26.3	7.4	100.4	23.99	77	2.43	7.33
	2020		31.7	23.7	10.9	65.9	20.95	66	0.84	-1.03
	2021		42.4	25.2	1.0	135.3	42.77	100	1.33	0.58

Table 2 suggests that during the year, the vast majority of weather parameters are marked by significant variability in the coefficient of variation (*ν>25 %*), except for the indicator U_{avg} (*ν>11-25 %*), which shows substantial scattering of the minimum and maximum values of the random variable from the distribution centre. The greatest variability can be traced by indicators (T_{avg}) and (*IA*), which is explained by the considerable range (84-98%) of the average monthly air temperature, considering temperatures below zero in winter and the aridity index (83-99 %) during the year.

Precipitation, air temperature, and their characteristics are of great importance for seed germination in spring, development, and preservation of Scots pine seedlings during the growing season. Figure 3 presents the dynamics of precipitation and air temperature by month during 2019-2021.

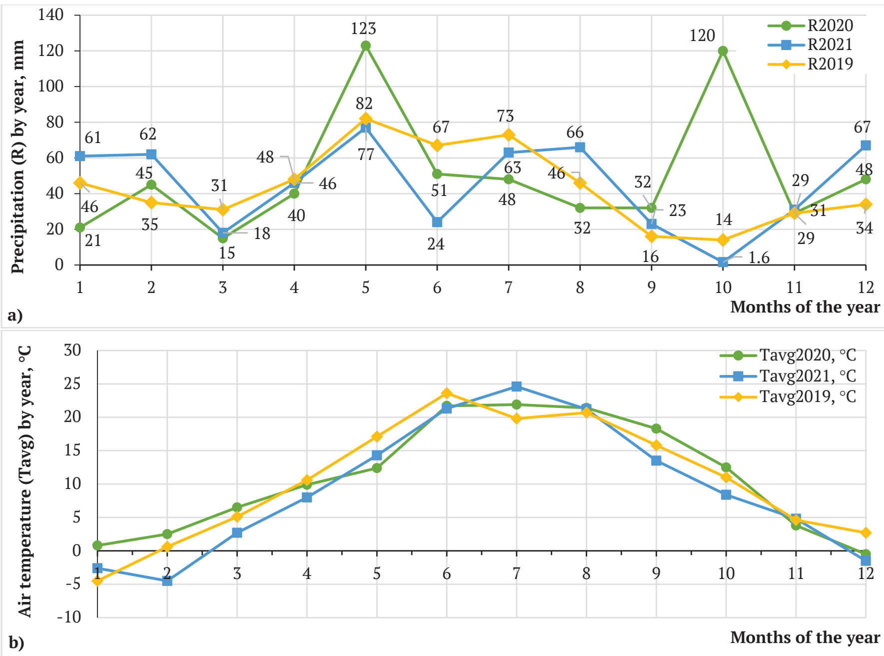

Figure 3. Dynamics of precipitation (a) and air temperature (b) by month during 2019-2021

Monthly precipitation fluctuations during 2019-2021 are heterogeneous, as evidenced by the data in Fig. 3. The total annual precipitation by year has the following distribution: 2019 – 521 mm, 2020 – 604 mm, and 2021 – 540 mm; annual precipitation in months with an average air temperature ≥10°C: 2019 – 346 mm, 2020 – 446 mm, and 2021 – 253 mm; the sum of active temperatures in 2019 – 3626°C, 2020 – 3610 °C, and 2021 – 2904°C. During March 2020, a dry period was noted, which lasted until the third decade of April. It is known that the absence of precipitation in early spring does not substantially affect seed germination, since moisture availability is important at the time of emergence and in subsequent months [3; 6]. Subsequently, spring-summer and autumn rain highs were observed in May-June and October. Thus, in 2020, despite the decade-long droughts in March-April, as well as in August-September, favourable conditions for natural forest regeneration developed. In May and June, there was an increase in precipitation (174 mm) compared to March-April (55 mm) and July-August (80 mm), as well as for the same period in 2019 (17%) and 2021 (72%). Sufficient moisture in May and June had a positive effect on the emergence and subsequent rooting of natural renewal in the experimental site.

To investigate the dynamics of the aridity of the climate and the humidification of the territory in the experimental areas during 2019-2021, the average monthly fluctuations of the R and T_{avg} indicators and their dependence on the De Martonne aridity index and G.T. Selyaninov's hydrothermal moisture coefficient were analysed [32].

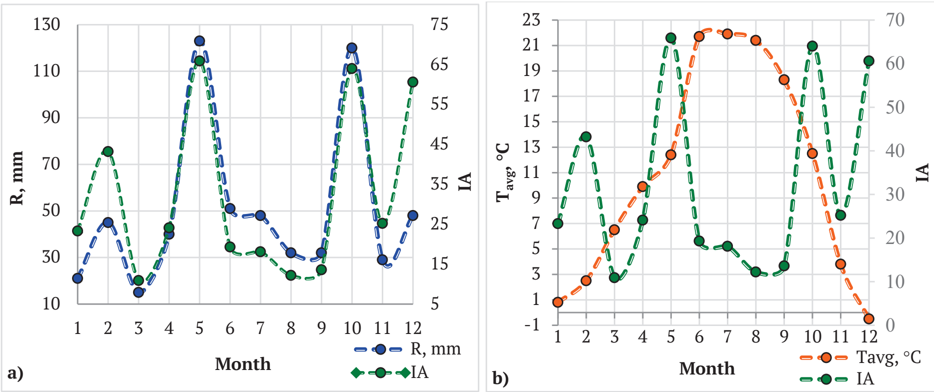

Figure 4. Dynamics of precipitation (a) and aridity index (b) by month during 2019-2021

Results of nonparametric correlation analysis (Fig. 4) indicate a naturally close relationship between the average monthly precipitation and the aridity index (r=0.85) and a moderate inverse relationship between the aridity index and the average monthly air temperature (r=-0.62). The aridity index, as an indicator of climate dryness, turned out to be sensitive to climate indicators, namely the humidification regime of the territory, where its growth is noted with an increase in precipitation. Extended periods of rainlessness and an increase in air temperature have close feedback, which affects the decrease in the aridity index in the region under study.

The HTC value during 2019-2021 was not substantially changed, specifically in 2019-2020 this indicator was 1.0 and 1.2, respectively, which on the scale of assessment of the coefficient values belongs to Group 5 – sufficiently wet conditions, which is crucial for the normal development of seedlings. In 2021, the humidity of the territory changed, and the HTC indicator decreased to 0.9, which corresponds to Group 4 – a weak drought in the region under study. The decrease in the HTC indicator in 2021 is explained by the decrease in the amount of precipitation during the growing season, with average monthly air temperatures ⩾10°C.

During 2020-2021, climate indicators were generally favourable for the emergence, growth, and development of natural renewal of Scots pine in experimental site. Further studies of the growth and development of natural forest regeneration allow obtaining more detailed results on the impact of climate indicators and other environmental factors on natural regeneration of pine forests in the region under study.

Natural forest regeneration at the experimental site. In the first years of life, natural forest regeneration suffers from suppression and intense competition from grass vegetation and shrubs, which adversely affects the further development of seedlings [3, 35]. To avoid the adverse impact of the grass-shrub storey in the autumn (September) of 2020, forest sanitation was performed by felling the bushes of the understorey on all the circular plots of the experimental site.

The results of accounting for natural forest regeneration in the first year of life after felling indicate its good success. The characteristics of natural forest regeneration on circular plots are presented in Table 3.

Table 3. Characteristics of natural forest regeneration on circular plots in the Scots pine stand of the Plesetske Forestry of the SS NULES of Ukraine "Boiarka FRS" (thousand pcs·ha^{-1})

Circular plot number	Composition of forest regeneration	Age and height of forest regeneration		Total	Projected cover of forest ground vegetation (numerator – points, denominator – %)
		up to 1 year, up to 0.50 m	5-7 years, 0.51-1.50 m		
1	100% Scots pine	18.3	0.7	19.0	5 / 90 (*Calamagrostis epigejos* (L.) Roth.)
2	100% Scots pine	29.9	–	29.9	4 / 60 (*Calamagrostis epigejos* (L.) Roth., *Rubus caesius* L.)
3	100% Scots pine + Common oak + Silver birch	Scots pine – 40.0; Common oak – 0.1; Silver birch – 0.1	–	40.2	3 / 30 (*Calamagrostis epigejos* (L.) Roth.)

Table 3, Continued

Circular plot number	Composition of forest regeneration	Age and height of forest regeneration		Total	Projected cover of forest ground vegetation (numerator – points, denominator – %)
		up to 1 year, up to 0.50 m	5-7 years, 0.51-1.50 m		
4	100% Scots pine + Common oak + Silver birch	Scots pine – 50.3; Common oak – 0.7; Silver birch – 0.3	–	51.3	3 / 30 (*Calamagrostis epigejos* (L.) Roth.)
6	100% Scots pine + Common oak	Scots pine – 31.9; Common oak – 0.1	–	32.0	4 / 70 (*Calamagrostis epigejos* (L.) Roth.)

Results of autumn (September) accounting of natural forest regeneration on circular plots No. 1, 2, 3, 4, 6 in the year of felling show that the composition of natural forest regeneration is dominated by Scots pine. Participation of other tree species (Common oak, Silver birch) in the natural forest regeneration does not exceed 5%. The natural forest regeneration on the above-mentioned circular plots is 19.0-51.3 thousand pcs·ha^{-1}, including natural regeneration of Scots pine – 18.3-50.3 thousand pcs·ha^{-1}, which is explained by the 100% presence of Scots pine trees in the parent stand (Table 1) and their average (3 points) seed bearing. This amount of natural forest regeneration is sufficient to restore the felled circular site naturally. Natural regeneration in circular plots is evenly distributed (over 85% of the area) and is healthy and shallow (up to 0.5 m). A small amount (0.7 thousand pcs·ha^{-1}) of previous, medium-height (0.51-1.50 m) natural regeneration of Scots pine is observed only on circular site No. 1. The amount of natural reforestation on circular plots No. 3, 4 without measures to promote natural regeneration is greater (40.2-51.3 thousand pcs.·ha^{-1}) than on circular plots No. 2, 6 (29.9-32.0 thousand pcs.·ha^{-1}), where the soil surface was loosened with a BDN–1.8 disc harrow in two tracks. This is explained by the fact that on all circular plots there is a direct dependence of the amount of forest regeneration on the projected cover of the forest ground vegetation.

The smallest amount of natural reforestation (19.0 thousand pcs.·ha^{-1}) on the circular site No. 1 is explained by the continuous sodding of the soil surface between the furrows by bushgrass (*Calamagrostis epigejos* (L.) Roth.). The natural regeneration of Scots pine on this circular site is mainly found in the furrows formed by the PKL–70 plough and in a small amount between the furrows. Given the average (3 points) degree of soil sodding by bushgrass (*Calamagrostis epigejos* (L.) Roth.), the amount of natural forest regeneration is 40.2-51.3 thousand pcs·ha^{-1} (circular plots No. 3, 4). With an increase in soil cover from 50% to 75% of the area (4 points), the amount of natural forest regeneration decreases – 29.9-32.0 thousand pcs·ha^{-1} (circular plots No. 2, 6).

In the future, for the growth of the main species (Scots pine), it is necessary to provide appropriate care (agrotechnical care; cutting of understorey bushes and parts of the understorey of secondary species that suppress the growth of the main species; cutting the worst specimens of the understorey of the main species; uniform placement of the best specimens of the understorey on circular plots, etc.).

The next method of felling should be assigned subject to the completion of the regeneration of the main rock on previously felled circular plots according to the standards defined in the instructions for design, technical acceptance, accounting, and quality assessment of forest-cultural objects for the transfer of natural renewal to areas covered with forest vegetation [36]. The next felling method should also be performed in years of average (3 points) and above seed-bearing points by expanding existing circular plots or setting up new circular plots with a size of 1.5-2.0 H_{avg} of the stand. The area of existing circular plots is doubled by felling trees on it, measuring 1.5-2.0 H_{avg} of the stand that are adjacent to existing circular plots in a southerly direction. This will contribute to better illumination of the natural forest regeneration. New circular plots are being expanded according to the same principle. To evenly fell the stand on the site, circular plots with a size of 1.5-2.0 H_{avg} of the stand on the site in the first step of felling should be placed at a distance of 1.5-2.0 H_{avg} of the stand apart from each other.

Scientists-foresters [4; 5; 6] indicate that the reforestation by natural seeding is vital for the formation of long-lasting, biologically stable, and highly productive stands. At the same time, the current "Rules for improving the qualitative composition of forests" [24] do not make provision for felling that would allow for a sufficient amount of healthy, viable natural regeneration of economically valuable species in tree stands of any age class, composition, and structure. According to some authors [12; 13; 25], this task is particularly relevant for recreational and health-improving, protective forests, forests of nature protection, scientific, historical, and cultural purposes, where it is necessary to perform felling so that the forest is reproduced, if possible, naturally, and its structure has a complex structure.

The natural regeneration of coniferous and deciduous tree species is influenced by numerous factors that can hinder its growth processes at different stages of development. Dry periods [4; 12; 37], fires [5; 35], insufficient lighting [6; 9], suppression by bush and grass vegetation [6; 38], stand density [4, 8, 23] are the most common and decisive environmental factors affecting the quantitative and qualitative indicators of natural forest regeneration [6; 9]. Climate change is also one of the most difficult challenges facing forestry [9]. It is expected that the impact of climate on forests will substantially increase in the coming decades [2; 38; 39]. Rising temperatures, prolonged droughts, and insufficient precipitation during the growing season can be crucial environmental factors for preserving the natural forest regeneration [2; 4; 5].

The results of the study of natural forest regeneration on circular plots are confirmed by A.V. Vishnevsky's conclusion [20] on the better preservation and increase in natural regeneration of Scots pine under complex felling methods and measures to promote natural forest regeneration and the conclusions of A.M. Zhezhkun [21], I.V. Porokhniach [22] on the better passage of natural regeneration of Scots pine in rounded gaps and a smaller amount of natural regeneration of Scots pine after loosening the soil surface with a disk harrow. The established dependence of the amount of natural forest regeneration on the projective cover of forest ground vegetation is also confirmed by studies of M. Arend, R. Link, R. Patthey, G. Hoch, B. Schuldt, A. Kahmen [3], M. Poore [6], C. Senf, A. Buras, C. Zang, A. Rammig, R. Seidl [38], M. Gordienko, N. Gordienko [17], V. Rybaka [18].

Conclusions

In 2020, despite the ten-year droughts in March-April, as well as in August-September, favourable conditions for natural forest regeneration developed. Sufficient moisture in May-June had a positive effect on the emergence and subsequent rooting of natural renewal in the experimental site.

To obtain viable, high-quality seed natural regeneration of economically valuable species in forests of any category, age class, composition, structure, the Rules for improving the quality composition of forests must make provision for felling to promote natural forest regeneration in compliance with organizational and technical indicators:

1) the felling area is determined by the area of the intended survey (economic) plot;

2) circular platform size – 1.5-2.0 H_{avg} of the stand;

3) the distance between circular plots in the first step of felling is 1.5-2.0 H_{avg} of the stand;

4) the direction of expansion of the circular plots is southern;

5) the next reception of felling is assigned subject to the completion of the regeneration of the main rock on a pre-felled circular plots;

6) measures to promote natural forest regeneration (special tillage; care for forest renewal; formation of an open edge around a circular site; fencing of the area with natural forest regeneration; prohibition of grazing; the simplest forest crops in places with no regeneration; felling season; clearing of felling sites).

Adverse impact on natural forest regeneration on circular plots measuring 1.5 H_{avg} of the forest stand is made up of a dense understorey and soil sodding with a forest ground vegetation. Therefore, it is mandatory to carry out agrotechnical care for natural forest regeneration. It is established that felling to promote natural forest regeneration should be assigned in the years of average (3 points) and more points of seed bearing (fruiting) of trees in the stand. Felling should begin before the mass departure of seeds or fruit falls and finish before they germinate. It is advisable to carry out special treatment of the soil surface under the condition of significant soil sodding (over 50% of the area) with a forest ground vegetation. Otherwise, such measures are ineffective.

Further studies of the growth and development of natural forest regeneration will give more detailed results on the impact of environmental factors and proposed organizational and technical indicators of felling on natural forest regeneration.

References

[1] Global Forest Resources Assessment 2020. (2020). Retrieved from https://www.fao.org/3/ca9825en/ca9825en.pdf.

[2] Freudenschuss, A., Brändli, U., Fridman, J., Cienciala, E., & Linser, S. (2020). Maintenance and appropriate enhancement of forest resources and their contribution to global carbon cycles. In *State of Europe's Forests Report 2020* (pp. 29-50). Zvolen: Forest Europe.

[3] Arend, M., Link, R.M., Patthey, R., Hoch, G., Schuldt, B., & Kahmen, A. (2021). Rapid hydraulic collapse as cause of drought-inducedmortality in conifers. *National Academy of Sciences of the United States of America*, 118(16), article number e2025251118. doi: 10.1073/pnas.2025251118.

[4] Jandl, R., Spathelf, P., Bolte, A., & Prescott, C. (2021). Forest adaptation to climate change – is non-management an option? *Annals of Forest Sciencethis*, 76(2), article number 48.

[5] Aguiar, F.C., Rodrigues, C., Pina, J.P., & Soares, P. (2021). Regeneration of riparian and maritime pine forests after a large wildfire on the largest public forest of Portugal. *Forests*, 12(4), article number 477. doi: 10.3390/f12040477.

[6] Zatula, V., & Zatula, N. (2019). Statistical analysis of climate aridity in Ukraine. *Physical Geography and Geomorphology*, 93(1), 19-24.

[7] Lavny, V.V., & Spatgelf, P. (2016). The practice of close to nature forestry in the pine forests of northeastern Germany. *Collection of Scientific Works: Scientific works of the Forestry Academy of Sciences of Ukraine*, 14, 52-57. doi: 10.15421/411606.

[8] Public report of Head of the State Agency of Forest Resources of Ukraine for 2021. (2021). Retrieved from https://forest.gov.ua/storage/app/sites/8/публічні%20звіти/publichniy-zvit-za-2021.pdf.

[9] Matias, L., Castro, J., Villar-Salvador, P., Quero, J.L., & Jump, A.S. (2017). Differential impact of hotter drought on seedling performance of five ecologically distinct pine species. *Plant Ecology. Springer Link*, 218, 201-212.

[10] Gordienko, M.I., Bondar, A.O., Rybak, V.O., & Gordienko, N.M. (2007). *Forest crops of the plain part of Ukraine*. Kyiv: Urozhai.

[11] Brang, P., Spathelf, P, Larsen, J.B., Bauhus, J., Bončina, A., Chauvin, C., Drössler, L., García-Güemes, C., Heiri, C., Kerr, G., Lexer, M.J., Mason, B., Mohren, F., Mühlethaler, U., Nocentini, S., & Svoboda, M. (2014). Suitability of close-to-nature silviculture for adapting temperate European forests to climate change. *Forestry*, 87, 492-503. doi: 10.1093/forestry/cpu018.

[12] Schütz, J., Saniga, M., Diaci, J., & Vrška, T. (2016). Comparing close to-nature silviculture with processes in pristine forests: Lessons from Central Europe. *Annals of Forest Science*, 73, 911-921.

[13] Maurer, V.M., & Kimeichuk, I.V. (2020). Dynamics of the number and state of natural regeneration of Scots pine on log cabins in the conditions of fresh birch of Kyiv Polissya. *Ukrainian Journal of Forest and Wood Science*, 11(1), 45-54. doi: 10.31548/forest2020.01.045.

[14] Kopiy, L.I., Fizik, I.V., Baran, S., Lavniy, V.V., Kopiy, S.L., Presner, R.B., & Agiy, V.O. (2017). Natural seed reproduction of oak plantations as an element of forestry close to nature. *Scientific Bulletin of UNFU*, 27(9), 9-13. doi: 10.15421/40270901.

[15] Ishchuk, G.P. (2017). Natural regeneration of oak and hornbeam under the tent of plantations and on the log cabins at the State Enterprise "Korsun-Shevchenkivske Forestry". *Scientific Bulletin of UNFU*, 27(1), 15-18. doi: 10.15421/40270102.

[16] Matusyak, M.V., & Tsyganska, O.I. (2018). Assessment of the level of biodiversity and natural regeneration of common oak in the forestry zone of Vinnytsia. *Scientific Bulletin of UNFU*, 28(8), 56-60. doi: 10.15421/40280811.

[17] Gordienko, M.I., & Gordienko, N.M. (2005). *Forestry properties of woody plants*. Kyiv: LLC "Vistka".

[18] Rybak, V.O. (Ed). (2005). *The experience of forestry in the Boyar LDS NAU (to the 80th anniversary of the Boyar FRS and the 100th anniversary of artificial reforestation)*. Kyiv: PPNV.

[19] Didenko, M.M., & Polyakov, O.K. (2018). The state of natural regeneration of oak under the forest tent in the Left Bank Forest-Steppe. *Forestry and Forest Melioration*, 132, 25-34. doi: 10.33220/1026-3365.132.2018.25.

[20] Vyshnevsky, A.V. (2010). Reforestation under trees crown canopy of mature pine stands in the forests of Rivne Polissya. *Scientific Bulletin of UNFU*, 205, 33-37.

[21] Zhezhkun, A.M. (2015). Experimental felling in Pine stands of Eastern Polissya. *Collection of Scientific Works: Forestry and Agroforestry*, 126, 35-43.

[22] Zhezhkun, A.M., & Porokhnyach, I.V. (2015). Reforestation in pine stands after the first methods of deforestation. *Collection of Scientific Works: Forestry and Forest Melioration*, 127, 15-22.

[23] Levchenko, V.V. (2018). Reconstructive felling as a measure to promote natural regeneration of the forest. *Ukrainian Journal of Forestry and Wood Science*, 14, 58-63. doi: 10.31548/forest2020.01.045.

[24] Resolution of the Cabinet of Ministers of Ukraine No. 724 "On Approval of the Rules for Improving the Quality of Forests". (2007, May). Retrieved from https://zakon.rada.gov.ua/laws/show/724-2007-%D0%BF#Text.

[25] Guldin, J., Bragg, D., & Zingg, A. (2017). Plentern with pine – results from the USA. *Schweiz Zeitschrift Forstw,* 168(2), 75-83. doi: 10.3188/szf.2017.0075.

[26] Pobedinsky, A.V. (1966). *Study of reforestation processes*. Moscow: Nauka.

[27] Shvidenko, A.Y., & Ostapenko, B.F. (2001). *Forestry*. Chernivtsi: Green Bukovyna.

[28] Project of organization and development of forestry of NULES of Ukraine "Boyarska LDS" of Kyiv region. (2018). In *Plesetsk forestry. Part I* (quarters 244–423). Irpen: Ukrderzhlisproekt.

[29] Nesterov, V.G. (1961). *General forestry*. Moscow: Selkhozgiz.

[30] Poore, M.D. (1955). The use of phytosociological methods in ecological investigations: The Braun-Blanquet System. *Journal of Ecology*, 43(1), 226-244. doi: 10.2307/2257132.

[31] Official website of the Ukrainian Hydrometeorological Institute of the SES of Ukraine and the National Academy of Sciences of Ukraine. (2022). Retrieved from https://www.nas.gov.ua/UA/Org/Pages/default.aspx?OrgID=0000623.

[32] Selyaninov, G.T. (1958). *Assessment of agrometeorological conditions for understanding droughts and dry winds and their distribution in the European territory of the USSR. Droughts and their origin, recurrence and impact on yield*. Leningrad: Gidrometeoizdat.

[33] *A*groclimatic resources. Handbook of agroclimatic resources of Ukraine. (1995). (Vol. 1.). Kyiv: Urozhay.

[34] Tiscar, P.A., Candel-Perez, D., Estrany, J., Balandier, P., Gomez, R., & Lucas-Borja, M.E. (2017). Regeneration of three pine species in a Mediterranean forest: A study to test predictions from species distribution models under changing climates. *Science of the Total Environment*, 584-585, 78-87. doi: 10.1016/j.scitotenv.2017.01.150.

[35] Gumeniuk, V., Holiaka, D, Soshenskiy, O., & Koren, V. (2021). Effects of surface fires on Scots pine forests of the Poliskyi Nature Reserve. *Forestry Ideas*, 27(1(61)), 3-18.

[36] Order of the State Committee of Forestry of Ukraine No. 260 "On Approval of the Instruction on Design, Technical Acceptance, Accounting and Quality Assessment of Forestry Facilities". (2010, August). Retrieved from https://zakon.rada.gov.ua/laws/show/z1046-10#Text.

[37] Ribeiro, S., Cerveira, A., Soares, P., & Fonseca, T. (2022). Natural Regeneration of maritime pine: A review of the influencing factors and proposals for management. *Forests*, 13(3), article number 386.

[38] Senf, C., Buras, A., Zang, C.S., Rammig, A., & Seidl, R. (2021). Excess forest mortality is consistently linked to drought across Europe. *Nature Communications*, 11, article number 6200.

[39] Valeriano, V., Gazol, A., Colangelo, M., & Camarero, J. (2021). Drought drives growth and mortality rates in three pine species under Mediterranean conditions. *Forests*, 12(12), article number 1700. doi: 10.3390/f12121700.

Експериментальна рубка сприяння природному поновленню лісу у Київській області

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Анотація. Ведення лісового господарства в Україні необхідно здійснювати з урахуванням змін клімату та деградації і масового всихання лісів, а також з дотриманням принципів збереження умов відтворення біологічно стійких, високопродуктивних насаджень та раціонального і невиснажливого використання лісових ресурсів. Тому одним із головних завдань ведення господарства у лісах є максимальне використання природного насіннєвого потенціалу лісових насаджень. Такому принципу відповідають рубки, які спрямовані на максимальне використання природного насіннєвого поновлення лісу, як методологічної основи створення високопродуктивних, біологічно стійких лісових насаджень. Мета дослідження – розробити спосіб рубки, який сприяє природному поновленню лісу та запропонувати організаційно-технічні показники для його проведення. Облік природного поновлення лісу проводили за методикою А.В. Побединського; оцінку природного лісопоновлення здіснювали за шкалою В.Г. Нестерова; проективне покриття живого надґрунтового покриву визначали за шкалою Браун-Бланке; сухість клімату визначали за індексом аридності Де Мартонна; умови зволоження на дослідній ділянці вивчали з використанням гідротермічного коефіцієнту Г. Т. Селянінова; суму активних температур визначали за методикою Укргідрометцентру. Проаналізовано нормативно-правову базу проведення рубок формування і оздоровлення лісів. Встановлено, що діючі Правила не передбачають проведення рубок, які були б максимально сприятливими для природного поновлення господарсько цінних деревних порід у лісах будь-якої категорії, віку, складу і структури. Представлено результати обліку та оцінки природного поновлення лісу на вирубаних кругових площадках. Встановлено, що за умови середнього (3 бали) і вище балів насіннєношення (плодоношення) та достатньої кількості вологи на кругових площадках діаметром 1,5 Нср. деревостану спостерігалося дуже густе, здорове, рівномірно розміщене по площі природне поновлення лісу. Негативний вплив на природне лісопоновлення у перший рік життя чинять густий підлісок та значне задерніння поверхні ґрунту (більше 50 % площі) живим надґрунтовим покривом. У противному випадку останнього, проведення спеціального обробітку ґрунту є малоефективним. У 2020 році, не зважаючи на декадні посухи у березні-квітні, а також у серпні-вересні склалися сприятливі умови для природного поновлення лісу. У травні та червні відмічено зростання кількості опадів порівняно з попередніми та наступними місяцями після появи сходів, що позитивно вплинуло на їх укорінення та ріст. Рубку, яка сприяє природному поновленню лісу, слід віднести до рубок формування і оздоровлення лісів та встановити для неї запропоновані організаційно-технічні показники. Одержані висновки слугуватимуть методологічною основою для запровадження у лісових насадженнях нового способу рубки, який був би максимально сприятливим для отримання у достатній кількості якісного, життєздатного природного поновлення господарсько цінних деревних порід

Ключові слова: кліматичні показники, деревостан, кругова площадка, сходи, життєздатність підросту, природне лісопоновлення