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Silvicultural options to promote natural regeneration of Scots pine (*Pinus sylvestris* L.) in Western Ukrainian forests

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Abstract: Scots pine (*Pinus sylvestris* L.) forests belong to the most relevant forest types in the Western Ukrainian Roztochia area. The promotion of close-to-nature forest management in Ukraine in the framework of the forest strategy 2 035 supports natural regeneration and the application of diverse felling methods beyond clearcutting. In the present study, natural regeneration was analysed in mixed Scots pine stands on poor and relatively rich soils, after small clearcuts, shelterwood cutting and gap fellings (with or without soil preparation), with respect to tree species composition, species abundance and height growth. It could be shown that Scots pine is the most abundant species in all the felling systems, with on average more than 100 000 plants per ha on poor soils. Other admixed tree species only occur with small shares. Natural regeneration, especially of Scots pine, was less abundant on rich soils and in shelterwood, compared to a small clearcut. After the young plants have established, their abundance declined in the second and third year due to competing herbaceous plants and thick litter.

Keywords: abundance; admixed species; felling schemes; rejuvenation; seedling density; silviculture

Forests are a natural wealth of Ukraine. In Ukraine, foresters pay great attention to reforestation and afforestation that belong to the most effective measures aimed at improving the productivity and quality of forest resources (Shvidenko et al. 2017). The task of the employees of forestry enterprises is to ensure the establishment of biologically stable and highly productive forest stands, thereby providing manifold ecosystem services. Recently, close-to-nature silviculture (CNS) has been introduced in Ukraine in order to promote biodiversity and to reduce forest vulnerability to negative climatic factors (Krynytskyy et al. 2014). Moreover, CNS is seen to be the most promising silvicultural ap-

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proach in the current discussions about the Ukrainian national forestry strategy 2035. CNS aims at the development of mixed forests with high structural diversity from natural regeneration. Many scientists recommend especially natural regeneration as a rejuvenation method, given its advantages over artificial methods (Maurer 2007, 2012; Stefańska-Krzaczek 2012; Maurer et al. 2013; Brang et al. 2014; Krynytskyy et al. 2014; Bílek et al. 2016, 2018; Krynytska 2019; Gallo et al. 2020; Maurer, Kimeichuk 2020; Lavnyy 2021). It is acknowledged that the natural regeneration of plants under the shelter of the mother stand significantly improves the initial growth and quality of the plants, reduces risks and enhances adaptation to a changing climate. Moreover, successful natural regeneration requires less effort and money than artificial regeneration, such as planting and direct seeding. At the same time, the issue of ensuring natural regeneration requires comprehensive research and development of scientifically sound recommendations for practical application (Levchenko, Mazurenko 2017). Even mixed stands, which involve 5–7 species, including light-demanding species, can be restored naturally using appropriate felling systems (Ivanytskyy 2011).

The sustainable management of the Roztochia forests at the main European watershed has a high priority in Ukraine (Soroka 2008). Particularly relevant is the problem of restoring natural stands of Scots pine – the most common and economically valuable tree species in Ukraine in general, and the Ukrainian Roztochia in particular. Pine forests in the Ukrainian Roztochia area have been extensively studied with respect to their monitoring (Danchuk et al. 2015), hydrology and management (Kovalchuk, Petrovska 2003), flora (Soroka 2008), natural regeneration (Zvarych et al. 2016; Krynytska 2019), forestry and management indices (Myklush et al. 2021).

The goal of the present study is to analyse the success of natural regeneration of Scots pine and related tree species with respect to different felling methods (silvicultural systems). The study was conducted in the Ukrainian Roztochia area along an edaphoclimatic gradient from wet Polissya (Fuchylo 2011) to dry steppe (Soroka 2008).

MATERIAL AND METHODS

Ukrainian Roztochia is a physical-geographical area, 13–34 km wide in size, which starts from the outskirts of Lviv and extends approximately 60 km northwest to the border with Poland (Gerenchuk 1972) (Figure 1).

Roztochia forms a watershed between the Dnister and Western Bug (Wisla) river basins. Its relief consists of hilly ridges and hills, stretching mainly from southeast to northwest and reaching a height of over 390 m above sea level. The surface of Roztochia is divided by a dense network of streams and small rivers, as well as by a system of ravines and gullies (Gerenchuk 1972; Kovalchuk, Petrovska 2003). The soils are mostly Podzols. According to forestry zoning, Roztochia is a subdistrict of the Opilla-Roztochia forestry district with beech, pine-beech, oak and hornbeam-oak forests of the Western Ukrainian forest-steppe district (Gensiruk 1981). Among other lowland areas of the Lviv region, Roztochia has the highest forest cover, which is about 40%. Forests are mostly mixed, they contain mainly Scots pine (*Pinus sylvestris* L., 42%), oak (*Quercus robur* L., 23%) and beech (*Fagus sylvatica* L., 15%). Pine-beech and beech stands grow on elevated relief elements, in places of limestone bedrock and most often in hilly areas, whereas the foothills and valleys between the hills are occupied by oak and pine-oak stands (Gerenchuk 1972).

To determine the amount of natural regeneration of Scots pine and other tree species, 26–50 quadratic sample plots per ha ranging in size from 1 m^2 to 4 m^2 were established

(*i*) in a 95-year-old mixed oak-pine forest on relatively poor soils in the Stradch Forestry Training Enterprise,

(*ii*) in a 114-year-old mixed hornbeam-oak-pine forest on relatively rich soils in the Stradch Forestry Training Enterprise,

(*iii*) in two small clearcuts of 1 ha (114-year-old forest on relatively rich soils) in the Stradch Forestry Training Enterprise.

We counted the number of seedlings and measured their heights; then we grouped the results into the following height classes: up to 20 cm, 21–50 cm, 51–130 cm and over 130 cm.

The treatments which were established in the test stands are as follows:

(*i*) seven circular gaps with different diameters (20, 30 and 40 m), after irregular shelterwood cutting (95-year-old forest on relatively poor soils),

(*ii*) a uniform shelterwood cutting with an intensity of 142 $m^3 \cdot ha^{-1}$ (from 593 $m^3 \cdot ha^{-1}$ = 24% of stand volume), and

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Figure 1. Map of the Ukrainian Roztochia

(*iii*) two small clearcuts of 1 ha (114-year-old forest on relatively rich soils).

The number of sample plots depended on the size (diameter) of the circular gap and ranged from 13 to 49. On four circular gaps the soil was treated with a harrow to remove plant cover and stimulate litter decomposition and mineralisation. For comparison, we left three circular gaps without soil mineralization. The conducted dispersion analysis proves the significance of the influence of soil mineralization on the amount of self-seeding and undergrowth of tree species.

RESULTS

In the 95-year-old sampled mixed pine forest on relatively poor soils, natural regeneration of Scots pine is abundant. The total amount of regrowth lies in the range from 55 918 individuals·ha^{-1} to 183 513 individuals·ha^{-1}, with an average value of 113 842 individuals·ha^{-1} (Table 1). On the plots with litter mineralization, the total amount of self-seeding and undergrowth was on average 80% higher compared to those areas without this measure (Table 1).

In order to get a better general idea of the course of natural regeneration in pine forests in the test area, we summarized the data in Figure 2.

Analysing the average composition of undergrowth on all the sample plots, we recognize that there is a dominance of Scots pine, which averages 94.8% of the total number of individuals. This means that in the case of natural regeneration of these mixed beech-oak-pine stands, Scots pine will again become the dominant species under these conditions. Additionally, there is isolated natural regeneration of other species, such as pedunculate oak, rowan, willow, beech, birch and hornbeam (Table 1, Figure 2). The abundance of Scots pine (i.e. the percentage of the number of sites with regeneration of the respective tree species to the total number of sites) is 89.3%, i.e. Scots pine was found on 45 out of 50 sample plots. All other tree spe-

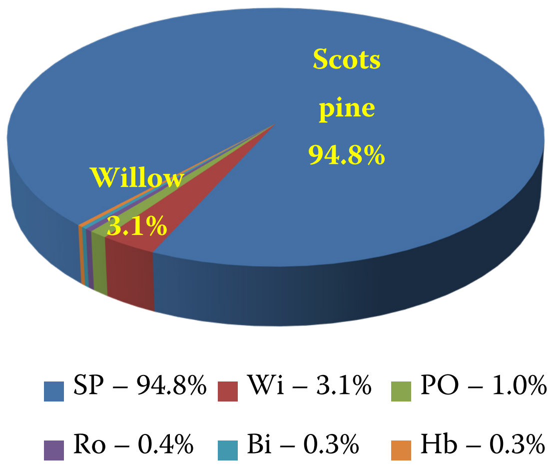

Figure 2. Tree species distribution in the natural regeneration and undergrowth on all the sample plots

SP – Scots pine; Wi – willow; PO – pedunculate oak; Ro – rowan; Bi – birch; Hb – hornbeam

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Table 1. Tree species composition and amount of self-seeding and undergrowth on sample plots in gaps after the 1st cutting of irregular shelterwood method, by height group (individuals·ha⁻¹)

Tree species	Height groups (cm)	No. of gap/D of gap (m)							On average
		I/30	II/40	III/20	IV/30	V/30	VI/40	VII/20	
Scots pine	≤ 20	182 703	54 082	93 846	109 730	79 189	90 000	146 923	108 068
	21–50	–	–	–	–	–	–	–	–
	51–130	–	–	–	–	–	–	–	–
	> 130	–	–	–	–	–	–	–	–
Pedunculate oak	≤ 20	270	408	2 308	541	541	–	–	581
	21–50	270	–	769	–	1 351	–	–	341
	51–130	270	–	–	–	–	–	–	39
	> 130	–	204	–	270	–	–	–	68
Rowan	≤ 20	–	–	–	–	541	–	–	77
	21–50	–	408	–	–	–	–	–	58
	51–130	–	408	–	–	–	–	–	58
	> 130	–	204	–	270	–	–	–	68
Willow	≤ 20	–	–	10 769	–	2 973	1 224	9 231	3 457
	21–50	–	–	–	–	270	–	769	148
	51–130	–	–	–	–	–	–	–	–
	> 130	–	204	–	–	–	–	–	29
Beech	≤ 20	–	–	–	–	270	–	–	39
	21–50	–	–	–	–	270	–	–	39
	51–130	–	–	–	–	–	–	–	–
	> 130	–	–	–	–	–	–	–	–
Birch	≤ 20	–	–	–	–	270	612	769	236
	21–50	–	–	–	–	270	–	–	39
	51–130	–	–	–	–	–	–	–	–
	> 130	–	–	–	–	–	–	–	–
Hornbeam	≤ 20	–	–	–	–	–	408	3 077	498
	21–50	–	–	–	–	–	–	–	–
	51–130	–	–	–	–	–	–	–	–
	> 130	–	–	–	–	–	–	–	–
Total amount of self seeding		183 513	55 918	107 692	110 811	85 945	92 244	160 769	113 842
Measures taken		mineralization	–	mineralization	mineralization	–	–	mineralization	–

cies (oak, willow, rowan, birch, beech and hornbeam) are less frequent – the values vary from 0.8% to 11.8% (Figure 3), which characterizes an uneven distribution of the species in the area. The analysis shows that Scots pine regeneration mainly comprises small seedlings below 20 cm in height, whereas larger undergrowth can also be seen with the rarer species (Table 1).

A close correlation was established between the amount of undergrowth and its abundance in the fresh oak-pine forest on relatively pure soils in the Stradch forest district (R^2 = 0.8).

According to the rate of abundance of the tree species in the undergrowth, it is possible to predict its further participation in the composition of the future stand.

We assume that one of the main reasons leading to the mortality of self-seeding is its suppression by grass vegetation (Gordienko, Kovalevsky 2002; Maurer et al. 2013), besides other factors such as the

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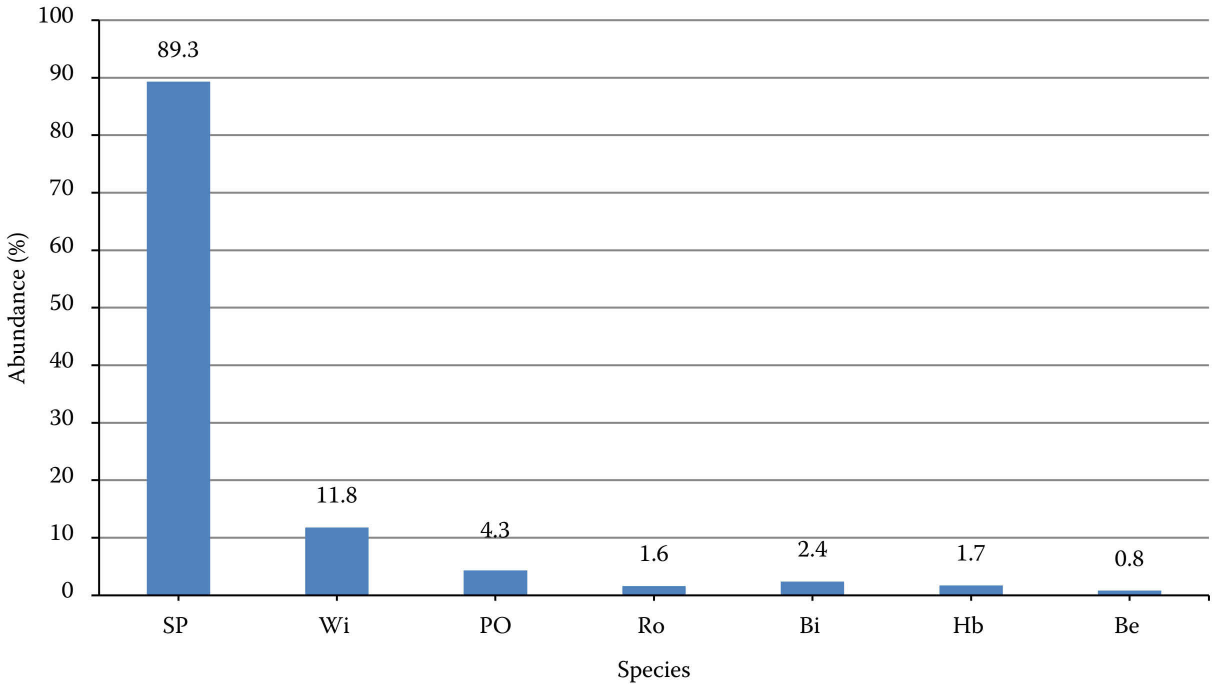
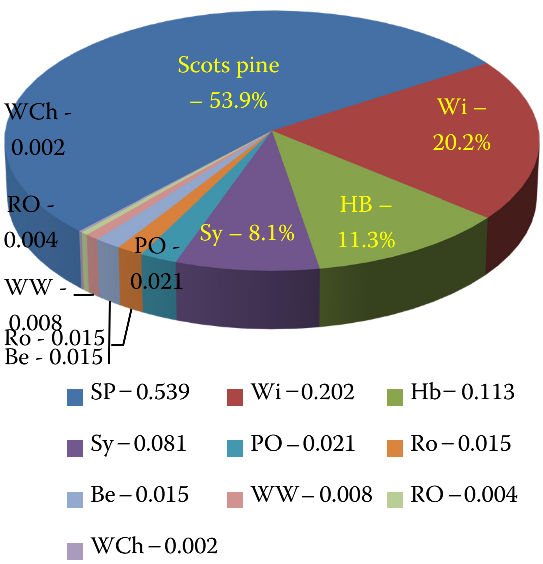


Figure 3. Abundance of undergrowth of tree species (%) in patches after irregular shelterwood cutting in a 95-year-old pine forest of Stradch forest entreprise

SP – Scots pine; Wi – willow; PO – pedunculate oak; Ro – rowan; Bi – birch; Hb – hornbeam; Be – beech

canopy closure of the parent stand. The value of the grass layer coverage on the sample plots was 7%–27%, and its height was 6–16 cm. The composition of the grass cover was uniform. Herbaceous species such as blueberries (*Vaccinium myrtillus* L.) and blackberries (*Rubus caesius* L.) dominate in the test



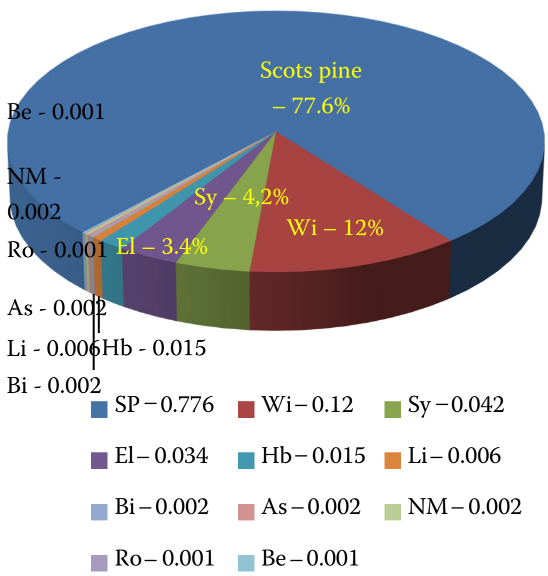


Figure 4. Tree species composition of self-seeding and undergrowth on the sample plots in the fresh hornbeam-oak-pine forest on relatively rich soils (A) after establishment cut (shelterwood system); (B) after small clearcut (1 ha)

SP – Scots pine; Wi – willow; Hb – hornbeam; Sy – sycamore; PO – pedunculate oak; Ro – rowan; Be – beech; WW – white willow; RO – red oak; WCh – wild cherry; Bi – birch; El – elm; Li – lime; As – aspen; NM – Norway maple

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Table 2. Species composition and amount of self-seeding and undergrowth of tree species on sample plots (shelterwood) in fresh hornbeam-oak-pine forest on relatively rich soils, by height group (individuals·ha^{-1})

Tree species	Height groups (cm)	Time of counting		
		spring 2020	autumn 2020	autumn 2021
Scots pine	≤ 20	481	13 269	10 481
	21–50	96	96	–
	51–130	–	–	–
	> 130	–	–	–
Pedunculate oak	≤ 20	96	–	192
	21–50	192	192	–
	51–130	–	96	192
	> 130	–	–	–
Rowan	≤ 20	–	–	–
	21–50	–	96	–
	51–130	–	–	288
	> 130	–	–	288
Goat willow	≤ 20	–	288	577
	21–50	–	192	2 788
	51–130	–	–	5 096
	> 130	–	–	192
Beech	≤ 20	–	–	–
	21–50	385	–	–
	51–130	192	–	96
	> 130	–	–	–
Wild cherry	≤ 20	–	–	–
	21–50	–	–	–
	51–130	–	–	–
	> 130	–	–	96
Hornbeam	≤ 20	96	385	385
	21–50	96	865	192
	51–130	–	2 596	96
	> 130	–	–	385
Sycamore	≤ 20	96	–	1 635
	21–50	–	192	–
	51–130	–	1 731	–
	> 130	–	–	–
White willow	≤ 20	–	192	–
	21–50	–	96	–
	51–130	–	96	–
	> 130	–	–	–
Red oak	≤ 20	–	192	–
	21–50	–	–	–
	51–130	–	–	–
	> 130	–	–	–
Total amount of self seeding		1 730	20 574	22 979

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Table 3. Species composition and amount of self-seeding and undergrowth of tree species on sample plots (small clearcut) in fresh hornbeam-oak-pine forest on relatively rich soils, by height group (individuals·ha^{-1})

Tree species	Height groups (cm)	Time of counting		
		spring 2020	autumn 2020	autumn 2021
Scots pine	≤ 20	43 700	41 700	33 600
	21–50	200	100	4 600
	51–130	–	100	400
	> 130	–	–	–
Elm	≤ 20	–	–	–
	21–50	–	–	–
	51–130	–	–	1 400
	> 130	–	–	4 100
Rowan	≤ 20	–	–	–
	21–50	–	–	100
	51–130	–	–	–
	> 130	–	–	–
Goat willow	≤ 20	–	–	800
	21–50	–	–	3 600
	51–130	–	–	11 900
	> 130	–	–	3 000
Beech	≤ 20	100	–	–
	21–50	–	–	–
	51–130	–	–	–
	> 130	–	–	–
Norway maple	≤ 20	–	300	–
	21–50	–	–	–
	51–130	–	–	–
	> 130	–	–	–
Hornbeam	≤ 20	200	200	400
	21–50	–	–	400
	51–130	300	300	500
	> 130	–	–	100
Sycamore	≤ 20	600	100	5 500
	21–50	–	–	400
	51–130	–	–	100
	> 130	–	–	–
Birch	≤ 20	–	–	100
	21–50	–	–	100
	51–130	–	–	100
	> 130	–	–	–
Linden	≤ 20	–	300	–
	21–50	–	–	100
	51–130	–	–	100
	> 130	–	–	500
Aspen	≤ 20	–	–	–
	21–50	–	–	100
	51–130	–	–	200
	> 130	–	–	–
Total amount of self seeding		45 100	43 100	72 200

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plots, less common is sedge (*Carex brizoides* L.) and male fern (*Dryopteris filix-mas* L. Schott).

The results of our research indicate that abundant natural regeneration of tree species could also be seen in a 114-year-old stand with shelterwood cutting and on two small clearcuts (1 ha each).

After shelterwood cutting, the total amount of self-seeding and undergrowth on the sample plot varies from unsatisfactory (1.730 individuals·ha^{-1}) at the beginning to good (20.574 individuals·ha^{-1}) in autumn 2020. At the end of the vegetation period in 2021, the amount of self-seeding and undergrowth in the sample plot reaches 22.979 individuals·ha^{-1} (Table 2).

Natural regeneration, however, was more abundant after clearcut. Here, the amount of self-seeding and undergrowth after felling was 45.100 individuals·ha^{-1} (May 2020) and increased to 72.200 individuals·ha^{-1} by the end of the vegetation period in 2021 (Table 3).

In contrast, after the establishment cut in a shelterwood system, a significant increase in self-seeding and undergrowth of Scots pine during the vegetation period in 2020 from 577 individuals·ha^{-1} to 13 365 individuals·ha^{-1} could be observed. One year later, at the end of the vegetation period of 2021, pine undergrowth decreased by almost three

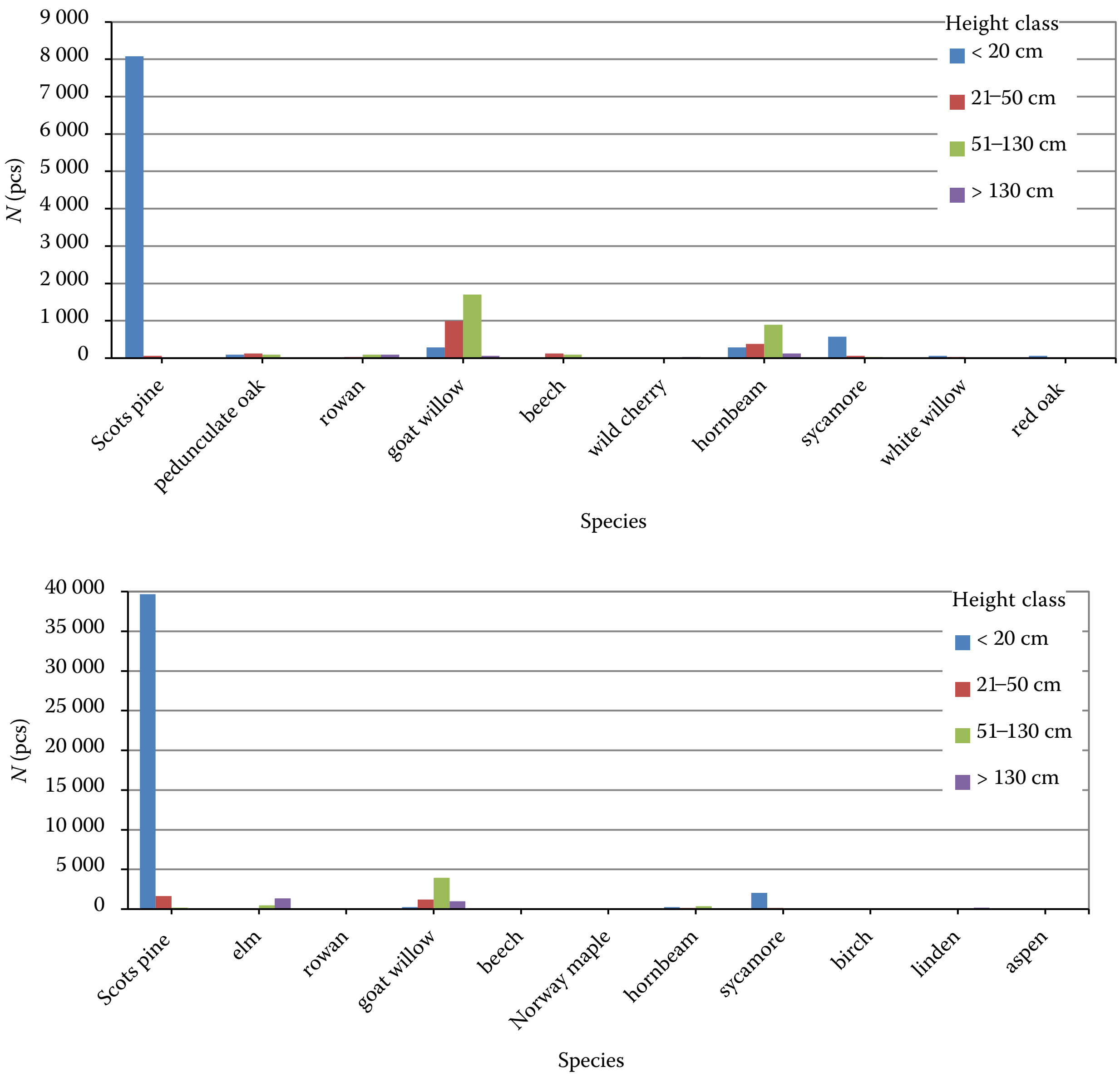

Figure 5. Distribution of undergrowth by height category on sample plots in fresh hornbeam-oak-pine forest on relatively rich soils: (A) shelterwood and (B) small clearcut.

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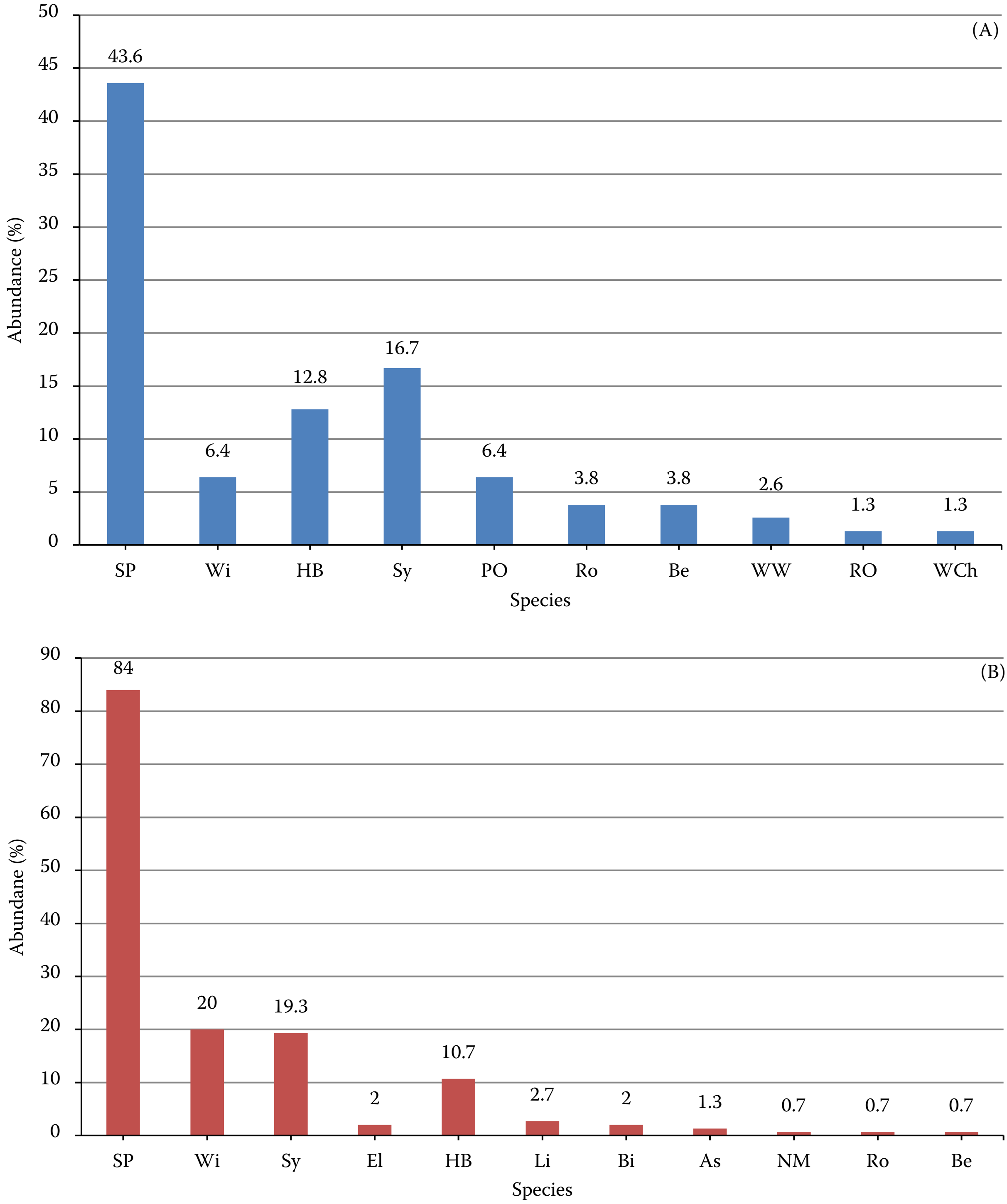

Figure 6. Abundance of self-seeding and undergrowth of tree species (%) on sample plots in fresh hornbeam-oak-pine forest on relatively rich soils: (A) shelterwood and (B) small clearcut

SP – Scots pine; Wi – willow; HB – hornbeam; Sy – sycamore; PO – pedunculate oak; Ro – rowan; Be – beech; WW – white willow; RO – red oak; WCh – wild cherry; Bi – birch; El – elm; Li – lime; As – aspen; NM – Norway maple

thousand individuals to 10 481 individuals·ha^{-1}. This may be due to the fact that young individuals of Scots pine cannot compete with blackberry, which is beginning to dominate at this stage. Moreover, thick litter (on average 3.4 cm) prevents young individuals to reach the mineral soil.

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The same trend could be seen on the clearcut plots. The amount of self-seeding and undergrowth of Scots pine has slightly decreased during the study – from 43 900 individuals·ha^{-1} in spring 2020 to 38 600 individuals·ha^{-1} at the end of the vegetation period 2021. The higher amount of Scots pine self-seeding here goes back to the exposure of mineral soil. The thickness of the litter on the clearcut area was only 1.1 cm on average. Also in this area, fewer blackberries were found compared to the shelterwood stand, and more sunlight, which allows young individuals of Scots pine to compete with grasses.

Due to the recent felling on both sample plots, it is normal that the small fraction of self-seeding and undergrowth of Scots pine (≤ 20 cm) dominates in both areas: its share amounts to 99% on the shelterwood area and 96% on the clearcut area. The undergrowth of elm, hornbeam, lime, goat willow with heights of around 51 cm and above is mostly of vegetative origin.

The share of the naturally regenerated tree species on both sample plots in the fresh hornbeam-oak-pine forest on relatively rich soils is presented in Figure 4A, 4B.

On the second small clearcut (results not shown in figures), the amount of self-seeding of Scots pine in spring 2020 was 42 000 individuals·ha^{-1}, they were all up to 20 cm in height. In autumn 2021, the amount of self-seeding of Scots pine increased to 104 800, when 92 000 of which were up to 20 cm height, and 12 800 between 21 cm and 50 cm. As part of self-seeding in this area accompanying species were also present (hornbeam, goat willow, maple, sycamore, white willow, aspen, larch, red oak, pedunculate oak) with an amount of 10 100 individuals·ha^{-1}. Thus, in this area, natural regeneration was abundant and the stand could be established without planting.

The results of the tree species composition in natural regeneration reveal that there is a dominance of Scots pine with 54% in the shelterwood and 78% on the small clearcut. Concomitant species, which can be found, are willow, sycamore, elm, and hornbeam. Occasionally, there is natural regeneration of rare species such as wild cherry, white willow, rowan, birch, beech, linden, aspen and Norway maple (Tables 2 and 3, Figure 4A, 4B). The analysis of the height structure of natural regeneration shows that small seedlings dominate, especially in the abundant Scots pine (Figure 5A, 5B). However, many of these small trees will die later on due to density-related competition.

The distribution of self-seeding and undergrowth by area indicates that the natural regeneration of all tree species in the sample plots is characterized by an uneven distribution in the area. Scots pine has the highest abundance – 43.6% on the area after the establishment cut of shelterwood and 84.0% on the area after the small clear cut, much less common are all other tree species (willow, hornbeam, sycamore, oak, rowan and others) – from 0.7% to 20.0% (Figure 6A, 6B).

Close correlations exist between the number of self-seeding and undergrowth on the sample plots and its abundance (R^2 = 0.9–1.0).

Likewise, under the conditions of the 114-year-old stand, the best process of natural regeneration takes place in areas with low plants and with a small coverage of the grass cover. The composition of the grass cover on the sample plots was uniform: blackberries (*Rubus caesius* L.), bushgrass (*Calamagrostis epigejos* L. Roth.), quaking sedge (*Carex brizoides* L.) and red raspberry (*Rubus idaeus* L.) predominated.

DISCUSSION

The main results of our research are consistent with many scientific studies on Scots pine natural regeneration in Central Europe. But, what is outstanding for Ukraine in this study is the analysis of natural regeneration of Scots pine according to different felling types or silvicultural systems. Especially alternatives to clearcut and their impact on natural regeneration are a major challenge in CNS all over Europe.

To date, many Ukrainian scientists have studied the natural regeneration of pine after clearcut at different times (Fuchylo 2011; Maurer et al. 2013; Levchenko, Mazurenko 2017; Maurer, Kimeichuk 2020) and foreign scientists (Dong et al. 2003; Andrzejczyk, Żybura 2012; Dobrowolska 2015; Czyżyk 2017; Aleksandrowicz-Trzcińska et al. 2018; Bílek et al. 2018; Saursaunet et al. 2018; Długosiewicz et al. 2019; Przybylski et al. 2021). Fuchylo (2011) described the abundant natural regeneration in the humid forests of Eastern Polissya. The natural regeneration of Scots pine under the canopy of mature and overmature pine stands in Maleh Polissya depends on the type of forest vegetation conditions and soil moisture (Fed-

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enyshyn 2014). Lukisha and Pirogova studied the peculiarities of natural reproduction of Scots pine in the harsh climatic conditions of the dry steppe and found that in pine plantations at younger ages of 30-35 years, there is a sufficient natural renewal with good growth (Lukisha, Pirogova 2012). Moreover, under the canopy of ancient stands in Roztochia, satisfactory and good regeneration of trees could be found, including larger advanced growth with more than 2 m height (Zvarych et al. 2016).

Our studies have shown that the amount of Scots pine undergrowth in different test areas after the irregular shelterwood cutting varies from 54 082 individuals·ha^{-1} to 182 703 individuals·ha^{-1}. There is evidence that the success of natural regeneration depends on many factors (Przybylski et al. 2021), such as litter, competition with other plants and properties of the mineral soil. With an increase in litter thickness from 0.3 cm to 5.0 cm, the amount of pine regeneration decreases from 10.5 to 0.1 thousand individuals per ha (Levchenko, Mazurenko 2017).

A study conducted in Scandinavia (Saursaunet et al. 2018) revealed that the pine seedling density increased with the intensity of litter decomposition. These findings were backed by Polish forest scientists, underlining that the seedling density is positively correlated with soil tillage (Aleksandrowicz-Trzcińska et al. 2018). Soil properties and the development of herbaceous plants are other important factors influencing the intensity and quality of regeneration. Herbaceous vegetation has a negative effect on the regeneration of the main tree species, in particular Scots pine, both on clearcut areas and under the stand canopy. Moreover, the roots of the seedlings are located in the upper layer of the soil in the early growth period; thus, plants have only limited access to nutrient stocks. The top soil moisture has a significant impact on the adaptation and survival of seedlings of most tree species and can lead to the development of various fungal diseases and soaking of plants (Ivanytskyy 2011). In order to significantly increase the intensity of self-seeding and pine growth, it is recommended to actively prepare the soil and protect the pine seedlings against weeds and unwanted woody vegetation (Fuchylo 2011).

Polish scientists have concluded that the factor that most affects the regeneration of Scots pine is abundant rainfall during the first growing season and competition with other plants such as grass (*Deschampsia caespitosa* or *Calamagrostis*), raspberry and blackberry (Aleksandrowicz-Trzcińska et al. 2018). Dobrowolska (2015) analyzed the impact of wind disturbances in Northeast Poland (Szast forest) on natural regeneration and found that Scots pine dominated on all sample plots except the severely disturbed stands; in the latter birch was more frequent than Scots pine. Given the above-mentioned factors, the recovery of pine, even in the presence of large numbers of seeds, may be unsatisfactory.

Lavnyy and Spathelf (2016) describe essential conditions for successful natural regeneration in the pine forests of northeastern Germany. The silvicultural systems applied are gap cuts (as a consequence of irregular shelterwood cutting), shelterwood cuts and small clearcuts (strips). Species composition and canopy closure have a significant impact on the success of natural pine regeneration. It occurs best in areas with bare mineral soil or thin litter and no grass cover. There, seedling numbers with more than 80 000 or 100 000 individuals per ha are possible. Seedlings which cannot reach the mineral layer of the soil mostly die. In addition, mosses and lichens are no obstacles for regeneration success. If soil conditions are unfavourable, or the competition for water resources due to grass (*Calamagrostis, Deschampsia*) or ferns is significant, soil tillage is recommended: e.g. the removal of small strips at a distance of 2 m with ploughs or special attachments at tractors (Hafemann, Stähr 2007; Lavnyy, Spathelf 2016).

Concerning the treatment of the overstorey, stands have to be gradually opened in the process of regeneration to successfully establish a light-demanding species (Fuchylo 2011). At stocking 0.7, the density of regeneration seedlings is highest, but their growth development is better at lower densities, e.g. 0.3 or 0.4 (Gordienko, Kovalevsky 2002; Andrzejczyk, Żybura 2012). Thus, variable retention systems match perfectly with the requirements for natural regeneration of pine (Gustafsson et al. 2020). Likewise, Krynytska argues that in mixed stands with hornbeam, oak and pine, the best conditions for the emergence and growth of Scots pine undergrowth are created by conducting a uniform gradual two-stage felling (Krynytska 2019). Historically, these gradual fellings (called shelterwood cutting) were developed and popularized in Germany at the end of the 18th century by Georg-Ludwig Hartig (Krynytskyy et al. 2014). In contrast, in Ukraine, shelterwood cutting in pine plantations was first recommended by the revision of forest

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management in 1878 for the Cherkasy forest. Another silvicultural system suited to promote natural pine regeneration is small clear cutting (up to 1 ha), especially in the moderately fresh oak-pine forest.

CONCLUSION

In general, Scots pine natural regeneration is good in the fresh hornbeam-oak-pine forest on relatively rich soils (54%–78%), as well as on poor soils (95%). Moreover, the height structure shows a predominance of small seedlings. It is assumed that the process of natural regeneration is complex and influenced by a set of environmental factors, namely: litter thickness, density and closure of the herbaceous plant layer, methods and intensity of felling and the mother stand. The most abundant natural regeneration occurs in places with only sparse competitive ground vegetation and low plants. The type of silvicultural system does not significantly influence the amount of seedlings. But it can be recommended to increase the natural regeneration success by soil scarification to improve the seedbed for germination. This allows us to increase the amount of reliable self-seeding and undergrowth by 80%. In order to protect and preserve the vulnerable 1-2-year-old self-seeding of Scots pine, it is necessary to remove weeds and unwanted woody vegetation. Finally, the right combination of these measures and their timely implementation will ensure the high-quality natural regeneration of Scots pine.

REFERENCES

Aleksandrowicz-Trzcińska M., Drozdowski S., Studnicki M., Żybura H. (2018): Effects of site preparation methods on the establishment and natural-regeneration traits of Scots pines (*Pinus sylvestris* L.) in northeastern Poland. Forests, 9: 717.

Andrzejczyk T., Żybura H. (2012): Sosna zwyczajna. Odnawianie naturalne. Alternatywne metody hodowli. Warszawa, PWRiL: 278. (in Polish)

Bílek L., Vacek S., Vacek Z., Remeš J., Král J., Bulušek D., Gallo J. (2016): How close to nature is close-to-nature pine silviculture? Journal of Forest Science, 62: 24–34.

Bílek L., Vacek Z., Vacek S., Bulušek D., Linda R., Král J. (2018): Are clearcut borders an effective tool for Scots pine (Pinus sylvestris L.) natural regeneration? Forest Systems, 27: e010.

Brang P., Spathelf P., Larsen J.B. Bauhus J., Boncčina 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.

Czyżyk K. (2017): The diversity of characteristics of the natural regeneration of Scots pine (*Pinus sylvestris* L.) in the clear-cutting. Acta Scientiarum Polonorum. Formatio Circumiectus, 16: 59–70.

Danchuk O.T., Korol M.M., Chaskovskyy O.G., Tsunyak A.M. (2015): Forest monitoring of Roztochia as a system component of multifunctional sustainable forestry. Proceedings of Forest Academy of Sciences of Ukraine, 13: 64–69. (in Ukrainian)

Dobrowolska D. (2015): Forest regeneration in northeastern Poland following a catastrophic blowdown. Canadian Journal of Forest Research, 45: 1172–1182.

Dong P.H., Diep D.Q., Schüler G. (2003): Kiefern-Naturverjüngung im Pfälzerwald. Forst und Holz, 59: 83–86. (in German)

Długosiewicz J., Zając S., Wysocka-Fijorek E. (2019): Evaluation of the natural and artificial regeneration of Scots pine (*Pinus sylvestris* L.) stands in the Forest District Nowa Dęba. Leśne Prace Badawcze, 80: 105–116.

Fedenyshyn M.R. (2014): Peculiarities of natural renewal of Scots pine in the conditions of Maleh Polissya of Ukraine. Scientific Bulletin of NLTU of Ukraine, 24: 57–62. (in Ukrainian)

Fuchylo Y.D. (2011): Natural regeneration of pine forests of Eastern Polissya. Scientific Bulletin of NLTU of Ukraine, 21: 57–61. (in Ukrainian)

Gallo J., Bílek L., Šimůnek V., Roig S., Bravo Fernández J.A. (2020): Uneven-aged silviculture of Scots pine in Bohemia and Central Spain: Comparison study of stand reaction to transition and long-term selection management. Journal of Forest Science, 66: 22–35.

Gensiruk S.A. (1981): Basic principles of complex forestry zoning. Kyiv, Naukova dumka: 360. (in Russian)

Gerenchuk K.I. (1972): Nature of Lviv region. Lviv, Publishing House of Lviv University: 151. (in Ukrainian)

Gordienko M.I., Kovalevsky S.B. (2002): Natural regeneration of Scots pine in the conditions of fresh soils with different intensity of growth of herbaceous plants. Scientific Bulletin of UkrDLTU, 12: 8–13. (in Ukrainian)

Gustafsson L., Bauhus J., Asbeck T., Augustynczik A.L.D., Basile M., Frey J., Gutzat F., Hanewinkel M., Helbach J., Jonker M., Knuff A., Messier C., Penner J., Pyttel P., Reif A., Storch F., Winiger N., Winkel G., Yousefpour R., Storch I. (2020): Retention as an integrated biodiversity conservation approach for continuous-cover forestry in Europe. Ambio, 49: 85–97.

Hafemann E., Stähr F. (2007): Zur Verjüngung der Kiefer. Eberswalder Forstliche Schriftenreihe Band XXXII: 414–420. (in German)

https://doi.org/10.17221/73/2022-JFS

Ivanytskyy R.S. (2011): Natural stands regeneration on clearcut areas in Surazh forest dacha. Scientific Bulletin of NLTU of Ukraine, 21: 19−24. (in Ukrainian)

Kovalchuk I.P., Petrovska M.A. (2003): Geoecology of Roztochia. Lviv, Publishing Center of LNU: 192. (in Ukrainian)

Krynytska O.G. (2019): Forestry and Ecological Principles of Natural Reproduction and Formation of Pine-Oak Forests in the Conditions of Lviv, Roztochia: Thesis for Awarding Scientific Degree of Candidate of Agricultural Sciences in Speciality 06.03.03 – Forest Sciences and Silviculture. Kharkiv, Ukrainian Research Institute of Forestry and Forest Melioration: 20. (in Ukrainian)

Krynytskyy G.T., Chernyavsky M.V., Derbal Y.Y., Delehan I.V., Myklush S.I., Parpan V.I., Lavnyy V.V., Shparyk Y.S., Henyk Y.V., Rekovets M.M., Korzhov V.L., Shpilchak M.B., Kaspruk O.I., Kremenetska Y.O., Revutskyy M.I., Bruhanik R., Sarvashova Z., Jaloviar P. (2014): Close-to-Nature and Multifunctional Forestry Management in the Carpathian region of Ukraine and Slovakia. Uzhhorod, Kolo: 280. (in Ukrainian)

Lavnyy V. (2021): Silvicultural and Ecological Principles of Primary Stands Regeneration on Windthrow Areas in the Ukrainian Carpathians. Lviv, Halytska vydavnycha spilka: 354. (in Ukrainian)

Lavnyy V., Spathelf P. (2016): The practice of close-to-nature silviculture in the pine forests of North-East Germany. Scientific works of the Forestry Academy of Sciences of Ukraine, 14: 52−57. (in Ukrainian)

Levchenko V.V., Mazurenko O.V. (2017): Natural forest regeneration in pine stands of the "Boyarska LDS". Forestry and horticulture, 11: 10−20. (in Ukrainian)

Lukisha V.V., Pirogova P.V. (2012): Natural recovery of *Pinus silvestris* L. as an indicator of stability of artificial forest phytocenoses of Kinburn. Ecological sciences, 2: 29−37. (in Ukrainian)

Maurer W.M. (2007): Natural regeneration is a key element of optimization of forest reproduction in Ukraine on the basis of ecologically oriented forestry. Scientific Bulletin of NAU, 113: 57–65. (in Ukrainian)

Maurer W.M. (2012): Modern tasks for improving the reproduction of forest resources in the context of sustainable forest management. Scientific Bulletin of the National University of Life and Environmental Sciences of Ukraine, 171: 68–75. (in Ukrainian)

Maurer V.M., Kimeichuk I.V. (2020): Dynamics of the number and state of natural regeneration of Scots pine on clearcut areas in the conditions of oak forests on fresh, relatively rich soils of Kyiv Polissya. Ukrainian Journal of Forest and Wood Science, 11: 45−54. (in Ukrainian)

Maurer W.M., Fuchylo Y.D., Sbytna M.V. (2013): Prospects for the use of natural regeneration of Scots pine in the conditions of Kyiv Polissya. Forestry and horticulture, 3: 20−32. (in Ukrainian)

Myklush Y., Myklush S., Havryliuk S., Savchyn V. (2021): Main forestry and management indices of pine (*Pinus sylvestris* L.) stands involving beech (*Fagus sylvati*ca L.) in composition of Ukrainian Roztochia. Folia Forestalia Polonica, Series A – Forestry, 2: 81−87.

Przybylski P., Konatowska M., Jastrzębowski S., Tereba A., Mohytych V., Tyburski Ł., Rutkowski P. (2021): The possibility of regenerating a pine stand through natural regeneration. Forests*,* 12*:* 1055.

Saursaunet M., Mathisen K.M., Skarpe C. (2018): Effects of increased soil scarification intensity on natural regeneration of Scots pine (*Pinus sylvestris* L.) and birch (*Betula* spp. L.). Forests*,* 9: 262.

Shvidenko A., Buksha I., Krakovska S., Lakyda P. (2017): Vulnerability of Ukrainian forests to climate change. Sustainability, 9: 1152.

Soroka M.I. (2008): Vegetation of Ukrainian Roztochia. Lviv, Svit: 432. (in Ukrainian)

Stefańska-Krzaczek E. (2012): Species diversity across the successional gradient of managed Scots pine stands in oligotrophic sites (SW Poland). Journal of Forest Science, 58: 345–356.

Zvarych O.D., Zaika V.K., Stryamets G.V., Zvarych Y.V., Parobiy S.B. (2016): Natural regeneration in the old-growth forests of the nature reserve "Roztochia". Scientific Bulletin of NLTU of Ukraine, 26: 77−85. (in Ukrainian)

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