ORIGINAL RESEARCH ARTICLE

Evaluation of the natural and artificial regeneration of Scots pine *Pinus sylvestris* L. stands in the Forest District Nowa Dęba[1]

**Justyna Długosiewicz,[2] Stanisław Zając[3] , Emilia Wysocka-Fijorek[4]* **

[2]Nowa Dęba Forest District, ul. Wł. Sikorskiego 2, 39–460 Nowa Dęba, Poland; [3]University of Łódź, Branch in Tomaszów Mazowiecki, Institute of Forest Sciences, ul. Konstytucji 3 Maja 65/67, 97–200 Tomaszów Mazowiecki, Poland; [4]Forest Research Institute, Department of Forest Management, Sękocin Stary, ul. Braci Leśnej 3, 05–090 Raszyn, Poland

*Tel. +48 22 7153813, e-mail: e.wysocka-fijorek@ibles.waw.pl

Abstract. The main purpose of this article was to highlight the potential for enhancing positive silvicultural effects and their dependency on the management method in Scots pine Pinus sylvestris L. stands. We therefore assessed the impact of natural and artificial regeneration on vitality and health, compaction, surface coverage and seedlings height. Another important goal was to assess the severity of damage in the selected forest sites.

A comparative analysis was carried out based on results from field work conducted in the autumn 2010 in the Forest District Nowa Dęba. As part of this field work, also the breeding quality of the analyzed pine renewals was assessed.

The obtained results indicate that natural regeneration of Scots pine under the conditions of a fresh coniferous forest as well as a fresh mixed coniferous forest is the most reasonable management practice. In wet mixed coniferous forests however, the naturally regenerating Scots pine seedlings are of lower silvicultural quality and growth parameter values compared to those in artificially regenerated stands. In fresh mixed broadleaved forests, naturally regenerated Scot pine trees showed slightly lower silvicultural quality and vitality than artificially regenerated trees. Our results indicate furthermore that there are indeed conditions under which the restoration of Scots pine in the Nowa Dęba Forest District using natural regeneration is preferable. We also found that the employed method of renewing has a significant impact on pine growth parameters in the moist mixed coniferous forest habitat. Naturally renewing pines are characterized by a lower overall viability, but at the same time natural regeneration provides a larger number of individuals with the best viability (1st vitality class), which can be a valuable selection basis for trees used in breeding.

Keywords: Scots pine, natural regeneration, artificial regeneration, silvicultural quality of regeneration, height of trees, density

1. Introduction

The literature on the subject devotes much space to the issues concerning the regeneration of Scots pine *Pinus sylvestris* L. Ilmurzyński and Mierzejewski (1956), Mierzejewski (1975), Jastrzębski (1975) and Okoń (2016) have written about the possibilities of its natural regeneration. Numerous studies have been conducted, for example, on the influence of soil preparation (Andrzejczyk, Drozdowski 2003; Andrzejczyk, Augustyniak 2007; Pigan 2010), cutting methods (An-

drzejczyk 2000; Andrzejczyk et al. 2009), habitat conditions (Dobrowolska 2010; Gmyz, Skrzyszewski 2010) and maintenance and protection activities (Aleksandrowicz-Trzcińska 2008; Kopeć 2011) for the growth and development of natural and artificial pine regeneration. Issues concerning the natural regeneration of pine in areas where disturbances occurred, such as fires or hurricanes (Hawryś et al. 2004; Dobrowolska 2008), or in the gaps in the stands (Dobrowolska 2007) have also been addressed. There are also many scientific publications on the artificial renewal of Scots pine concerning the

time and method of planting, type of planting material, technology of its production, or type of cutting (Rudnicki 1954; Białobok et al. 1993; Barzdajn 2006; Buraczyk, Szeligowski 2008; Buraczyk et al. 2012; Sewerniak et al. 2012).

Numerous studies have been conducted, among others, on the influence of individual factors (abiotic and biotic) on the growth and development of Scots pine in various geographical regions (Barzdajn et al. 1996; Kowalczyk et al. 2000; Paluch 2004; Boiko 2008; Zachara et al. 2011). The growth characteristics of seedlings and saplings differing in the way they were renewed were also compared (Wolski, Robakowski 2008).

The aim of this study is to assess the influence of the method of natural and artificial regeneration on growth, lifespan, health, density, surface coverage and height of the renewal. An important goal is also to assess the severity of damage to naturally and artificially regenerated pine crops in selected types of forest habitats. The implementation of the adopted research objectives serves to provide arguments for increasing the share of the optimal (natural or artificial) methods of regenerating pine stands in Poland.

2. Study area

The research covered naturally and artificially planted pine crops, as well as those with a predominant share of Scots pine, located in Nowa Dęba Forest District (Regional Directorate of State Forests in Lublin).

Nowa Dęba Forest District has an area of nearly 25,700 ha, of which 21,700 ha is forest. The District has three forest precincts: Buda Stalowska, Dęba and Babule. The District has forests that are large and dense forest complexes with the presence of all forest-forming species occurring in this region. The average abundance of the tree stands is 200 m³/ha. The share of species in the stand reflects the habitats occurring here, which is why the most important and most abundant species is Scots pine. Stands with prevailing Scots pine cover 80.6% of the Forest District's area and constitute 85.5% of the stock. Stands of all age classes are made up of this species (the largest area is occupied by stands of age class IVa) and achieves an average site index of Ia−II, an abundance of 212 m³/ha and an average age of 57 years. An important element of the District's forestry management is also the fact that protective forests cover 75.6% of the forest area. These are mainly forests of particular importance for the security and defense of the state and to protect water resources in its intake and source zones.

Within the area of Nowa Dęba Forest District, 40 soil types and subtypes were distinguished, which formed on quaternary geological formations of aeolian and riverine origin. The largest surface shares are found for rusty podzols (RD) − 27.4%, true podzols (Bw) − 26.5%, mineral-muck (MRm) − 6.9%, rusty brown (RDbr) − 6.3% and gleyic

podzols muck soils (Bgms) − 6.2%. The Forest District's area of operation lies in the catchment area of the Vistula River and its tributaries, the Trześniówka and Łęg rivers.

The dominant trophic habitat group is the coniferous types of forests. The largest share is represented by the fresh mixed coniferous forest − 31.8%, fresh coniferous forest − 21.1% and moist mixed coniferous forest − 16.3%. Broadleaf forest occupy a total of 25.4% of the area, of which the most is the mixed fresh forest − 13.4%. The area of the remaining forest habitat types does not exceed 6% of the total area of the Forest District. In terms of habitat status, natural and near-natural habitats dominate.

3. Material and research methodology

The study used source material and numerical data mainly from the State Forests Information System (SILP). In addition, we used the data included in the forest management plan for Nowa Dęba Forest District (formerly Buda Stalowska) for 2003–2012, status as of 01.01.2003 (forest area, share of forest habitat types, share of tree species) and the results of field studies conducted in 2010 on circular plots of 10 m².

The research was divided into three stages:

I – obtaining data from the SILP database on Nowa Dęba Forest District,

II – field work in the study plots, enabling an assessment to be made of the impact on selected breeding characteristics depending on the method used to regenerate pine stands,

III – compiling and analysing the collected source data in the office.

The work of stage I consisted of selecting a specific database from SILP that met the assumed selection criteria. Natural and artificial renewals were selected for the research analysis in accordance with the following criteria:

• the share of pine in the species composition was equal to or greater than 50%,

• the material used for the artificial regeneration were 1-year-old Scots pine seedlings with the symbol 1/0,

• the regeneration was conducted within the framework of clear cutting and complex cutting systems,

• the natural regeneration of the pine was acknowledged in the year of sowing, that is, the pine was 1-year-old in the year of recognizing the renewal.

From the obtained set of pine crops, we included those for further analysis from the greatest possible number of habitats (allowed by the available research material), that is, fresh coniferous Bśw, fresh mixed coniferous BMśw, moist mixed coniferous BMw and fresh mixed LMśw forests. Because of their very small share, crops with pine in moist mixed LMw, alder Ol and mixed marsh coniferous BMb forests were not included in further analysis. In order to limit the impact of atmospheric

conditions in a given year (e.g., weather anomalies) on the breeding quality of the renewals, the study took into account four crop years, which in 2010 were between 3 and 6 years of age. A total 157 renewals with prevailing or co-dominant pine of a total area of 332.31 ha were identified, practically located in every precinct of Nowa Dęba Forest District.

The field work of the study's second stage was conducted in the autumn of 2010 to assess the breeding quality of the analysed pine regenerations. As a standard (to the extent allowed by the research material), four research areas were selected for each habitat, renewal method and age. In each area, circular sample plots of 10 m² were delineated, regularly arranged in a grid of rectangles or squares whose sides were adapted to the size of the given research area. The sum of the sample plots accounted for about 1% of the surface area occupied by pine in the given research area. The number of circular sample plots ranged from 6 to 32 per research area. In total, over 19,600 individual pines were measured and classified from more than 1,300 circular sample plots.

The following elements were assessed and measured in each circular sample plot:
• number (individuals/circular sample plot);
• height (cm) measured with a steel tape or scaled staff with an accuracy of 1 cm;
• increment of apical shoot from the previous year (cm), measured with a steel tape or scaled staff with an accuracy of 1 cm;
• root collar thickness (mm) measured with callipers with an accuracy of 1 mm;
• the degree of Lophodermium needle cast infection – visual assessment according to the share of infected needles: 1st degree – 0–25%, 2nd degree – 26–50%, 3rd degree – 51–75%, 4th degree – 76–100%;

• vitality classes – visual assessment according to the established vitality classes: 1st class – individuals with high vitality, 2nd class – individuals slightly weakened, 3rd class – individuals severely damaged, dying (Fig. 1);
• damage – visual assessment by the following types: dying shoots, pine twist rust, browsing, bark stripping from ungulate gnawing or rubbing, breakages, other;
• defects categorized by: schoolmarm trees, curved tree trunks.

As part of the desk work (stage III of the study), the collected numerical data were compiled and analysed using the Microsoft Office suite. This work consisted of assessing the breeding quality of the naturally and artificially planted pines aged 3−6 years for the two methods of regeneration and four habitat variants. For each type of crop, average values of the analysed characteristics (including height, abundance, root collar thickness, degree of dothistroma [red band] needle blight infection, vitality, damage, defects) were determined from the measurements and assessments made at the circular study plots. One-way and two-factor analysis of variance was used in a completely random system, taking into account the second order interactions. Assumptions about the homogeneity of variance were checked. To separate homogeneous groups, the Tukey test was used at the significance level of $\alpha = 0.05$. In the absence of a normal distribution of variables or failure to meet the assumptions of the homogeneity of variance, the non-parametric Kruskal-Wallis test using post-hoc multiple comparison tests was used. Calculations were performed using the Statistica 10.0 package (StatSoft, Inc. 2011).

4. Results

The number of trees and the degree of coverage (natural/artificial regeneration). In natural regeneration, the

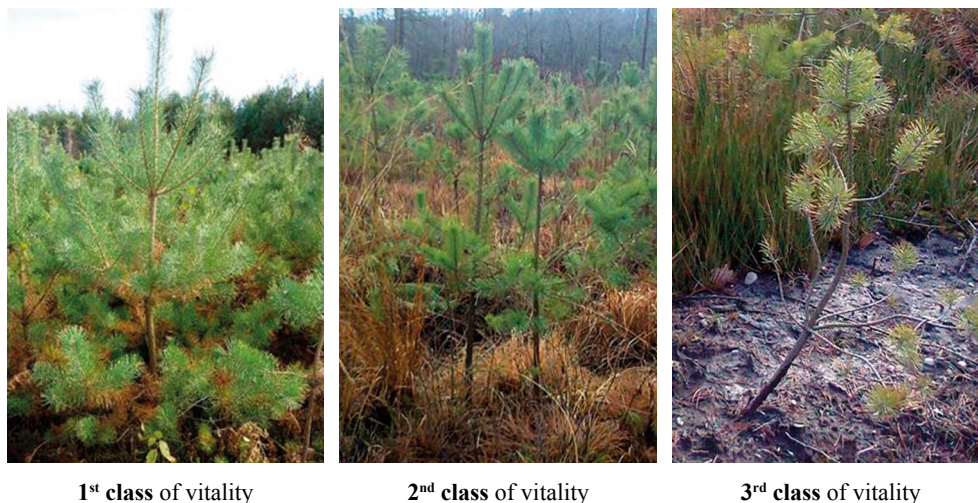1st **class** of vitality   2nd **class** of vitality   3rd **class** of vitality

Figure 1. Classes of Scots pine natural and artificial seedlings vitality

density of Scots pine trees systematically decreased with age. Statistical analysis did not show, however, that this relationship was significant ($H = 4.700$; $p = 0.195$). The highest density was found in the Bśw and BMw habitats for seedlings in their 5th year, and in the remaining habitats, in the crops aged 4 years. The density dynamics in the artificially regenerated study plots differed, where there was a strong variation relating to the number of specifically aged trees, but without a clear downward or upward trend. The number of artificially regenerated trees also did not depend on their age for the range of the ages being studied ($H = 5.475$; $p = 0.140$). We observed that in some cases, especially in the LMśw habitat, the density was higher than what one would expect from the number of seedlings planted (the standard planting is 10,000 seedlings per hectare), which indicates that the composition of the crop was supplemented with self-sown trees.

The differences in the number of pines depending on the regeneration method turned out to be statistically significant in the following habitats: Bśw ($H = 5.05$; $p = 0.0246$), BMśw ($H = 16.04$; $p = 0.0001$) and BMw ($H = 10.64$; $p = 0.0011$). In natural regeneration, the highest average number of pine trees was found in BMśw – 31,100 individuals/ha, and the lowest in BMw – 23,300 individuals/ha and LMśw – 23,800 individuals/ha (Fig. 2). In artificial regeneration, the greatest number of pine trees grew in the LMśw habitat – an average of 16,300 individuals/ha, and the lowest in BMśw – 9,600 individuals/ha.

In addition to numbers, an important feature of density is the distribution of individual trees in the crop. Seedlings from artificial regeneration were more evenly distributed in the analysed research areas. This is indicated by a higher percentage of surface coverage. In each studied habitat, its average
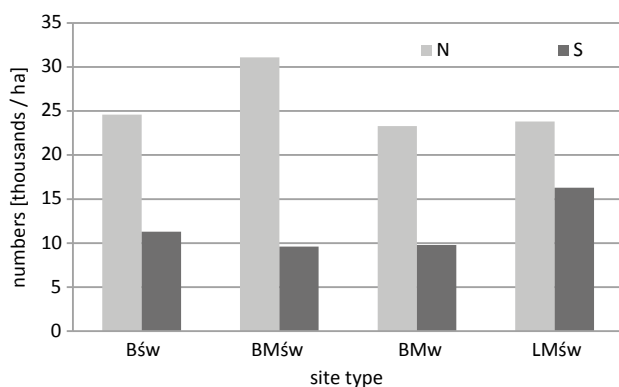
Bśw – fresh coniferous forest, BMśw – fresh mixed coniferous forest, BMw – moist mixed coniferous forest, LMśw – fresh mixed broadleaved forest, N – forest cultivation with natural regeneration of Scots pine stands (self-seeding), S – forest cultivation with artificial regeneration of Scots pine (cuttings with an open root system).

Figure 2. Average number [thous. pcs/ha] of pine trees on tree growing, depending on the methods of regeneration and forest site type

value was in this case higher than 80%, while in the naturally regenerated crops, such an average value was obtained only in the BMśw habitat. The largest differences between the considered forest regeneration methods occurred in the LMśw and BMw habitats, where regenerations using traditional seedlings showed an average of 10% higher surface coverage.

Tree height. The height of the trees varied depending on their age, habitat conditions and regeneration method. In the case of artificial regeneration, the highest average height was observed for 6-year-old trees in the BMw habitat, where the largest disparities in average tree height differing by regeneration method also occurred. Artificially regenerated pine trees achieved higher average height values in each crop year. At 6 years of age, the difference in tree height was 48.1 cm and proved to be statistically significant (for $p = 0.05$). The lowest values of average tree height for artificial crops were recorded in the Bśw habitat. Naturally regenerated pine reached its highest average height values in the BMśw habitat, and the lowest in the Bśw habitat.

The differences in the average height of pines in the Bśw, BMśw and LMśw habitats between artificially and naturally regenerated crops were not found to be statistically significantly (for $p = 0.05$). The regeneration method influenced tree height only in the case of the BMw habitat ($F = 10.913$; $p = 0.004$), where artificially regenerated pines were significantly higher than the naturally regenerated pines in the research areas.

Height differences between individual crop years were statistically significant ($F = 77.49$; $p < 0.001$). Despite the observed differences in average values of tree height, the impact of habitat conditions on the discussed characteristic turned out not to be statistically significant. Significant differences in height occurred in individual cases of the analysed crop years. The examined feature was characterized by quite high variability, which persisted with age regardless of the method of regeneration and habitat. The lowest values of the coefficient of height variation occurred in crops in the BMśw habitat. In other habitats, this feature was characterized by a significant range of values – from 38.6% to 50.8% for natural regeneration, and from 25.2% to 51.9% for artificial regeneration. The coefficient of variation of this feature decreased with age only for research areas with artificially regenerated pine in the BMw habitat.

The analysis of pine height showed that in the early years of growth (3–4 years of age), trees in crops of different origin obtained similar height parameters with slightly better average results in natural regeneration. This situation changed at 5–6 years of age, when pines in the areas using traditional planting material reached a higher height than the trees from natural regeneration. This is very clearly illustrated by the graphs of tree height distribution in specific habitats. At the age of 3–4 years, the height distribution of the trees was similar for both regeneration methods. The differences appe-
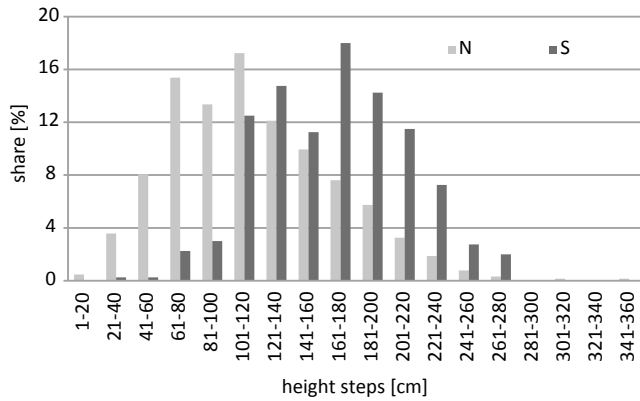
Explanation as in figure 2

Figure 3. Distribution of pine heights on 6-year-old tree growing in the BMw site type

ared in the 5th to 6th year, when the share of higher trees was greater in artificially regenerated areas. These changes were most clearly visible in the BMw habitat, where differences in the height distribution with age between the two regeneration methods became more pronounced (Fig. 3). In the remaining habitats, these differences were not so pronounced and turned out not to be statistically significant.

Thickness of the trees at the root collar. Differences were found during the analysis of root collar thickness depending on the regeneration method, habitat and age. In the BMśw and BMw habitats, trees that were artificially regenerated achieved a statistically significantly higher average root collar thickness than naturally regenerated pine trees ($F = 26.83$; $p < 0.001$ and $F = 24.35$; $p < 0.001$). No significant effect of either regeneration method or age was found on root collar thickness in one habitat – Bśw. In the remaining habitats, this feature was strongly correlated with age. Over the years, its average value increased. The lowest average root collar thickness values were observed in the LMśw habitat for trees of 3–4 years of age from both regeneration methods (Table 1). The highest average values of this feature were recorded for artificially regenerated crops at 6 years of age in the BMw habitat – 3.6 cm and the LMśw habitat – 3.1 cm, and for naturally regenerated seedlings at 6 years of age in the BMśw habitat – 2.3 cm.

At the age of 6, the naturally regenerated pine trees achieved a similar average root collar thickness regardless of habitat, which indicates the lack of a differentiating impact of habitat conditions on the value of the analysed feature. In artificially regenerated crops, we observed a tendency of increased root collar thickness of the pine trees as habitat fertility improved. At 3 years of age, the mean root collar thickness value was similar for both regeneration methods. However, in other crop years, that is, at 4, 5 and 6 years of age, artificially regenerated pine trees had significantly (for $p = 0.05$) higher average values of the examined characteristic.

Tree vitality. The best vitality was observed for 5-year-old pine crops planted in the BMśw habitat. The poorest assessment of vitality was recorded for 5- and 6-year-old self-seeding crops in the BMw and LMśw habitats (Table 2). Although in virtually every variant examined, the average vitality of artificially regenerated pines in the research areas was better than that of the naturally regenerated crops, a statistically significant difference between the analysed regeneration methods was observed only in the BMw habitat, where self-seeded pine renewals had clearly lower vitality ($H = 10.64$; $p = 0.001$).

Crops established using traditional planting material had the greatest share of trees with a high vitality (class 1) in the BMśw habitat (Fig. 4). The highest number of trees with poorer vitality occurred in Bśw and LMśw habitats in 6-year-old crops. We observed that the share of trees with the best vitality tended to increase with age, but the analysis did not show statistically significant differences for individual years. Among the naturally regenerated pines, the largest share of trees in the first vitality class was recorded in Bśw and BMśw habitats. Regenerations in the BMw habitat had

Table 1. Average thickness in the root collar [cm] depending on the age, forest site type and the method of regeneration

| Age [years] | Average thickness in the root collar [cm] | | | | | | | |
| | Bśw | | BMśw | | BMw | | LMśw | |
	N	S	N	S	N	S	N	S
3	–	0.7	0.8	0.9	–	0.7	0.6	0.9
4	1.3	1.7	1.2	1.7	1.1	1.5	0.9	0.9
5	1.6	1.7	1.7	2.4	1.6	2.3	1.4	–
6	2.2	2.3	2.3	2.8	2.2	3.6	2.2	3.1

Explanation as in figure 2.

Table 2. Average vitality of pines in the studied forest culture (according to the scale 1–3)

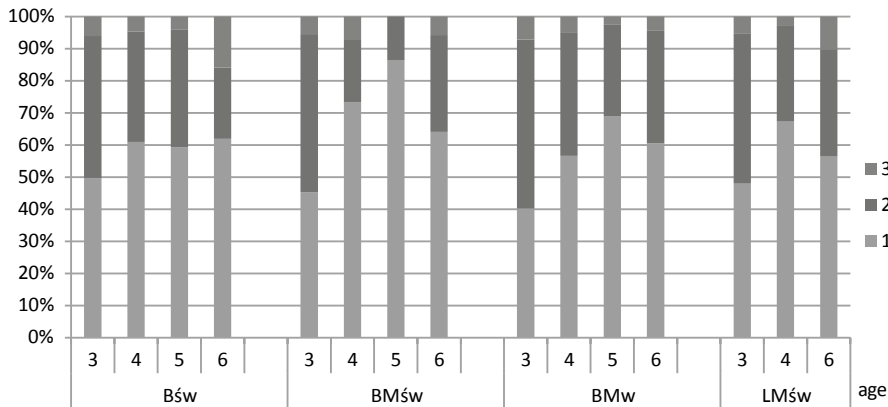| Age [years]	Bśw		BMśw		BMw		LMśw	
	N	S	N	S	N	S	N	S
3	–	1.57	1.41	1.6	–	1.67	1.61	1.59
4	1.48	1.44	1.70	1.34	1.66	1.45	1.62	1.36
5	1.55	1.45	1.64	1.13	1.67	1.34	1.71	–
6	1.61	1.54	1.59	1.4	1.67	1.42	1.61	1.49

Explanations as in figure 2

Natural regeneration of Scots pine stands
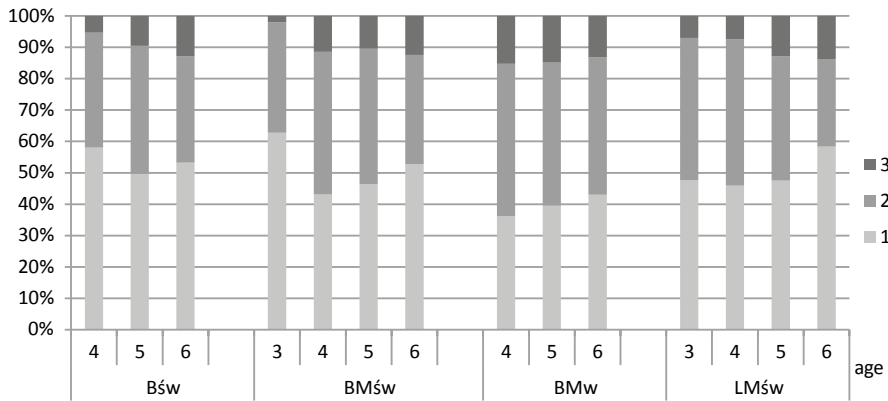
Explanation as in figure 2

Artificial regeneration of Scots pine stands

Explanation as in figure 2

Figure 4. Structure of vitality of pine regeneration depending on the age and forest site type (life class: 1 – individuals with high vitality, 2 – slightly weakened individuals, 3 – strongly damaged, dying)

the highest share of poorly performing trees, in the 2nd and 3rd viability classes. In the studied age range, the vitality of the pines remained at a similar level.

After the statistical analysis, we found that habitat conditions do not determine the vitality of either naturally or artificially regenerated pine. Because the research areas with

natural pine regeneration had a much higher density of trees, which could have an impact on the average vitality result obtained, an analysis of the occurrence of trees in only the first vitality class was conducted for the two regeneration methods. Despite obtaining a lower average vitality score for naturally regenerated pine, the number of trees with the

best vitality, which may constitute a potential selection base for stand breeding in subsequent development phases, was definitely higher for these trees (Table 3). In these renewals, the highest average number of pines with the best vitality was found in the BMśw habitat – 14,500 individuals/ha, and the lowest in BMw – 9,500 individuals/ha. The obtained number of trees per unit of area is higher than the recommendation of 'Forest Breeding Guidelines' (2012) for planting within the framework of artificial forest regeneration.

Table 3. Average number of pine specimens in the first class of life per unit of area [thous. pcs./ha] depending on the forest site type and the method of regeneration

Forest site type	The number of Scots pine trees first-class vitality [thous. pcs/ha]	
	natural regeneration	artificial regeneration
Bśw	12.9	6.8
BMśw	14.5	6.4
BMw	9.5	6.3
LMśw	11.9	9.5

Explanation as in figure 2

A similar average number of artificially regenerated pine trees from the three habitat variants, that is, Bśw, BMśw and BMw, were categorized to the 1st vitality class, that is, from 6,300 to 6,800 individuals/ha. A slightly higher number of trees was confirmed for the LMśw habitat – 9,500 individuals/ha.

The degree of infection of the trees by dothistroma (red band) needle blight. Research conducted in 2010 on the occurrence of dothistroma (red band) needle blight showed that the most infected crops occurred among the artificial renewals at the age of 4 and 5 years in the BMw habitat and among the natural renewals at the age of 4 and 5 years in BMśw habitat (Fig. 5). The greatest differences in the rate of dothistroma infection between the examined regeneration methods were also found in these habitats. These disparities disappeared in 6-year-old crops in both habitats. It was also observed that in most cases, the average degree of infection (WO) for both regeneration methods was similar and remained at 1.2 at age 6.

The crops in the BMw habitat were the exception, where the trees were more infected by the blight, reaching an average infection rate for naturally regenerating pine at 1.3, and close to 1.4 for artificially regenerated pine. In this habitat, the average WO value increased over the years. BMw was the only habitat in which the regeneration method had a statistically significant impact on the obtained average value of the degree of dothistroma needle blight infection of the trees
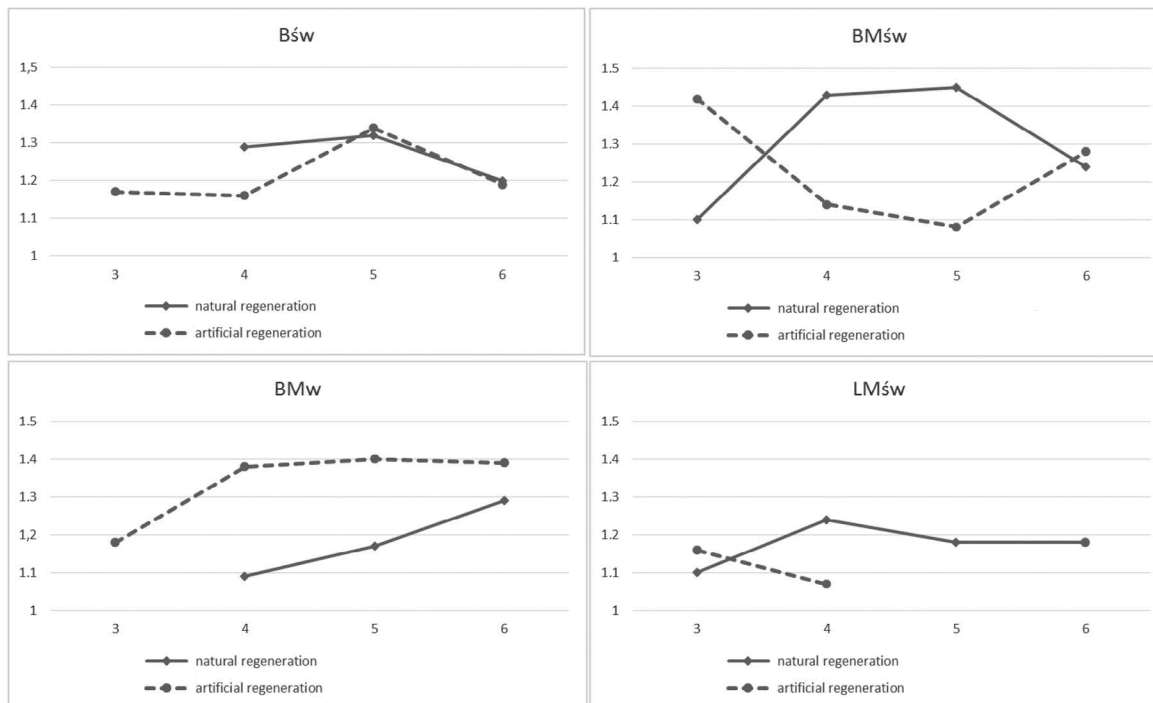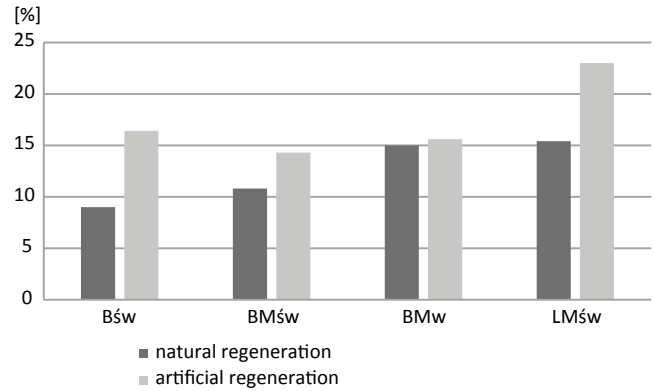

Explanations as in figure 2

Figure 5. Dynamics of changes in the average degree of dothistroma (red-band) needle blight of pines (WO) with age in the examined habitats

(H = 8.727; p = 0.003). In this habitat, artificially regenerated pine were more affected by the blight than their naturally regenerated counterparts. In the remaining cases, there were no significant differences in the degree of blight infection depending on regeneration method and age. The habitat conditions for a given regeneration method did not significantly impact the degree of infection by the fungal pathogen in question.

Tree damage and defects. In terms of morphological structure, crops established by using container-grown seedlings were characterized by a greater number of damaged trees compared to crops of naturally regenerated pine. Renewals in the BMw habitat were an exception, where an average of 15% of damaged trees occurred for both regeneration methods (Fig. 6).

In crops established using traditional planting material, the share of damaged trees ranged from 14.3% to 16.4%. An increase in the average size of damage to 23% was observed only in the LMśw habitat. The predominant type of damage in all habitats was browsing, which constituted 41.9% to 68.5% of all damage (Table 4). Frost damage to shoots and bark stripping from ungulate gnawing or rubbing were the next most numerous types of damage. In naturally regenerated crops, the least damaged trees were in the Bśw – 9% and BMśw – 10.8% habitats, while the most damaged were in LMśw – 15.4% and BMw – 15%. Breakages turned out to be the least numerous form of damage, while the most common were dying shoots, pine twist rust and browsing. Several types of damage in one tree accounted for a small share of overall damage in both renewal variants.

Crops with artificially regenerated pine were characterized by a higher share of trees with defects than similar crops from natural regeneration (Fig. 7). The largest differences occurred in the Bśw – 3.8% and BMw – 3.2% habitats. The highest share of defective individuals was found in the BMw habitat, both for artificially regenerated crops – 12.7% on

Explanations as in figure 2

Figure 6. Average percentage of damaged trees depending on the type of method of regeneration and forest site type
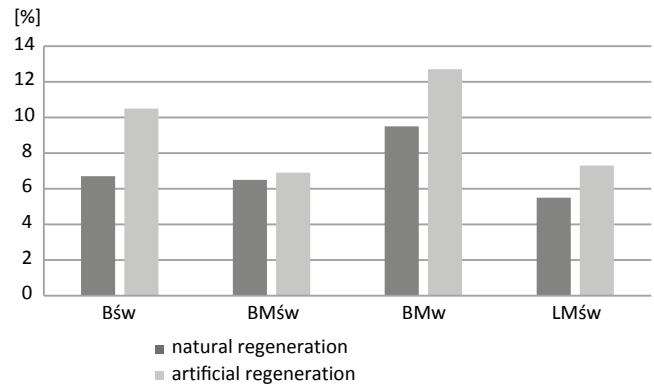
Explanations as in figure 2

Figure 7. Average percentage of defective trees depending on the type of method of regeneration and forest site type

Table 4. Average percentage share [%] of individual types of damage in the total number of damaged trees by forest site type and method of regeneration

Damage type	Bśw		BMśw		BMw		LMśw	
	N	S	N	S	N	S	N	S
Dying of shoots, pine twist rust	57.00	26.40	35.50	11.00	31.10	28.10	24.10	13.60
Tapping of board	9.30	7.90	19.40	12.30	4.30	18.40	0.20	29.00
Break	0.70	0.00	0.50	0.60	0.50	1.00	0.20	1.80
Browse damage	15.60	50.70	33.30	68.50	49.00	41.90	59.70	48.50
Other	17.00	12.90	10.50	6.20	14.00	9.70	15.90	6.00
Several at the same time	0.40	2.10	0.90	0.60	1.00	1.40	0.00	0.60

Explanations as in figure 2.

average, and naturally regenerated ones – 9.5% on average. Due to the age range of the trees surveyed, the dominant defect (over 90% of cases) was schoolmarm trees.

5. Discussion

According to Barzdajn et al. (1996) 'Pine as a native species, adapted to our climatic, soil and biocenotic conditions, must be capable of generational renewal.' The research results obtained in this work are another example of this. The effectiveness of the renewal process is the result of many variables, including those that can be shaped and controlled by humans, such as the use of appropriate renewal cuts, soil preparation, or selection of appropriate cultivation treatments. The success of natural regeneration depends to a much greater extent than is the case with artificial renewals on weather conditions in the year of sowing and on a good seed yield – a factor that is lacking in artificial regeneration. Further factors also determining the success of the renewal process are: greater breeding risk, ecological requirements of the species or habitat conditions, as well as the experience and knowledge of forestry staff.

Obtaining the right amount of renewals is an important element, but its breeding quality and value are also important. In terms of the growth parameters of pines from Nowa Dęba Forest District, differences were observed between the two regeneration methods. The average height in the Bśw, BMśw and LMśw habitats in the early years of development (renewals at 3–4 years of age) was comparable. Naturally regenerated pine trees reached a slightly higher height than artificially regenerated ones. At the age of 5–6 years, the situation changed and artificial renewals were found to have a higher average height. However, these differences were not statistically significant. This may indicate that artificially regenerated pines need more time to adapt to new growth conditions and react with a greater increase in height only in their 2–3 year after planting. The exception was the research areas in the BMw habitat. The study results of Wolski and Robakowski (2008) conducted in Bśw habitat in Pomerania confirmed the lack of differences in the height of 15-year-old trees of naturally and artificially regenerated pine.

Although the presented results indicate that in the initial stage of development, habitat conditions did not significantly affect the pine tree growth, studies by other authors testify to the possibility of such relationships. Dobrowolska (2008, 2010) showed that the average height of natural pine regeneration was significantly higher in LMśw and BMw habitats than in the BMśw habitat. On the other hand, Andrzejczyk and Drozdowski (2003) observed that as a result of the high competition of undergrowth plants, the height of pine trees in the BMśw habitat was significantly lower than in Bśw.

The high coefficient of variation in tree height, especially in moist habitats (BMw and LMśw) and of naturally regenerated crops, indicates a varied height structure. In the crops of our study, it remained at a level of about 40–50%. Such variability of the discussed feature is characteristic for naturally and artificially generated pine seedlings growing under a stand canopy and varying in age (Barzdajn et al. 1996). Trees in stands with a varied height structure are characterized by thinner branching, higher density of wood and less tapering of the stem. A similar effect can be obtained when planting trees in a densely spacing but the resulting benefits do not compensate for the expenditure incurred to obtain them. Therefore, it is desirable to shape the right structure using natural regeneration (Brzeziecki 2008). However, according to the research of Boiko (2008) and Glura and Korzeniewicz (2013), this characteristic will decrease with age. It is worth emphasizing that pine growth parameters in individual habitat variants were at a similar level, and in many cases, were higher compared to the results of other authors in other parts of Poland, which indicates favourable conditions for pine growth (Andrzejczyk, Drozdowski 2003; Paluch 2004; Aleksandrowicz-Trzcińska 2008; Pigan 2009).

The weaker growth of natural regeneration in more fertile and wetter habitats may be due to, among others, the strong competition of herbaceous plants in the undergrowth, difficulties in pine seed germination due to the relatively large layer of humus and turf, which easily over-dry, and the inability to use pine fill-in planting in subsequent years (Andrzejczyk, Drozdowski 2003; Paluch 2004; Pigan 2010). The greater amount of nutrients within reach of the roots influences the lower extent of their development, which may be conducive to greater susceptibility of the trees in the first years of life to periodic fluctuations and shortages of water (Sewerniak et al. 2012). In the early stages of the development of pine regeneration, statistically significant differences in biometric characteristics, resulting, among others, from soil preparation, disappear with age (Kocjan 2002; Andrzejczyk et al. 2003; Wolski, Robakowski 2008).

In addition to growth traits, the breeding quality of the new forest generation is also important. The characteristic of vitality was a reflection of the results associated with growth traits. In Bśw and BMśw habitats, despite the fact that artificially generated pine crops exhibited a slightly higher average vitality, it was possible to confirm the high quality of the renewals of both regeneration methods. There were definitely larger disparities between the variants in the BMw and LMśw habitats. Statistical analysis showed a significantly better vitality of pine renewals established traditionally only in the case of the BMw habitat. Research conducted in moist habitats in the Kobiór Forest District confirmed this relationship, however, the structure of the quality of the re-

newals was worse (Pigan 2009, 2010). The share of the best quality trees was definitely lower than in the renewals of Nowa Dęba, regardless of how they were regenerated. This characteristic was not correlated with habitat and age, which is confirmed by the results of Dobrowolska's study (2010).

Bearing in mind the definitely higher density of trees in natural regeneration, which could have an impact on the obtained average vitality score, the share of the best quality trees (1st vitality class) was analysed. The results showed that in natural regeneration, especially in the Bśw and BMśw habitats, there is a much larger number of trees with the best vitality than in the artificially regenerated stands, which in the future may constitute the basis for selecting trees for further breeding.

The dynamics of dothistroma (red-band) needle blight infection varied depending on the regeneration method. In subsequent years of growth, the differences between the renewal variants diminished and at the age of 6, crops established in different ways exhibited a comparable level of dothistroma infection. The exceptions were renewals in the BMw habitat, where artificially regenerated trees were characterized by a significantly higher share of infected needles. These data are consistent with previous observations, which found that damage from dothistroma needle blight in the naturally regenerated crops is not of great importance for their development (Todys, Wójcik 1999; Derek 2007). The research of Andrzejczyk et al. (2009) found that in clear cut areas, the health of naturally regenerated pine improves with age, and the occurrence of dothistroma needle blight is a natural selection factor, leading to the thinning of overly dense pine seedlings. The studied crops were established in regeneration areas after clear cuts, and it should be noted that the research of Aleksandrowicz-Trzcińska (2008) showed that the type of regeneration area significantly influences the quantity and quality of the crops. Clear cuts have a much lower incidence of pine infection than in intermediate clear cutting, or in areas under a canopy. Infection incidence also decreases with age. In favourable conditions, blight can be a serious threat to naturally regenerated pine seedlings. If the infection is extensive, the authors propose to consider chemically treating the pine seedlings. The tested fungicides effectively eliminating dothistroma pine blight did not limit the formation of mycorrhizas nor did they adversely affect the growth and development of the seedlings. The results of the research conducted in Nowa Dęba Forest District do not indicate the need for the chemical treatment of this fungal group with the dominant *Lophodermium seditiosum* Minter, Staley et Millar.

Due to the higher density of naturally regenerated pine trees, the share of damaged and defective trees was smaller, particularly in the Bśw and LMśw habitats, where disparities between the renewal variants were the largest. It can be assumed that a greater number of pines means a smaller share of damage, and therefore, more trees remain in the area

without damage, which would later develop into a stand of good quality trees. A 10–15% level of damage in coniferous forest habitats for both regeneration methods is similar to the results obtained by Glura and Korzeniewicz (2013). The greater share of damage in artificially regenerated crops in the LMśw habitat, which was 23%, was due to their location and the lack of fencing. The dominant type of damage was that caused by deer, mainly in the form of browsing. Schoolmarm trees were the most common defect. Their highest concentration occurred in the BMw habitat and in older crops. The size of damage was strongly diversified, conditioned, among others, by the location of the research area within the forest district. The level of damage is also influenced by the location of research areas on a national scale, as well as the managed hunting conducted in a given area and the forestry methods applied to protect the crops. Studies by other authors confirm the occurrence in Poland of renewals with a high proportion of deformed trees, up to 60%, as well as renewals with a low proportion of them, amounting to only 2%. However, the structure of the damage and defects is similar, with browsing damage and schoolmarm trees predominating (Szabla 1998; Hawryś et al. 2004; Paluch 2004; Dobrowolska 2008, 2010; Pigan 2009). Damage by animals significantly reduces the breeding quality of the stand and weakens its resistance to abiotic factors. The high share of shape defects, especially schoolmarm trees, can be important for the future quality of the stand, in the case of, for example, limiting or abandoning cultivation treatments. It seems that due to the high density of trees, defects disappear more quickly in natural renewals. By properly regulating the density of pines, as a part of the ongoing cultivation treatments, the level of damage from game animals can be influenced.

6. Summary and Conclusions

In searching for rational solutions in forest breeding, one should consider using natural regeneration to a greater extent, enabling the achievement of the assumed breeding goals with less expenditures for their implementation. The optimal use of the possibilities of naturally regenerating Scots pine results in increased management intensity. Even though the very benefits to the nature of using natural regeneration for pine renewals entitles forestry managers to widely apply this method, there are many factors influencing its success that need to be considered when deciding on its use.

When choosing a specific procedure, one should pay attention to the fact that the success of natural regeneration depends to a much greater extent than in the case of artificial renewals on the weather conditions prevailing in the year of sowing and on a good seed yield – a factor that is lacking in artificial renewals. The next factors contributing to the suc-

cess of the renewals are greater breeding risk, the ecological requirements of the species, as well as habitat conditions.

Research indicates the possibility of effective pine regeneration in the Bśw, BMśw, BMw and LMśw habitats under conditions similar to those occurring in Nowa Dęba Forest District. The obtained research results allow us to formulate the following conclusions:

1) The regeneration method significantly influences pine growth parameters in the moist mixed coniferous forest (BMw) habitat. Trees growing in artificially regenerated crops show statistically significant, more favourable growth (root collar thickness) and qualitative characteristics compared to natural renewals.

2) Naturally regenerated pine is characterized by lower overall vitality, but at the same time, it provides a greater number of trees in the best vitality class (1st vitality class), which can be a valuable selection base of trees for further breeding. The high level of vitality of the renewals is independent of habitat conditions.

3) Nowa Dęba Forest District has favourable conditions for effective Scots pine renewal using its natural regeneration. In the time perspective of the study, cultivation treatments take longer and are more intense with naturally regenerated crops, although the date of the first treatment is often delayed. The intensity of cultivation treatments increases as the fertility of the habitat increases.

4) Pine crops established with the use of traditional planting material were characterized by decidedly better height growth than their corresponding naturally regenerated pines. This was confirmed by the analysis of the distribution of the trees' height and the analysis of variance, which indicated statistically significant differences in height.

5) The potential threat posed by dothistroma needle blight was small in the case of the studied renewals. Fungal pathogens were not observed to have posed a threat to pine growth and development.

Conflicts of interest

The authors declare the lack of potential conflicts of interest.

Acknowledgements and source of funding

References

Aleksandrowicz-Trzcińska M. 2008. Wzrost naturalnych odnowień sosny zwyczajnej i stan ich mikoryz po chemicznej ochronie przed osutką. *Leśne Prace Badawcze* 69(1): 7–14.

Andrzejczyk T. 2000. Wpływ odległości od ściany drzewostanu na zagęszczenie i przeżywalność nalotów sosny zwyczajnej (*Pinus sylvestris* L.) na zrębach zupełnych i gniazdach. *Sylwan* 144(1): 27–42.

Andrzejczyk T., Aleksandrowicz-Trzcińska M., Żybura H. 2009. Wpływ cięć rębnych na zagęszczenie, wzrost i stan zdrowotny odnowień naturalnych sosny w warunkach Nadleśnictwa Tuszyma. *Leśne Prace Badawcze* 70(1): 5–17.

Andrzejczyk T., Augustyniak G. 2007. Wpływ przygotowania gleby na wzrost sosny zwyczajnej w pierwszych latach uprawy. *Sylwan* 151(8): 3–8. DOI 10.26202/sylwan.2006103.

Andrzejczyk T., Drozdowski S. 2003. Rozwój naturalnego odnowienia sosny zwyczajnej na powierzchni przygotowanej pługiem dwuodkładnicowym. *Sylwan* 147(5): 28–35. DOI 10.26202/sylwan.2003952.

Barzdajn W. 2006. Wpływ technologii produkcji i pory sadzenia jednolatek sosnowych (*Pinus sylvestris* L.) na udatność i początkowy wzrost uprawy. *Sylwan* 150(8): 38–51. DOI 10.26202/sylwan.2005153.

Barzdajn W., Drogoszewski B., Zientarski J. 1996. Naturalne odnawianie drzewostanów sosny zwyczajnej. *Postępy Techniki w Leśnictwie* 60: 15–21.

Białobok S., Boratyński A., Bugała W. 1993. Biologia sosny zwyczajnej. Instytut Dendrologii PAN, Kórnik, 624 s.

Boiko S. 2008. Odnowienie naturalne sosny zwyczajnej jako element strategii ekosystemowego zagospodarowania lasu. Instytut Badawczy Leśnictwa, Sękocin Stary, 73 s.

Brzeziecki B. 2008. Podejście ekosystemowe i półnaturalna hodowla lasu (w kontekście zasady wielofunkcyjności lasu). *Studia i Materiały Centrum Edukacji Przyrodniczo-Leśnej* 3(19): 41–54.

Buraczyk W., Szeligowski H. 2008. Wpływ wilgotności i gatunku gleby na wzrost sadzonek sosny zwyczajnej z zakrytym systemem korzeniowym. *Leśne Prace Badawcze* 69(4): 291–297.

Buraczyk W., Szeligowski H., Aleksandrowicz-Trzcińska M., Drozdowski S., Jakubowski P. 2012. Wzrost mikoryzowanych i niemikoryzowanych sadzonek sosny zwyczajnej (*Pinus sylvestris* L.) w warunkach zróżnicowanej wilgotności i żyzności podłoża. *Sylwan* 156(2): 100–111. DOI 10.26202/sylwan.2011047.

Derek J. 2007. Naturalnie czy sztucznie? *Trybuna Leśnika* 2: 8–9.

Dobrowolska D. 2007. Odnowienie naturalne lasu w drzewostanach uszkodzonych przez wiatr na terenie północno-wschodniej Polski. *Leśne Prace Badawcze* 68(2): 45–60.

Dobrowolska D. 2008. Odnowienie naturalne na powierzchniach uszkodzonych przez pożar w Nadleśnictwie Rudy Raciborskie. *Leśne Prace Badawcze* 69(3): 255–264.

Dobrowolska D. 2010. Warunki powstawania odnowień naturalnych sosny zwyczajnej (*Pinus sylvestris* L.) na terenie Nadleśnictwa Tuszyma. *Leśne Prace Badawcze* 71(3): 217–224. DOI 10.2478/v10111-010-0017-y.

Glura J., Korzeniewicz R. 2013. Hodowlana i ekonomiczna ocena zakładania upraw sosnowych z wykorzystaniem sadzonek z zakrytym i odkrytym systemem korzeniowym. *Sylwan* 157(3): 177–186. DOI 10.26202/sylwan.2011024.

Gmyz R., Skrzyszewski J. 2010. Wpływ zróżnicowania mikrosiedliskowego boru świeżego na liczebność odnowienia natural-

nego sosny zwyczajnej (*Pinus Sylvestris* L.). *Sylwan* 154(3): 173–181. DOI 10.26202/sylwan.2009031.

Hawryś Z., Zwoliński J., Kwapis Z., Małecka M. 2004. Rozwój sosny zwyczajnej na terenie pożarzysk leśnych z 1992 roku w Nadleśnictwie Rudy Raciborskie i Potrzebowice. *Leśne Prace Badawcze* 2: 7–20.

Ilmurzyński E., Mierzejewski W. 1956. Badanie wartości hodowlanej istniejących samosiewów sosny pospolitej. *Sylwan* 100(3): 75–84.

Jastrzębski S. 1975. Aspekty ekonomiczne odnowień naturalnych w Puszczy Solskiej. *Sylwan* 119(4): 67–72.

Kocjan H. 2002. Wzrost sosny zwyczajnej (*Pinus sylvestris* L.) w 25-letnim drzewostanie na powierzchni z różnym przygotowaniem gleby. *Acta Silvarum Colendarum Ratio et Industria Lignaria* 1: 59–65.

Kopeć K. 2011. Ocena metod pielęgnowania naturalnie odnowionych młodych drzewostanów sosnowych. Praca doktorska. Szkoła Główna Gospodarstwa Wiejskiego w Warszawie; Wydział Leśny, 120 s.

Kowalczyk J., Matras J., Żybura H., Sabor J., Barzdajn W. 2000. Zmienność sosny pospolitej i hodowlana wartość jej proweniencji. Instytut Badawczy Leśnictwa, Warszawa, 164 s.

Mierzejewski W. 1975. Badania nad uzyskaniem i wykorzystaniem odnowień naturalnych sosny i dębu. Dokumentacja naukowa. Instytut Badawczy Leśnictwa, Warszawa, 141 s.

Okoń S. 2016. Wpływ sposobu odnowienia na wzrost i jakość hodowlaną upraw sosny zwyczajnej (*Pinus sylvestris* L.) na przykładzie wybranych obiektów Regionalnej Dyrekcji Lasów Państwowych w Radomiu. Praca doktorska. Szkoła Główna Gospodarstwa Wiejskiego w Warszawie. Wydział Leśny, 120 s.

Paluch R. 2004. Stan, warunki i problemy odnowienia naturalnego sosny w Puszczy Białowieskiej. *Sylwan* 148(11): 9–21. DOI 10.26202/sylwan.2004048.

Pigan I. 2009. Wpływ sposobu przygotowania gleby na stan upraw sosnowych w warunkach siedlisk wilgotnych. *Sylwan* 153(11): 745–757. DOI 10.26202/sylwan.2009038.

Pigan I. 2010. Odnowienie naturalne sosny (*Pinus sylvestris* L.) na siedliskach wilgotnych przy zastosowaniu różnych metod przygotowania gleby. *Sylwan* 154(8): 524–534. DOI 10.26202/sylwan.2009213.

Rudnicki J.W. 1954. Wpływ przygotowania gleby na udatność upraw oraz wzrost młodników. *Sylwan* 98(4): 309–316.

Sewerniak P., Gonet S. S., Quaium M. 2012. Wpływ przygotowania gleby frezem leśnym na wzrost sadzonek sosny zwyczajnej w warunkach ubogich siedlisk Puszczy Bydgoskiej. *Sylwan* 156(11): 871–880. DOI 10.26202/sylwan.2011115.

StatSoft, Inc., 2011. Statistica (data analysis software system), version 10. www. statsoft.com

Szabla K. 1998. Odnowienie lasu i ochrona upraw powstałych na wielkim pożarzysku w Nadleśnictwie Rudy Raciborskie. *Postępy Techniki w Leśnictwie* 67: 41–48.

Todys J., Wójcik R. 1999. Odnowienie naturalne sosny. *Las Polski* 5: 16–17.

Wolski P., Robakowski P. 2008: Przydatność hodowlana naturalnego odnowienia sony zwyczajnej w Nadleśnictwie Bytów. *Sylwan* 152(10): 17–26. DOI 10.26202/sylwan.2008008.

Zachara T., Ambroży S., Bieniek J., Boczoń A., Dobrowolska D., Gil W., Kaliszewski A., Kopryk W., Michalska A., Mionskowski M., Nowakowska J., Olszowska G., Paluch R., Zajączkowski G. 2011. Odnowienie naturalne najważniejszych gatunków lasotwórczych w Polsce jako element strategii trwałego i zrównoważonego zagospodarowania lasu. Instytut Badawczy Leśnictwa, Sękocin Stary, 128 s.

Zasady Hodowli Lasu 2012. Centrum Informacyjne Lasów Państwowych, Warszawa, 72 s.

Authors' contribution

J.D. – literature review, concept, methodology, data acquisition, data preparation and analysis, discussion; S.Z. – methodology, preparation of the paper; E.W.-F. – preparation of the paper, proofreading.