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Comparative analysis of natural and artificial regeneration in Nowa Dęba Forest District

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Abstract

New challenges related to the multifunctional role of forests in consideration of both natural environment and economy come into view sequentially. In current forestry practice, an important element is not only the quality of forest cultivations (silvicultural aspect) but also the costs incurred for their production and tending (economic aspect).

The main purpose of this article is to show the prospect of increasing positive silvicultural effects depending on the method used in management of Scots pine stands under given site conditions. The comparative analysis was carried out using the study results obtained in the Forest District Nowa Dęba and those presented in other relevant studies. In the present study, we examined whether the site conditions have significant effects on silvicultural and economic effectiveness of regeneration and development of Scots pine stands or those predominated by Scots pine in the initial stages of stand growth. Significance of the regeneration method effects on growth characteristics of Scots pine regeneration as well as the costs of forest cultivation management was analysed.

The study on silvicultural and economic effectiveness was carried out in the Forest District Nowa Dęba. The results obtained showed that using Scots pine natural regeneration under the conditions of fresh coniferous forest site and fresh mixed coniferous forest site was the way of management based on reason. This was supported by both the values of regeneration growth parameters and silvicultural quality along with clearly lower expenditures incurred to achieve these effects. In wet mixed coniferous site, Scots pine seedlings regenerated naturally; however, the results indicated their lower silvicultural quality and growth parameter values when compared to those artificially regenerated. In fresh mixed broadleaved forest site, equally for silvicultural and economic reasons, the more optimal option was to regenerate forest using traditional planting material as natural Scots pine regeneration showed lower silvicultural effects. The unit costs of regeneration and maintenance of stands with self-sown Scots pine in fresh mixed broadleaved forest site were higher when compared with other examined forest sites.

On the basis of the results of the present study, it can be concluded that regardless of the regeneration method examined, the most differentiating factor of the final economic effect of Scots pine stand establishment and maintenance was the cost of regeneration operation. The expenditure for this purpose consumed the largest part of expenses

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incurred in artificial regeneration variant. The higher cost of corrections in artificially planted forest cultivations in poorer forest sites was one of the reasons behind the profitable final balance of naturally regenerating Scots pine stands. Differences between other costs analysed were not significant.

The results of the present study may contribute to comprehensive assessments of natural and artificial ways of forest regeneration and indicate forest production costs that are the most closely related to site conditions.

Key words

Scots pine, natural regeneration, artificial regeneration, costs, effectiveness assessment

Introduction

There are very few literature-evidenced studies related to comparative analysis of the silvicultural and economic effectiveness of different ways of pine stands regeneration carried out on the same research object. In Poland, there are favourable conditions or can be properly formed sites for pine regeneration, also with the use of natural sowing methods (Andrzejczyk 2000; Andrzejczyk and Drozdowski 2003; Barzdajn et al. 1996; Białobok et al. 1993; Mierzejewski 1966; Głaz and Zajączkowski 2002; Jaworski 1995, 2011; Dobrowolska 2007, 2010; Pigan 2009, 2010). 'Pine as a native species, adapted to our climate, soil and biocenotic conditions should have the ability to exchange generations' as it was noted by Polish scientists (Barzdajn et al. 1996). The effectiveness of the regeneration process is the resultant of many variables, including possible anthropopressure formation, such as the use of appropriate regeneration felling, soil preparation or the selection of proper breeding treatments. Their implementation in natural regeneration is connected with incurring specific financial outlays. The use of natural pine regeneration will not be a rational solution in some conditions.

In current forestry practice, an important element is not only the quality of the second-growth forest, the breeding aspect, but also the costs incurred for their establishment and care, the economic aspect. An attempt to evaluate the effectiveness of pine tree management or with the predominance of pine using natural and artificial renewal, which was undertaken in this study, may be helpful in conducting more rational forest management. The obtained conclusions may constitute an important element supporting decision-making process in the field of forest breeding.

The main objective of the research is to indicate the possibility of increasing positive breeding and economic effects depending on the use for managing pine stand measures in the given forest site conditions. The comparative analysis was carried based on the results of experiments carried out in Nowa Dęba Forest District (Długosiewicz et al. 2019 a, b) and other studies concerning these problems.

During the studies, it was verified whether the site conditions have a significant impact on the economic and breeding efficiency of renewal and management of pine cultivations and those with the predominant share of pine in the initial stages of their growth.

Methods

In the first stage, a specific database was selected from the State Forests Information System (SILP), which determined the assumed selection criteria. The selection criteria were defined as the proportion of pine in the species composition equal to or greater than 50%; the materials used for artificial regeneration were 1-year-old Scots pine seedlings with the symbol 1/0; regeneration was carried out as a part of complete clearcutting (IB, IC) and shelterwood cutting (III AU, III BU); natural regeneration of Scots pine renewals recognised in the year of sowing, that is, in the year of recognition, the seedlings were 1-year old.

Four age groups of renewals were included in the study, which ranged from 3 to 6 years in 2010 (i.e. the 2005–2008 for areas with naturally regenerated Scots pine and the 2006–2009 for artificially planted seedlings). The idea was to limit the impact of weather conditions in a given year (e.g. weather anomalies)

on the costs incurred for care treatments of renewals. For further analysis, the selected management activities performed as part of the forest-breeding plan for 2003–2014 were taken into account. Particularly, data on soil preparation, forest restoration, soil care treatment, and early thinning, as well as corrections and re-planting activities were extracted. As a result of the determination, 157 plantations were selected with prevailing or co-dominating Scots pine with a total area of 332.31 ha.

In the second stage of the research, as part of fieldwork carried out in autumn 2010, the studies enabling the assessment of the breeding quality of the analysed renewals of Scots pine were carried out. In selected experimental plots, the circular-trial areas were determined, each of them, with an area of 10 m^2, were placed regularly in a grid of rectangles or squares with borders adjusted to the size of a given assumed research area. The number of sample plots was fitted to be the sum of their surface constituted about 1% of the area covered by Scots pine on a given research area. The number of circular-trials ranged from 6 up to 32 pieces per experimental area. In total, the investigations were carried out on more than 1,300 circular-trials, on which more than 19,600 individuals of Scots pine were measured and classified.

On each circular-trial, the assessment and measurement were carried out, including coverage percentage, visual estimation; number (pcs/area); height (cm); and the growth of the main stem during the last year (cm).

As part of the third stage, office works were carried out, involving the compilation and analysis of collected data using the Statistica software and the Microsoft Office software (Excel, Access, Word). Assumptions about homogeneity of variance were checked. To separate homogeneous groups, the Tukey test was used at significance level $\alpha = 0.05$. In the absence of normal distribution of variables or failure to meet the assumptions of homogeneity of variance, the non-parametric Kruskal–Wallis test using post-hoc multiple comparison tests was used. The economic analysis consisted of comparing costs incurred for setting up and cultivation of areas with artificially regenerated Scots pine trees with the costs of analogous activities for experimental plots with seedlings from self-seeding. The characteristics of the range of performed tasks and their costs were carried out for the period from 2003 to 2014, in order to obtain the history of all experimental plots from the moment when the trial was established until the seedling grew up to the age of 7 years. The comparative studies were carried out for four habitat types of forest: fresh coniferous forest, fresh mixed coniferous forest, moist mixed coniferous forest and fresh mixed broadleaved forest.

In the studies, the cash flow method was used – stream of costs incurred for the management of renewed areas. The estimation of an updated present value (PV) consisted of discounting future values and prolonging the amount of past cash flows to a predicted age (Klocek et al. 2012; Glura et al. 2016).

Results and discussion

The breeding efficiency of natural and artificial Scots pine regeneration

In the area of the Nowa Dęba Forest District, the occurrence of the Scots pine regeneration was confirmed on seven habitat types of forest – from fresh coniferous forest and bog mixed coniferous forest to moist mixed broadleaved forest and alder-ash forest. The contribution of pine regeneration with natural seeding utilisation was maintained at the very high level, and in 2005–2009, it was estimated at an average of 70% of the total area renewed by this species. By far, the largest share of the analysed natural regenerations (three to four times larger area than of artificial regeneration) was recorded in the coniferous forest sites: fresh coniferous forest and fresh mixed coniferous forest. These habitats are the most favourable for the establishment of Scots pine renewal (Białobok et al. 1993; Dobrowolska 2008, 2010; Jaworski 1995, 2011; Paluch 2004). When compared, in the years 1997–2001 in Konstantynowo and Antonin Forest Districts (Regional Directorate of Forest State Poznań), Kłobuck (Regional Directorate of Forest State Katowice) or Nowa Sól (Regional Directorate of Forest State Zielona Góra), natural renewals were estimated at 3–11% of all renewals (Szramka 2001, 2005). In the years 1990–2004 in the Tuszyma Forest District (Regional Directorate of Forest State Krosno), the share of natural pine regeneration was accounted as 35–70% of the total pine renewal area, where the forest management using its natural regeneration is implemented as part of an ecosystem approach (Rykowski 2008). The

conducted studies allowed to indicate both the similarities and differences occurring in the regeneration of pine depending on the method of used management.

In the Nowa Dęba Forest District, the average density of pines in self-sowing regeneration (14,000 up to 46,800 individuals per hectare) definitely exceeded the number of pines from artificial regeneration. Except for the fresh mixed broadleaved forest site, the difference was statistically significant. It was also observed that in some cases, the density of pine trees in artificial regeneration was higher than what is expected from the number of planted seedlings (as a rule, 10,000 seedlings per hectare were planted). It was indicated that there have been favourable conditions for the germination and growth of pine seeds, which could have been sown naturally among the planted seedlings and survived until the measurement.

The highest density of pine seedling was occurred in the habitats of fresh coniferous forest and fresh mixed coniferous forest, which confirmed the existence of favourable conditions for the natural regeneration of the forest. The density of seedlings that was abundant, comparable to the obtained results on these habitats, was also reported by other authors. In the Białowieża Primeval Forest, the studies conducted by Paluch (2004) showed the occurrence of 4–5 years old pines at the density level of 18,000–30,000 of plants/ha in the fresh coniferous forest habitat and 26,000–35,000 pcs/ha on fresh mixed coniferous forest one. The measurements carried out in Nowa Dęba Forest District indicated that on the other two habitats, that is, moist mixed coniferous forest and fresh mixed broadleaved forest, a satisfactory coverage of the area by a new generation of trees could be obtained. In forest practice, the wetland habitats recognised as difficult for regeneration were characterised by lower tree density; however, the obtained number of seedlings exceeded the number of individuals, recommended by Polish breeding forestry regulations for artificial regeneration (Zasady Hodowli Lasu 2012). In wetlands, the lower number of individuals may be affected by the limited possibility of using only one annual seed, because of the strong pressure of plants of forest undergrowth (Pigan 2010). However, in the area of the Tuszyma and Rudy Raciborskie Forest Districts, for similar age of plants, a higher density of self-sown pine trees was recorded in the fresh mixed broadleaved forest and moist mixed coniferous forest habitats than in the fresh mixed coniferous forest (Dobrowolska 2008, 2010). Under certain habitat conditions, it is possible to obtain the appropriate number of new progeny of trees. It was confirmed in studies carried out in the Nowa Dęba Forest District, as well as in other parts of the country. These are not accidental situations, resulting, for example, from extremely favourable natural or weather conditions in a given year, but these are systematic and repetitive actions. Also experiments of German foresters indicate the possibility of an effective natural regeneration of Scots pine, amongst others, in Pfälzerwald (Dong et al. 2003).

Obtaining proper amount of plants of natural regeneration is an important element of management, but the quality and breeding value of them are also important. In Nowa Dęba Forest District, the differences between two methods of silviculture management were observed in terms of growth parameters of pines. In the habitats of fresh coniferous forest, fresh mixed coniferous forest and fresh mixed broadleaved forest, the average height of plants of natural regeneration was comparable in the initial years (at the age of 3–4 years). The Scots pine seedlings of natural forest regeneration reached a slightly higher height than pines on artificial cultivations. The situation changed at the age of 5–6 years old plants when artificial regeneration showed a higher average height. However, the differences were not statistically significant. It could indicate that the artificial regeneration of pines required more time to adapt to the new growth conditions and could react with a greater height growth subsequently 2–3 years after planting. The opposite results were observed on experimental plots of the moist mixed coniferous forest habitats. Traditional planting pine material cultivations were characterised markedly better in height compared with the corresponding self-seeding ones used. This statement was confirmed by the analysis of tree height distribution as well as analysis of variance (ANOVA), which showed statistically significant differences in height. Lack of differences in height of 15-year-old trees in natural and artificial pine regeneration was confirmed by the results of Wolski and Robakowski (2008) studies conducted in Pomerania on the fresh coniferous forest habitat.

Despite the fact that the presented results indicated that in the initial stage of regeneration, the site conditions did not significantly affected the growth of Scots pines; however, studies of other authors have indicated

the possibility of such correlations. Dobrowolska (2008, 2010) showed that the average height of natural pine regeneration was significantly higher in the fresh mixed broadleaved forest and moist mixed coniferous forest habitat than in the fresh mixed coniferous forest habitat. On the other hand, Andrzejczyk and Drozdowski (2003) observed that the height of pines in the fresh mixed coniferous forest site was significantly lower than that at fresh coniferous forest as a result of high competition of undergrowth plants.

The high value of coefficient of variation was observed in the height of trees, especially in moist habitats, moist mixed coniferous forest and fresh mixed broadleaved forest, as well as in cultivations with natural regeneration, which indicated a varied structure of height. In the investigated cultivations, it was estimated at a level of around 40–50%. Such variability of described feature is characteristic of self-sown trees and undergrowth of Scots pine growing under the canopy of trees, which consist of seedling in different age (Barzdajn et al. 1996). Trees in forest stands with different height structure are characterised by a thinner branching, a higher density of wood and lower degree of tree taper. In the case of the use of higher planting spacing, a similar effect can be obtained but any result in benefits that do not compensate expenditures incurred to use more seedlings of trees. Therefore, shaping of the proper forest stand structure with the use of natural regeneration is desirable (Brzeziecki 2008). However, this growth feature will decrease with age as it would be shown according to Boiko (2008) and Glura and Korzeniewicz (2013). It is worth noting that the growth parameters of Scots pines in individual habitat variants were at a similar level. Even in many cases, they were higher compared to the results of studies obtained by different authors in other parts of Poland, which indicates favourable conditions for growth of the species in the Nowa Dęba Forest District (Aleksandrowicz-Trzcińska 2008; Pigan 2009; Andrzejczyk and Drozdowski 2003; Paluch 2004).

Lower growth of natural regeneration in more fertile and humid habitats may be caused by, amongst others, strong competition of herbaceous plants of the undergrowth, difficulties with germination of Scots pine seeds because of a relatively thick layer of raw soil humus and turf, which can be easily succumb to overdrying and the lack of sowing pine seeds in the following years (Andrzejczyk and Drozdowski 2003; Paluch 2004; Pigan 2010). More abundant nutrient resources within the range of the roots can affect a lower rate of their growth, which can be a reason of a greater sensitivity of trees to periodic fluctuations and water shortages in the first years of life (Sewerniak et al. 2012). In the initial stages of growth of Scots pine renewal, the impact of methods of soil preparation to statistically significant differences onto biometric features are lower with age (Andrzejczyk et al. 2003; Kocjan 2002; Wolski and Robakowski 2008).

The influence of habitat conditions on the economic efficiency of renewals

In accordance to the assumptions of intensive management, better utilisation of habitat conditions implicates an increase in efficiency and, hence, a reduction of costs of production and a more favourable final result (Andrzejczyk 1980; Leibundgut 1973; Szramka 2000; Szramka and Sobolak 2005). Looking for methods of limiting of costs related to establishing and managing of cultivations possesses great importance for the final balance (Bernadzki 2005; Glura and Korzeniewicz 2013). Previously, Leibundgut (1973) has drew attention to the conscious and thoughtful implementation of silviculture activities as inputs necessary to achieve a specific breeding goal. As it was noted by Arbatowski and Rybczyński (1989), the effectiveness of accounting enables the selection of the most optimal and rational variant, which is based on efficiency indicators. Amongst others, the improvement in operational efficiency can be achieved because of cost rationalisation (Kocel 1998, 2000; Glura et al. 2012; Piekutin and Parzych 2007). The investigations carried out in Nowa Dęba Forest District indicate that the habitat conditions and the method of forest regeneration are important factors affecting the level and structure of costs. The results were also confirmed by Andrzejczyk (1980), who showed that the costs of tree stands production depend on habitat conditions. According to this author, the share of costs in the field of silviculture in the structure of wood production costs is significant and ranges from 53% in the fresh coniferous forest habitat up to 61% in the fresh mixed coniferous forest habitat. The vast majority of expenditures incurred on forest breeding (about 70%) are spent in the initial stage of forest stand growth (up to the young trees stage). Tending stand treatments car-

ried out in the early stages of tree stand growth and the amount of expenditure incurred for their implementation may affect the quality of the stand in later growth periods (Glura and Moliński 2003). Expenditure incurred on silviculture management is component cost analysis of the core activity. According to Pachnowska (2001), just after timber harvesting (50%), these expenditures are the main constituted share in the costs of core activity (27%) and occupy an important position in the total balance. Because in the case of forest holdings, minimising the costs incurred is the main source of the improvement of the financial result, this factor can be considered an important measure of economic efficiency characterising the individual economic units (Kocel 2000, 2004a, 2004b).

On the basis of the results of the research from Nowa Dęba, it can be concluded that costs are lower in the variant when the natural regeneration of the forest was conducted for the management in the initial years of the growth of pine stands or with the predominance of pine in the tree stands. Natural and artificial regenerations differ diametrically in terms of the structure of costs incurred, which affects the final economic effect.

The average costs of soil preparation for cultivation with natural pine regeneration were estimated up to 996 PLN/ha and were 9% lower than the corresponding costs for artificial regeneration. This difference resulted from the application of different methods of soil preparation. More difficult surfaces for preparation to be regenerated, because of the humidity conditions, whether the soil cover and herbaceous vegetation, were more often qualified for artificial regeneration, which was combined with the use of a more expensive method of soil preparation using a rotary hoe-tiller. It was the reason why on habitats of moist mixed coniferous forest and fresh mixed broadleaved forest, there were 11% and 25% higher unit costs for preparing the soil. However, on poor habitats, fresh coniferous forest and fresh mixed coniferous forest, the combined method was more often used in natural regeneration, which resulted in higher costs per unit, from 2% to 10% comparing to regeneration using traditional seedlings.

The group of expenditures having the greatest impact on the final balance was costs related to forest regeneration. The regeneration of 1 ha of forest area was, on an average, lower by 1,548 PLN on areas where the natural possibilities of renewal of the Scots pine were used. For the coniferous habitats, the compared values were 4 times lower, that is, an average of 1,390 PLN/ha. On the habitat of fresh mixed broadleaved forest, the difference was even bigger – 6-fold and amounted to PLN 1,920/ha.

Partially, it was caused because of the greater proportion of Scots pine in the composition of self-seeding regeneration than in artificial renewal, 75% and 69%, respectively, and thus a smaller share of other additive species, which were artificially introduced, then it generated lower costs. Expenditures incurred on the renewal of 1 ha of forest in crops using self-sown Scots pine varied from 399 to 782 PLN/ha, whilst those in renewal with seedling regenerated artificially were calculated from 1,800 to 2,277 PLN /ha. The unit cost of renewals was increasing in relation to the fertility of the habitat as a result of the declining share of Scots pine in renewals and the increasing share of other admixture species, mainly multi-year-old seedlings.

The intensity of the replanting treatments was greater on areas with natural regeneration, where, on an average, 14.6% of the area of renewal was reintroduced by forest-forming species, whereas in artificial renewal, this treatment was carried out, on an average, by 13.3% of the area, that is, in regeneration with an renewal of Scots pines, the replanting treatments were made more often. In the period under consideration in the case of fresh coniferous forest and fresh mixed coniferous forest, the costs of additional replanting in artificial regeneration treatments were higher than in natural ones: 2.5-fold (271 PLN/ha) and 3-fold (682 PLN/ha) of renewal area, respectively. In the fresh mixed broadleaved forest habitat, the costs of replanting treatments in Scots pine in artificial regeneration were 7-fold lower, on an average, by 1,554 PLN/ha, which could influence the final value of the economic calculation of cultivation and establishment of renewal area in this habitat.

The other activities important for the cultivation of regenerated area related to forest management showed different pattern of contingency to the method of renewal. The first treatment in Scots pine in artificially regenerated areas was carried out in the year of renewal or in the following year, whilst in naturally regenerated ones, it was performed much more later, especially in poor habitats. Natural renewals required constant maintenance of about 50% of the regenerated area, during annual care for 5 years from the establishment of the re-

newal. In both variants of forest regeneration, the most labour intensive to regenerate turned out to be renewal area of the fresh mixed broadleaved forest habitat. The difference consisted in the intensity of the performed silvicultural treatments. Whilst during the period under consideration, in the renewals with naturally regenerated Scots pine, each hectare of renewal area was subjected to an average of 5-fold soil cultivation and early thinning; this ratio was 3.92 in artificial regeneration. In both cases, the least-intensive silvicultural treatments were carried out on research plots in the fresh coniferous forest habitat, where no significant differences were observed for this indicator (1.46 for artificial regeneration and 1.75 for natural one). The intensity of treatments increased with the improvement of fertility of the habitat, which affected the amount of expenditure incurred for their implementation. In the fresh coniferous forest habitat, this group of costs was calculated from 23% to 29% of the analogical costs spent in renewals at fresh mixed broadleaved forest habitat. In general terms, the analysed expenditures were higher, on an average, by 172 PLN/ha in naturally regenerated plots with Scots pine. On each analysed habitat, the self-sown pine plots required greater expenditure on care treatments. These values were higher from 5% on moist mixed coniferous forest, 15–19% on fresh coniferous forest habitat and fresh mixed coniferous forest up to 40% on the fresh mixed broadleaved forest habitat, where the difference of costs were estimated at the level of 870 PLN/ha of renewal area.

The opposite results were obtained by Kaliszewski (2006, 2017), who showed a larger size of re-planting as well as care treatments in artificial regeneration. However, as it was noted by the author, because of the small number of samples of natural regenerations taken into account for analysis and the incompleteness of the analysed data, the results concerning the intensity of these treatments in naturally regenerated plots were underestimated. Moreover, in both variants of regeneration measures, the highest intensity of care treatments was observed in the fresh mixed coniferous forest and moist mixed coniferous forest, and the lowest one was observed in the fresh mixed broadleaved forest habitat. Despite the fact that they did not take into account the influence of time on management costs, the indicated amount of volume of work on the coniferous habitat was higher than in the studied regenerated plots.

The total, real expenditure incurred on the renewal and care of research areas was higher in the variant using traditional seedlings with an open root system, on an average, by 1,443 PLN/ha of renewal. In the analysed period, that is, from the moment when the renewal was established (the year of regeneration/approval of establishing of regeneration plot) up to the moment where the Scots pine on each plot reached 7 years. This indicates that the costs of setting up and management of forest renewal with naturally regenerated pine are lower by, on an average, 29% than the corresponding costs for artificially established regeneration. In the Tuszyma Forest District, the difference was estimated at 59%. Owing to the underestimation of care treatments and re-planting costs in the simulation of cost increase consisting in doubling the intensity of these treatments in natural regeneration as a real variant applied by Kaliszewski (2006, 2017) showed that in the final balance, total costs increased and accounted for 70% of the sum of expenses incurred in artificial regeneration, which is corresponding to the results showed by Długosiewicz et al. (2019 a, b). Glura and Korzeniewicz (2013) showed that in the 5-year period, the total costs of cultivation treatments of Scots pine renewal in the fresh mixed coniferous forest site if established using traditional planting material are estimated at the 3,330 PLN/ha. However, the analysis based on the theoretical model of a set of treatments (not on their actual execution) and did not take into account the costs of replanting treatments. This is a much lower cost than the value obtained in the presented evaluation. Also in other regions outside Poland, the more favourable economic effect of using natural regeneration is emphasized. The elaborations published by the Federal Forest Office in Austria show that the savings on this account can be counted up to 1,700 EUR/ha during the several years of cultivation of regenerated areas (www.bfw.ac.at).

Glura and Moliński (2003) reported that the average cost of establishment and management of renewal increases with fertility habitat. They showed that when taking into account the discounting procedure according to the inflation rate, the total unit costs over a 7-year period is the lowest one in the fresh coniferous forest habitat. In the fresh mixed coniferous forest habitat, these expenditures are higher by about 30%, and on the fresh mixed broadleaved forest habitat, these are higher by 60%. In the presented studied tree stands,

similar results were obtained. In the case of naturally regenerated plots, the lowest expenditures were recorded at fresh coniferous forest habitat – 2,249 PLN/ha. For other habitats, the unit costs were higher, at fresh mixed coniferous forest by 49%, at moist mixed coniferous forest by 64%, and at fresh mixed broadleaved forest habitat by 173%. In artificially regenerated plots, the lowest costs were also recorded in the fresh coniferous forest habitat – PLN 3,740/ha -– but in other habitats, the increase in costs was much smaller and ranged from 37% for fresh mixed coniferous forest to 57% for fresh mixed broadleaved forest habitat. Further observations carried out by Glura et al. (2016) confirmed the dependence of variability of financial outlays on the forest site type, but these differences were statistically insignificant. Andrzejczyk (1980) evidenced that the costs of forest breeding are of decisive importance in the cost of pine stands management production and also it was confirmed that they depend on habitat conditions, that is, in the fresh mixed coniferous forest site, they are higher by about 39% than on fresh coniferous forest habitat.

Taking into account only the economic aspect, the most effective variant was the use of natural regeneration treatment of Scots pine in the fresh coniferous forest habitat. The total costs of natural regeneration, which amounted to 2,249 PLN/ha, were accounted for 60% of the total cost of the variant using the artificial method of pine renewal. In the fresh mixed coniferous forest habitat, this value was 65% (3,360 PLN/ha), and for moist mixed coniferous forest, it was 71% (PLN 3,703/ha) of analogical costs. Only in the case of regeneration treatments in the fresh mixed broadleaved forest habitat, the total costs of management of renewal plots using natural regeneration of Scots pine were higher, on an average, by 262 PLN/ha than in artificial renewals and were amounted to 6,158 PLN/ha. Scots pine saplings in this habitat have required much larger replanting efforts and the use of more frequent and more intensive care treatments.

The influence of the renewal measure on economic and breeding efficiency

The results of the investigations have shown that the decisions regarding the selection of the methods of forest regeneration have their stronger economic consequences than the breeding ones and were dependent on the size and frequency of care management and re-planting treatments made in a later period.

In the investigations carried out in Nowa Dęba Forest District regarding the breeding and economic efficiency of the management method, it was shown that it was rational to use the natural regeneration possibilities of Scots pine in the fresh coniferous forest and fresh mixed coniferous forest habitats. This is supported by both the obtained growth parameters and the breeding quality of renewals as well as clearly lower expenditures incurred to obtain these effects. In addition, as it was implicated according to studies by Wolski and Robakowski (2008), Scots pine trees, when natural regeneration methods were applied, were characterised by a more favourable slenderness ratio and greater adaptability to changing habitat conditions and resistance to stress factors, which could increase their stability. It explains the advantages of using this method of renewing of Scots pine. On the area of Nowa Dęba Forest District of fresh coniferous forest and fresh mixed coniferous forest sites, natural regeneration of the species can be introduced on a large scale and show very favourable growth characteristics and breeding quality. In addition, they are also a cheaper way to renew the forest compared to the artificial regeneration methods commonly used in Poland. The effect of production can be achieved with lower expenditures, making optimum use of factors of production.

In the moist mixed coniferous forest site, it is possible to create and develop Scots pine natural regeneration; however, the results obtained indicate their weaker breeding quality and growth parameters in relation to similar artificial regeneration methods that can be applicable. The lower total costs of management of undergrowth with natural regeneration, on an average by 1,486 PLN/ha, to some extent, compensate significantly weaker breeding effects. The choice of this variant of renewal may be more rational, it seems to be, due to the more favourable biometric features and the high quality of breeding characteristics of pines on plots established in a traditional way. In the case of renewals in the Nowa Dęba Forest District, this conclusion is also supported by the total costs of management in relation to the corresponding costs of renewals carried out in other regions of Poland, which are relatively low (in relation to the results of other authors). A possible delay in natural regeneration, resulting from waiting for favourable

conditions and the subsequent slower growth of seedlings, as well as the occurrence of surface fragments without renewal (20% of a plot on average) favour to obtain the natural renewal in longer time period. This phenomenon has an impact on the so-called costs of lost production capacities by abandoning the 'quick' artificial renewal. In this habitat, the results of the breeding efficiency of Scots pine natural regeneration did not confirm the results obtained, amongst others, by Pigan (2010) and Dobrowolska (2008).

The analyses presented in this research, performed based on the results obtained from Nowa Dęba Forest District, regarding unit costs of works in the field of forest breeding, can be used to analyse the financial result for other units operating in similar natural environment forest conditions. This approach was presented by Kocel (1998, 2000, 2004a, 2004b) in the research on rationalisation of operating costs. He stated that 'economic phenomena occurring in forestry managed units cannot be considered only in a descriptive way, because then there is no basis for their proper assessment'. In his opinion, it is necessary to evaluate these phenomena and refer them to a specific comparative database (Kocel 2000). The basis for assessing the management and economic decisions undertaken and also for increasing the efficiency of the operation is the analysis of actual costs with the accepted standard-normal costs to be incurred as part of effective management. An enterprise incurs costs to obtain a specific effect – a product of its operations from which it enables to generate income. The investigations conducted by Glura and Moliński (2003) indicated a lack of correlation between the amount of expenditure incurred and the quality of renewal plots. The amount of costs incurred in the five-year period, both in poor quality and in very good regenerated plots, was similar. An interesting result was the fact that the number of costs can affect the level of breeding quality of the regenerated area. The higher costs were incurred on renewal plots, where their quality was improved afterward. They also noticed that the financial analysis was influenced by the discounting method adopted and the interest rate applied.

The rationalisation effect resulting from savings associated with the use of natural regeneration of the forest may be a good reason to be taken into account in many cases, but this may not be a decisive factor. In many situations, it will still be the best practice to use artificial regeneration, for example, as a result of inadequate quality of mother stand, the necessity of quick tree stand conversion process, an unfavourable landform of the area that does not have possibilities to provide proper soil preparation. As it was noted by Šindelár (2001), the areas of natural regeneration are increasing. However, when the selection of the method of renewal is under consideration, then not only short-term goals, for example, savings resulting from lower costs related to renewal, but as well as long-term goals should be taken into account. Regarding *Pinus sylvestris var. mongolica*, the investigations of Jiao-jun et al. (2003) showed that the artificial regeneration of this species develops faster and they reach the culmination of height growth and volume of a tree earlier, but the period of expectancy of life for tree is about 60 years shorter than that in the case of natural regeneration. The planted Scots pines were also more susceptible to factors that diminish their health condition and cause their dieback. However, the investigations conducted in Lithuania by Malinauskas (2001) indicated that artificially regenerated Scots pine stands had better productivity and efficiency than those of naturally regenerated ones. Amongst others, the various initial densities of trees caused that planted Scots pine trees were higher and produced more wood. The difference between the variants of regeneration methods ranged from 17% up to even 40%.

Conclusions

The data obtained from Nowa Dęba Forest District confirmed the results of other authors, that is, using different methods of regeneration. Comparing the costs of establishing and management of plots depending on the method of renewal, it was also stated that the total costs may be lower when the natural ability of Scots pine to renew itself was applied. On the basis of the results of the study, in individual regeneration variants, it can be concluded that the costs of the renewal of plots were the most differentiating factor of the final economic effect of establishing and management of forest plantations with the participation of Scots pine. These costs consumed the largest part of expenditures in the variant using artificial forest regeneration methods. When the natural possibilities of Scots pine regeneration were used, higher costs of re-planting treatments in the artifi-

cially regenerated area in poorer habitats were also contributed to the more favourable final balance of establishment of plantations. Differences in the size of other cost groups were not significant. The financial accounting and silvicultural effects on the Scots pine of investigated regeneration variants allowed to perform rational breeding decisions based on the assessment and knowledge of the factors shaping them. Habitat conditions and methods of regeneration of plots proved to be important factors affecting the level and structure of unit costs in the field of forest breeding. In the proper management of a forest holding, the efficient control of production costs is indispensable. Already in the initial stages of the development of the tree stand, the consequences of the decisions undertaken regarding the methods of forest regeneration of plots are visible. They affect the level of costs of management of regenerated areas and the taxation character of the young generation of trees.

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