DOI: 10.1515/frp-2017-0035
Available online: www.lesne-prace-badawcze.pl

Leśne Prace Badawcze / *Forest Research Papers*
Grudzień / December 2017, Vol. 78 (4): 315–321

ORIGINAL RESEARCH ARTICLE

e-ISSN 2082-8926

Cost analysis of artificial and natural oak regeneration in selected forest districts

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Abstract. The aim of the paper is to present the results of a cost analysis for artificial and natural oak regeneration in selected forest districts in Poland. This research was conducted in six forest districts with a high share of natural oak regeneration, located in south-western and central Poland. Altogether 65 plots with artificial and 35 plots with natural regeneration were analysed based on the extent of silvicultural (weeding, blank-filling and pre-commercial thinning) and protective measures (chemical and mechanical wildlife damage control, fencing) performed on the regenerated areas for the six years following forest regeneration. An intensity ratio (i.e., a proportion of the area of measures to the area of forest regeneration) as well as the mean unit costs of the measures and mean costs of the measures per hectare of forest regeneration were calculated.

The results show that the total costs of silvicultural and protective measures in natural oak regeneration were considerably lower as compared to artificial regeneration. The cumulative average costs during 6 years (without costs of fencing) amounted to 1216 PLN/ha and 6543 PLN/ha for natural and artificial regeneration respectively. Lower costs of natural oak regeneration resulted from the complete lack of expenditures on seedlings and planting, a considerably lower weeding intensity, scarce blank-filling, and the absence of mechanical wildlife damage control measures. Nonetheless, natural regeneration generated higher costs for pre-commercial thinning due to its higher intensity, earlier initiation, and higher unit costs compared to artificial regeneration, as well as chemical wildlife damage control measures, for which the unit costs were higher by over 50%. However, the higher costs of pre-commercial thinning and chemical control measures did not significantly affect the measurable financial benefits of natural regeneration.

In conclusion, the matter of financial viability of natural oak regeneration should be explored in more detail over longer time spans.

Keywords: silvicultural measures, protective measures, intensity, unit costs

1. Introduction

Natural forest regeneration is one of the components of multifunctional, sustainable forest management (MOŚZNiL 1997). Rational use of natural forest reproduction is also one of the fundamental principles of silviculture (CILP 2012).

A wide use of natural regeneration is common in many countries (Leibundgut 2007). In Poland also, the share of naturally regenerated forests is gradually increasing (Szramka 2014), although it still remains relatively low when compared to the other European countries (Forest Europe 2015). In 2014, 9.2 thousand hectares of forests were naturally restocked, amounting to 16.3% of the total area of forest renewal in the country. Since 2006, the share of this method of regeneration has increased by 5.7 percentage points (CILP 2007, 2016).

Natural forest regeneration offers many advantages. Improving the genetic diversity of tree stands and – as a result – reducing the silvicultural risk, maintaining the continuity of forest production and favourable qualities of microclimate and soils, maintaining local tree ecotypes, good adaptation of forest regeneration to the site, and uninterrupted growth of self-sown seeding and underwood belong to the most important virtues (Jaworski 2011). Natural reproduction provides more effective protection of forest ecosystems against climate change and biodiversity loss, as well as protection of landscape values (Larsen, Johnson 1998; Sinha et al. 2017).

Received: 8.09.2017, reviewed: 30.10.2017, accepted: 3.11.2017.

At the same time, natural regeneration has some disadvantages, of which the most frequently mentioned are: high dependence on good harvest and vitality of seeds, uneven density of restocking, increased threat from herbaceous plants and from herbivores (because of the absence of fencing), as well as from other threats in initial phase of growth (Larsen, Johnson 1998; Jaworski 2011).

In view of cost savings in seeds and planting material, natural forest regeneration is cheaper when compared to artificial reproduction; although at the same time, it requires increased workload and financial resources for tending and blank-filling (Żybura 2014). However, in Poland, detailed studies on economic aspects of various methods of forest regeneration are carried out only occasionally.

A cost analysis of artificial and natural regeneration in the Konstantynowo Forest District was done by Szramka (2001). Because of a small area of natural regeneration, as well as a long period of reproduction and using mean values of costs, the results of the study are only indicative. According to this author, the issue should be further studied in other economic entities. Other research carried out by Szramka focused on the costs of natural and artificial forest regeneration – also dealt with generally – in three forest districts. The study enabled to define the relationships between the costs of artificial and natural forest reproduction and to conclude that the costs of natural regeneration were several times lower than the costs of artificial restocking (Szramka 2005).

The research done by Rykowski et al. concentrated on the evaluation of selected costs of silviculture and protection of pure pine tree stands or stands, where pine was a dominant species in the Tuszyma Forest District. The economic part of the study covers, among others, a detailed comparison of costs of natural and artificial forest reproduction and tending of pine stands of different origins (Rykowski et al. 2006).

This paper presents the results of the analysis of direct costs of initiation, silviculture and protection of artificial and natural oak regeneration in selected forest districts located in the Regional Directorates of the State Forests in Wrocław and Łódź (i.e., in south-western and central Poland).

2. Research method and objects

A request for data concerning a range of silvicultural and protective measures taken for natural and artificial oak regeneration during 6 years after the planting was done or natural regeneration was approved as well as financial expenditures for those activities was sent to 12 forest districts located within three Regional Directorates of the State Forests (Łódź, Poznań and Wrocław) in the second half of 2011. The forest districts were chosen from a group of districts where – according to the inventory carried out earlier – a high share of natural oak regeneration was proved (Zachara et al. 2011). In each case, the request concerned in particular:

- information about 12–15 forest compartments regenerated in natural and artificial way, approved in 2004 and – in case of missing data – also in 2005, located in fresh broadleaved (Lśw), fresh mixed broadleaved (LMśw) and upland mixed broadleaved (LMwyż) forest sites,
- information about the range of silvicultural and protective measures taken within subsequent years until 2010 as well as costs of those measures (in current values).

In response to the request data concerning 65 forest compartments regenerated artificially with oak (or with predominance of oak), located in 6 forest districts and 35 plots with natural oak regeneration (or with predominance of this species), located in 5 forest districts were obtained (Table 1).

The total area of the artificially reproduced plots amounted to 55.76 hectares. The largest plot covered 3.07 ha, and the smallest one – 0.10 ha; 74.9% of the total area (41.76 ha) was

Table 1. Number of plots and the total area of forest regeneration in the studied forest districts

Forest district	Artificial regeneration		Natural regeneration	
	Number of plots	Total area [ha]	Number of plots	Total area [ha]
Jawor	12	6.89	13	10.65
Bardo Śląskie	9	8.55	-	-
Oborniki Śląskie	3	1.51	10	11.99
Grotniki	12	15.70	4	2.13
Brzeziny	5	1.17	3	2.40
Poddębice	24	21.94	5	7.68
Total	65	55.76	35	34.85

covered by regeneration under shelterwood, 25.1% (14.00 ha) – by restocking of clear-cuts. The biggest share (38.5%) in the total area had the plots where oak was the only species (in total 21.49 ha). The area of regeneration with at least 80% of oak amounted to 39.11 ha (i.e., 70.1%). The majority of the plots (57) were established in 2004, and only 8 in 2005.

In case of natural oak regeneration, the study concerned 35 plots with the total area of 34.85 ha, approved in 2004 (20) and in 2005 (15). The area of separated plots varied from 0.20 ha to 3.38 ha. Shelterwood regeneration covered 32.35 ha (i.e., 92.8%). The area of plots with at least 80% of oak amounted to 30.02 ha (i.e., 86.1%). Oak was the only species on 71.7% of the total considered area.

Based on the data obtained from the forest districts, the following values were calculated:

- the mean intensity of individual silvicultural and protective measures, that is, a share of the area covered with a measure in subsequent years after regeneration was done to the total area of a plot (hereinafter referred to as an intensity ratio),
- the mean direct unit costs of measures (i.e., calculated for 1 hectare of a measure),
- the mean direct costs of measures for 1 hectare of forest regeneration.

For natural regeneration, the analysis covered costs of soil preparation, weeding, pre-commercial thinning, blank filling, chemical wildlife damage control (application of repellents) and fencing. In case of artificial reproduction, the analysis additionally covered the costs of seedlings and planting and the costs of mechanical wildlife damage control (application of tree shelters).

3. Results

The results of calculating the mean intensity of individual measures in subsequent years after forest reproduction and the mean costs of those measures are presented in Tables 2 and 3.

For artificial regeneration, the mean costs of establishing of stands for all the studied plots amounted to 3530 PLN/ha. The lowest costs were incurred in the Brzeziny Forest District (2579 PLN/ha), while the highest ones in the Bardo Śląskie Forest District (5018 PLN/ha).

Natural forest regeneration on the analysed plots was spontaneous in three forest districts (Jawor, Grotniki, Poddębice), with no previous soil preparation, and thus, also without financial expenses. In two other forest districts (Oborniki Śląskie and Brzeziny), the soil was prepared before seeding

Table 2. Mean intensity of silvicultural and protective measures in subsequent years after artificial forest regeneration or approval of natural regeneration

Measure	Regeneration method	Years since regeneration							Sum
		0	**1**	**2**	**3**	**4**	**5**	**6**	
Weeding	artificial	0.64	0.90	0.85	0.80	0.61	0.40	0.39	**4.59**
	natural	0.20	0.19	0.19	0.19	0.14	0.01	0.12	**1.04**
Supplementary planting	artificial	-	0.06	0.03	0.01	0.01	0.01	-	**0.12**
	natural	-	0.00	0.00	0.00	-	-	-	**0.00**
Precommercial thinning	artificial	-	-	-	-	0.07	0.04	0.06	**0.17**
	natural	0.00	0.03	0.05	0.20	0.11	0.06	0.04	**0.49**
Chemical wildlife damage control	artificial	0.19	0.26	0.31	0.15	0.11	0.07	0.01	**1.10**
	natural	0.36	0.17	0.21	0.13	0.11	-	-	**0.98**
Mechanical wildlife damage control	artificial	0.03	0.01	0.03	0.05	-	0.01	0.02	**0.15**
	natural	-	-	-	-	-	-	-	**-**
Fencing	artificial	0.13	-	-	-	-	-	-	**0.13**
	natural	0.05	0.07	-	-	-	-	-	**0.12**

Table 3. Mean costs of silvicultural and protective measures in subsequent years after artificial forest regeneration or approval of natural regeneration (PLN/ha, current prices)

Measure	Regeneration method	Years since regeneration							Sum
		0	**1**	**2**	**3**	**4**	**5**	**6**	
Weeding	artificial	233	365	333	385	364	233	232	**2147**
	natural	72	55	91	112	85	6	92	**513**
Supplementary planting	artificial	-	197	142	59	35	56	-	**489**
	natural	-	7	6	11	-	-	-	**24**
Precommercial thinning	artificial	-	-	-	-	38	24	34	**96**
	natural	-	17	32	118	100	18	23	**308**
Chemical wildlife damage control	artificial	38	58	73	32	28	19	1	**250**
	natural	148	68	56	30	40	-	-	**341**
Mechanical wildlife damage control	artificial	10	3	6	6	-	2	4	**31**
	natural	-	-	-	-	-	-	-	-
Fencing and fence repairs	artificial	571	-	32	12	3	-	-	**618**
	natural	129	83	-	-	41	16	10	**279**

costs on some parts of the compartments, but the mean costs incurred for this measure did not exceed 90 PLN/ha of forest reproduction. The average costs for the total area of natural regeneration on the studied plots amounted to 30 PLN/ha.

For artificial regeneration, the mean intensity ratio of weeding in the period 2004–2010 for all the forest districts amounted to 4.59. Most intensively, the measure was applied in the Brzeziny Forest District (5.91) and the least – in the Bardo Śląskie Forest District (2.88). The most intense weeding was carried out over a period of one to three years after the forest was planted (the mean intensity ratio for all plots in individual years amounted to 0.80–0.90). However, in the three studied forest districts (Bardo Śląskie, Brzeziny and Poddębice), the maximum intensity was observed one year after establishing of stands; and in the other three districts (Jawor, Oborniki Śląskie and Grotniki), it peaked two years after the forest reproduction.

For natural regeneration, the mean intensity ratio of weeding for the whole analysed period totalled 1.04. Weeding was carried out only in three forest districts: Oborniki Śląskie, Grotniki and Poddębice. The intensity ratio of the measure was practically equal in the year of regeneration and in three subsequent years, and it amounted to ca. 0.20 annually.

The mean unit costs of weeding for artificial and natural regeneration were similar and amounted to 466 PLN and 486 PLN per 1 hectare of weeding, respectively. However, the average costs of weeding per 1 hectare of forest regeneration were over four times higher in the artificial reproduction (2147 PLN/ha) as compared to the natural one (513 PLN/ha).

Blank-filling was mostly carried out in artificial regeneration and the total intensity ratio amounted to 0.12. Blank feeling was necessary in the Poddębice Forest District (intensity ratio = 0.16). In two forest districts (Jawor and Brzeziny), this measure was not carried out at all. Blank-filling was mostly introduced one year after the establishment of the plantations.

In natural regeneration, blank-filling was marginal: the total area in two forest districts (Grotniki and Poddębice) amounted to 0.6% of the regenerated compartments area.

The mean unit costs of blank-filling in compartments regenerated artificially were slightly higher as compared to those reproduced naturally and amounted to 4200 PLN/ha and 3958 PLN/ha, respectively. However, the costs per 1 hectare of regenerated forest were more than 20 times higher in plantations than in natural regeneration.

The mean intensity ratio of pre-commercial thinning in plots of artificial regeneration totalled 0.17. Relatively, most intensively tended were the forest cultures in the Jawor Forest District (intensity ratio = 0.34). The measures were carried out beginning from the fourth year after establishing of the stands. In two forest districts (Oborniki Śląskie and Grotniki), no pre-commercial thinning was carried out within the studied period.

On the naturally regenerated plots, pre-commercial thin-

ning wasn't carried out only in the Grotniki Forest District. Average intensity ratio of the measure amounted to 0.49, but in the Brzeziny Forest District, where its intensity was the highest, it peaked at 2.00. Pre-commercial thinning was carried out starting from the first year after natural regeneration was approved, and in maximum area, the measure was covered in the third year (intensity ratio = 0.20).

Average unit cost of pre-commercial thinning in the compartments regenerated naturally was 636 PLN/ha and it was by ca. 12% higher in comparison with artificial forest regeneration (538 PLN/ha). Because of the higher unit costs and the intensity ratio of the measure, the average costs of pre-commercial thinning per 1 hectare of forest regeneration were 3.2 times higher than in case of artificial formation of stands.

Fencing was carried out in three forest districts (Jawor, Bardo Śląskie and Poddębice) in the year of plantations establishment. The mean intensity ratio of the measure for all plots amounted to 0.13 and it was the highest in the Jawor Forest District (0.73).

Fencing of plots regenerated naturally was done only in the Oborniki Śląskie Forest District in the year of regeneration and one year later. Intensity ratio of the measure in that forest district totalled 0.36, which averaged to 0.12 per 1 hectare of all the studied plots regenerated in a natural way and was almost identical to the artificial forest regeneration.

The average intensity ratio of chemical wildlife damage control (application of repellents) in plantations amounted to 1.10 and was the highest in the Grotniki Forest District (intensity ratio = 2.40), while it was the lowest in the Poddębice Forest District (0.03). Chemical wildlife damage control was carried out to the largest extent two years after the plantation was established (average annual intensity ratio = 0.32), and it was gradually decreasing in the subsequent years.

In naturally regenerated compartments, the average intensity of chemical wildlife damage control for the whole analysed period amounted to 0.98 and was similar to artificial regeneration. However, the measure was carried out only in two forest districts: Jawor (intensity ratio = 2.64) and Oborniki Śląskie (intensity ratio = 0.23). The protective measures were most intense in the year of approval of natural regeneration, and in the subsequent years, it was gradually decreasing.

The mean unit cost of chemical wildlife damage control in natural regeneration over the whole studied period amounted to 348 PLN/ha and it was by some 55% higher in comparison to artificial regeneration (227 PLN/ha). Because of the higher unit costs with similar intensity of the measure, the average costs per one hectare of natural forest regeneration over the whole period were by some 35% higher in comparison to the artificial reproduction.

Mechanical wildlife damage control (tree shelters) was used only in artificial oak regeneration in two forest districts (Brzeziny and Poddębice). The mean intensity of the measure for all plots amounted to 0.15 (0.77 in the Brzeziny Forest District).

The mean unit costs of mechanical wildlife damage control amounted to 187 PLN/ha. They peaked in the year when the plantations were established and decreased in subsequent years. The average expenditures per 1 hectare of forest regeneration did not exceed 10 PLN/ha annually over the whole examined period.

4. Discussion

The results of the study show that the costs of silvicultural and protective measures in natural oak regeneration are significantly lower as compared to the corresponding costs in artificial regeneration. The total average costs of artificial forest regeneration together with silvicultural and protective measures during 6 years after the plantations were established amounted to 7161 PLN/ha (in current values). The corresponding costs of natural regeneration of this tree species amounted to about 1495 PLN/ha. It should be noted that the average unit costs of fencing plots reproduced artificially were about 2.5 times higher in comparison to those regenerated naturally. The overall cost of fencing depends, however, on the length of a fence (and thus, on the shape of a fenced plot), and not on the method of forest regeneration itself. Considering that the intensity of this measure was almost the same for both methods of forest regeneration, it may be assumed that that differences in costs resulted from the shape of the fenced plots and not the method of forest regeneration. Excluding the costs of fencing the plots, the total costs of artificial oak regeneration amounted to 6543 PLN/ha and were over five times higher in comparison to the total costs of natural oak regeneration (1216 PLN/ha).

The considered forest district differs in terms of natural and economic conditions, which in consequence affects the diversification of costs of silvicultural and protective measures and makes a comparison of the obtained results difficult. For this reason, the relative differences in the intensity of individual measures in both methods of forest regeneration seem more significant than their actual financial values. The cost structure of artificial regeneration is dominated by the expenditures related to planting (soil preparation, seedlings, planting), which accounts for 49.3% of all direct costs in the analysed period. The other significant costs relate to weeding (30.0%). In the natural oak regeneration, relatively highest costs were incurred for weeding (34.3%).

The following factors influenced the lower costs of natural oak regeneration:

- the absence of expenditures for production of seedlings, soil preparation and planting; in most of the analysed compartments, natural regeneration was spontaneous with no additional expenditures incurred, while the costs of se-

edlings and planting were the main factor influencing the overall costs of artificial forest reproduction;

- much lower intensity of weeding, which with a slightly higher unit costs of the measure resulted in about a four-fold reduction in costs per hectare in the studied plots;
- a virtual absence of blank-filling, while on the plots reproduced artificially, they covered 12% of the area on average;
- the absence of mechanical wildlife damage control measures.

At the same time, some of the measures performed during natural regeneration generated higher expenditures compared to the artificial forest reproduction. In natural regeneration, pre-commercial thinning was three times more intense; it also started earlier and had higher unit costs. This resulted from specific features of natural regeneration, characterised by greater density and requiring stronger selection of trees in the early stages of tree stands development. In addition, the unit costs of chemical wildlife damage control (repellents) were over 50% higher than in the artificially regenerated plots, which resulted in higher average costs per 1 hectare of forest regeneration.

The results partly confirm the results of previous studies, which indicate an economic viability of natural forest regeneration (Szramka 2001, 2005). The analysis carried out by this author in the Konstantynowo Forest District showed that 30—40% of the total costs of artificial forest reproduction were incurred for restocking, that is, planting and transportation and heeling of seedlings before planting. Together with the costs of seedling production, which amounted to 20–25% of the total financial expenditure, costs related to planting amounted to more than half of all the expenses (Szramka 2001). This author, however, didn't take into account the expenditures incurred for the protection of stands against game, which limits the possibility to compare his study outcomes with the results presented in this paper. It is also difficult to refer to a later research carried out by Szramka, as he noted himself that his studies allowed only to define a cost structure of artificial forest regeneration. He simultaneously underlined that the unit costs of natural forest reproduction in the three studied forest districts were very diverse, which resulted from, inter alia, their location and the applied procedures for approving natural regeneration, and additionally, from a method of calculating those costs and some arbitrariness in registering costs and area of natural regeneration. In the cost structure of artificial regeneration, the share of costs of seedlings prevailed (36–55%), followed by planting (19–38%) and blank-filling (12–21%) (Szramka 2005).

Foreign studies concerning the discussed issue are also very limited. Many researches are based not on real costs, but on the pre-set mean costs of measures and defined discount rate, and thus, bring rather theoretical considerations (Rosenstock 1991; Fürst, Johann 1994; Clasen, Knoke 2014; Hosius et al. 2016; Knoke et al. 2016), which are difficult to compare with the results of this research. The study carried out by Gürth and Vöhringer (1993) is exceptional, because it provides results of research on costs of oak regeneration on dozen or so experimental plots in the Müllheim Forest District in Baden-Württemberg (Germany). The study showed that depending on a cost calculating option (mean cost rates of measures, real costs, based on real labour intensity and a fixed hourly rate) and a natural forest regeneration method (with limited tending, thinning included, fencing included), direct financial expenditures on artificial regeneration and protection and tending of stands were from some 60% to more than 300% higher. In artificial regeneration, the structure of costs comprised weeding and pre-commercial thinning (ca. 45%), seedlings and planting (20–30%), blank-filling (15–25%), fencing (ok.10%) and initial fertilising (3%). The cost structure of natural reproduction included weeding and pre-commercial thinning (40–76%), fencing (18–44%) and blank-filling (1–41%). The authors noted that only by changing a method of forest regeneration, the costs of reproduction may be reduced by more than 40%. By simplifying methods of natural reproduction, the financial expenditures may be limited by further 10%, and by reducing fencing even by more than 70%; however, it is difficult to estimate the possibilities for maintaining the high quality of natural regeneration in such a case (Gürth, Vöhringer 1993).

It is hard to compare the results gained by Gürth and Vöhringer with the results presented in this study. The analysis carried out by the German researchers focused on different activities – for example, soil preparation was not specified separately, same as weeding and pre-commercial thinning, and protective measures include only fencing. Nevertheless, it should be noted that in both cases, artificial regeneration is dominated by the costs of planting (soil preparation, seedlings and planting itself) and weeding, and in natural reproduction, most of the direct costs are those associated with weeding. In addition to indisputable ecological advantages, natural regeneration also allows in some specific cases to reduce the financial expenditures.

5. Conclusions

The results obtained by this study allow formulating the following conclusions:

1. Natural oak regeneration is a cheaper method of forest reproduction in comparison to artificial regeneration of this species.

2. First of all, the quantifiable benefits of natural forest regeneration are associated with the absence of costs related to the production of seedlings and planting as well as the absence or a significant reduction of soil preparation costs. Higher costs of pre-commercial thinning and chemical wildlife damage control in the analysed natural regeneration did not

significantly affect the overall favourable economic result of this method of forest regeneration.

3. Because of its importance for economic practice, the matter of financial viability of natural oak regeneration and its tending and protecting should be explored in more detail over longer time spans.

Conflicts of interest

The author declares no potential conflicts of interest.

Acknowledgements and source of funding

The paper presents the results of the research implemented within the project 'Natural regeneration of the most important forest tree species in Poland as the element of a strategy for sustainable forest management' financed by the Directorate-General of the State Forests in Warsaw.

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Translated by Autor