138. Jahrgang (2021), Heft 4, S. 375–394

Austrian Journal of Forest Science
Centralblatt für das gesamte Forstwesen

Restoration of Declining Spruce Stands in the Czech Republic: a Bioeconomic View on Use of Silver Birch in Case of Small Forest Owners

Wiederherstellung absterbender Fichtenbestände in der Tschechischen Republik: Eine bioökonomische Blick auf die Verwendung der Silberbirke durch kleinen Waldbesitzern

Roman Dudík[1], Petra Palátová[1*], Vilém Jarský[1]

Keywords: Economic Efficiency, Forest Management, Bark Beetle Outbreaks, Restoration

Schlüsselbegriffe: Ökonomische Effektivität, Forstwirtschaftsmanagement, Borkenkäferausbruch, Wiederherstellung

Abstract

Norway spruce (*Picea abies*) and in many places also Scots pine (*Pinus sylvestris*) stands in the Czech Republic are affected by dieback, which has become more prevalent in the last five years. Forest owners have to deal with the restoration of dieback-affected stands. For small forest owners this problem is urgent as often their entire forest property is affected by dieback. Here we summarize the results of several studies from the Czech Republic and provides an operationally feasible solution applicable also for small forest owners. We propose a change in the common view of Silver birch (*Betula pendula* Roth) as a weed tree species towards seeing this species as an economically interesting alternative. The utilization of birch for restoration of dieback-affected stands can be an operationally applicable solution with a rather short standard rotation period of around 50 to 60 years. Lowering the rotation period up to 20 years does not lead to higher expected economic efficiency. Studies have shown that the economic efficiency of birch stands silviculture is significantly increased by the use of natural restoration of birch.

[1] Department of Forestry and Wood Economics, Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague; Kamýcká 129, 165 00 Prague, Czech Republic
*Corresponding author: Palátová Petra, palatovap@fld.czu.cz

Our results further underlines the importance of the price level of raw wood assortments, which becomes particularly important when comparing the economic results of birch stands with other commercial species in the Czech Republic.

Zusammenfassung

Fichten- (*Picea abies*) und oft auch Kiefernbestände (*Pinus sylvestris*) sind in der Tschechischen Republik im Absterben begriffen und dies hat in den letzten fünf Jahren noch mehr zugenommen. Waldbesitzer stehen vor der Aufgabe, die Wiederbegründung der Waldbestände zu gewährleisten. Für kleine Waldbesitzer kann das ein existenzbedrohendes Problem werden, da oft der gesamte Waldbesitz betroffen ist. Hier werden Ergebnisse mehrerer Studien aus der Tschechischen Republik zusammengefasst und eine operativ realisierbare Lösung dieser Situation wird vorgestellt, die auch für kleine Waldbesitzer gut anwendbar ist. Wir empfehlen eine Änderung der Sichtweise der Birke (*Betula pendula* Roth) als Unkraut oder dienende Baumart zu einer wirtschaftlich interessanten Alternative. Die Verwendung der Birke für die Wiederherstellung von absterbenden Waldbeständen ist eine betrieblich anwendbare Lösung mit einer relativ kurzen Umtriebszeit von 50 bis 60 Jahren. Eine um 20 Jahre noch kürzere Umtriebszeit führte nicht zur höherer ökonomischen Effektivität. Es zeigte sich, dass die ökonomische Effektivität in der Bewirtschaftung von Birkenbeständen bedeutend durch die Verwendung von natürlicher Birkenverjüngung erhöht wird. Die Bedeutung des Preisniveaus von den Rohholzsortimenten wird durch Forschungsergebnisse hervorgehoben, wobei diese besonders wichtig sind im Vergleich mit anderen Wirtschaftsbaumarten in der Tschechischen Republik.

1. Introduction

European forests and forest-based industries play an important role in the bioeconomy – they provide raw material (wood and non-wood forest products), bioenergy, and are connected with ecosystem services (Linser *et al.*, 2016; Ollikainen, 2014). In some countries, forestry is one of the key sectors in bioeconomy – for example in Finland (Pülzl *et al.*, 2014). The importance of forestry in significant also because forestry is directly linked to other economic sectors, especially to the wood-processing sector, which belongs to the traditional sectors in the Czech Republic. Further development of bioeconomy is directly dependent on research and implementation of innovations in practice, so also new, alternative use of wood (birch) raw material can be an impulse in the bioeconomy, as well as to change attitudes in terms of higher use and focus on the issue of birch forest management.

The article summarizes the main results of economic research conducted within two research projects in the time period 2016-2020 (Dudík *et al.*, 2018a; Dudík *et al.*, 2021).

Cultivation of birch has so far been very marginal issue in the Czech Republic. The exception were the areas affected by air pollution, where birch was actively introdu-

ced, however this cannot be considered as intentional and systematic cultivation of birch; birch was perceived as a weed tree species. It is therefore not surprising that at the beginning of research in 2015, standard models for tending or methods for restoration of stands with the target representation of birch were not developed. Only for air polluted areas, recommendations for tending and restoration of alternative birch stands leading to a more favourable microclimate were prepared. Abroad, cultivation procedures for birch forest management are more frequent, common are mostly in Scandinavia (Fahlvik *et al.*, 2015; Rytter and Werner, 2007) and in the Baltics (Zalitis T. and Zalitis P., 2007), but *e.g.* also in Poland (Socha, Zásada, 2015) and in Germany (Hein *et al.*, 2009). Only in recent years there have been efforts for a more significant economic use of this tree species (Košulič, 2004; Martiník, 2012; Martiník, 2016). Connections with the establishment and cultivation of birch stands in the Czech Republic are also investigated (*e.g.* Souček *et al.*, 2019; Martincová and Leugner, 2020). Efforts to change the species composition of forest stands are currently significantly related to addressing the impacts of climate change. In the conditions of the Czech Republic, the Economic and Production Effect of Tree Species Change as a Result of Adaptation to Climate Change was investigated by Remeš *et al.* (2020). Currently, after a change in related legislation in the Czech Republic (see Decree No. 298/2018 Coll.), birch is even considered as a soil-improving and stabilizing species on most forest sites. From the point of view of the legal framework, this provides a greater possibility of using birch in the restoration of forest stands.

In recent years, Czech forestry has been addressing an issue of spruce stands declining at lower and middle altitudes, especially in northern Moravia and in mountains of the Bohemian-Moravian Highlands (north-eastern and central part of the country). The reason was high temperatures and low total precipitation (as well as their uneven distribution during the year) in the past years, especially in 2015 and then in 2018. This causes an increased volume of salvage felling, resulting in an increase in the volume and cost of silvicultural operations. It is necessary to implement more costly measures to afforest forest openings which often merge into large areas as a result of the increasing share of salvage felling in threatened areas. Spruce stands are devitalized by drought and subsequently by bark beetle attacks. These stands, thinned by salvage felling, often fall victim to destructive winds. Such quickly spreading disaster areas are exposed to natural seeding of pioneer tree species, especially the Silver birch (*Betula pendula* Roth). The forest openings are not only more difficult and expensive to afforest with target production tree species, but the young forest stands become also more problematic to establish, requiring often multiple removal of weed tree species, including birch (Dudík *et al.*, 2018b).

However, in the above-mentioned cases it is possible to use the "creative force of nature" and to regulate the self-seeded birch until its felling maturity. Lower average costs can be expected in birch management than in that of the main commercial tree species in the Czech Republic (spruce – *Picea abies* L., beech – *Fagus sylvatica* L., oak – *Quercus petraea* L., pine – *Pinus sylvestris* L.). When talking about the yield,

it is necessary to take into account the shorter rotation period of the birch, resulting in earlier yields. Besides utilizing the birch wood for energy purposes, with a lower financial effect, the roundwood assortments can be used for furniture making etc. (Dudík *et al.*, 2018b).

In addition to the professional contexts, forest owners and their motivation to manage the forest will decide on the practical use of birch. Phenomenon of forest ownership has been studied quite extensively in the European context (Ficko *et al.*, 2019, Weiss *et al.,* 2019, Živojinović *et al.,* 2016), including the opinions on forest management (Feliciano *et al.*, 2017). Connection between ownership and climate change, or rather its impact (*e.g.* acceptance of species change by forest owners as a consequence of bark beetle calamity) however have not been much mapped.

A very fundamental problem will arise for small forest owners, who do not have, or due to the small size of their property, cannot have, a mixed species composition of their forest stands. In the Czech Republic (CZ), small forest owners predominate in terms of total number among all owners. These are represented mainly by individuals, of which there are about 350,000 (approximately 89% of all forest owners). According to Jarský and Wild (2016) there are about 268,000 of individuals owning a forest with a maximum size of 1 hectare (69% of all forest owners) in CZ. According to the Czech forestry legislation, a forest owner with assets over 50 hectares is obliged to manage the forest according to the forest management plans. Owners up to this area do not have this duty, so we understand the limit of 50 hectares as a limit when the owner is referred to as "small forest owner". Change in the composition of species is one of the form of innovations (Loucanova *et al.*, 2020). Innovations are generally better implemented by younger people. As study by Jarský (2017) show, about 60% of forest owners in the Czech Republic are older than 60 years.

Making models and decision-making on the choice of forest species composition from the point of view of economic efficiency has a long tradition in the Czech Republic. Recently, works such as Pulkrab *et al.* (2014), Kupčák *et al.* (2016), Švéda *et al.* (2020a, 2020b) were published. A number of factors enter into the economic models of forest production. Various risks affecting production processes and timber markets are of a great practical significance in forestry (Mutenthaler and Sekot, 2016). In addition to that, the specifics of the size or geographical location of forest assets and the possibility of obtaining accurate and complete economic information about these assets are also important; Toscani and Sekot (2017) have addressed this issue, for example. The importance of forest functions on a given forest property also play a role, while the production function may not be the most important.

The aim of the analysis is to decide on possibility of use of birch when restoring the declining spruce stands and at the same time to show that a change in species composition in favour of birch can be an interesting (and also economic) alternative also for small forest owners.

2. Material and Methods

Changing the view of the birch from a "weed tree species" to a "worthy" alternative production tree species was analyzed by Dudík *et al.* (2018a). Birch management in four groups of models of silvicultural management frameworks on three types of soil sites: acid, nutrient, affected by water (stagnic/gleyed) was examined.

With regard to the focus of this article on small forest owners, the results of two groups of models are presented:

- Cultivation of monocultural birch stands in a short rotation period (20 years), models "A".
- Cultivation of monocultural birch stands in a long rotation period (60 years), models "B".

These models can also be used by large forest owners. Thanks to their simple species composition, they are also especially suitable for small forest owners with regard to easier cultivation of such stands. Evaluation of economic efficiency of the above mentioned models took place on three representative group of forest habitat sites (according to the system of the forest site typology in the Czech Republic – Viewegh, 2003), geographically belonging to the territory of northern Moravia:

- 3K (acid soil type), models "A/acid, B/acid".
- 3B (nutrient rich soil type), models "A/nutr., B/nutr.".
- 3O (stagnic soil type/gleyed), models "A/stagn., B/stagn.".

Figure 1 shows the approximate boundaries of the interest area in northern Moravia.

Source: Seznam CZ, a.s., 2021, edited by the authors

Figure 1: Area of interest in northern Moravia.

Abbildung 1: Untersuchungsgebiet in Nordmähren.

Economic models refer to the wood production function of the forest stand in these six models (GYFP – gross yield of forest production). These take into account an establishment of birch stand from natural regeneration. Alternatively, modelling was performed considering the establishment of the birch stand from seeding (GYFP models marked with "S" below).

The findings on the silvicultural and production potential of birch stands serve as the basis for differentiated modelling of economic efficiency of the stands' management. The inputs for economic models dealing with the production potential and models of development of birch stands are the result of research of co-investigators´ workplace (FGMRI, Opočno) and are presented in Dudík *et al.* (2018a). Inputs were obtained from permanent and newly established research forest stand sites, which simulate the management of birch stand. The management represents a whole production cycle comprising planting, stand establishment, tending, felling and the sale of the raw timber assortments. The birch timber sorting is based on assortment tables, which were made within the frame of the project by co-investigator ´s workplace (Fo-

resta SG company). We also modeled silvicultural and harvesting operations in birch stands, thereby considering the range of operations in technical units. Unit costs and yields represent average levels in the Czech Republic in 2017.

To expand the range of information on the results of economic modeling of birch stands, the discussion presents the results of economic modeling of selected models in the price level of 2020. The calculation is used to quantify costs and yields in particular economic models. The only evaluation criterion for this approach is gross yield of forest production (GYFP). This is in this case defined as an annual average difference in yields and direct costs. However, in the models considered, the costs do not include overheads. This is due to the fact that the level of overhead costs can be very different between different groups of forest owners. From this point of view, the results of economic modelling are important for comparison between individual models, which are calculated by the same procedure. In addition to this, the level of overhead costs is significantly lower for small forest owners than for large forest enterprises. The area of the model forest stand is always 1 hectare.

The importance and the scope of use of the results of economic modelling for small forest owners follow from the survey of the ownership structure of forests in the Czech Republic. Data on forest owners were obtained by analyzing the entries from the Cadastre of Real Estate provided by the State Administration of Land Surveying and Cadastre. These data contain detailed information to each single plot in the Cadastre established as a land determined to fulfil forest functions. For a more detailed analysis, based on the data from website kurovcovamapa.cz [barkbeetle map] (2020), 10 districts which were mostly affected by bark beetle calamities (the total number is 77 districts in the Czech Republic) were selected (for details see Kupčák *et al.*, 2019). Forest ownership data are valid as of January, 1st, 2018.

3. Results

3.1 Ownership issues

Data from the Cadastre allows to identify three basic ownership categories – legal persons (LP), individuals (I) and non-share co-ownership of spouses (NSCOS). From the legal persons a state can be easily identified/excluded. Table 1 presents the basic ownership structure in the districts mostly affected by bark-beetle outbreaks:

Table 1: Ownership structure of the districts most affected by bark-beetle outbreaks.

Tabelle 1: Eigentümerstruktur der von Borkenkäferkalamitäten am meisten betroffenen Bezirken.

District	Forest area (ha)	NSCOS	Individuals (I)	State	Legal persons (LP)
Blansko	37,413	1.4%	14.6%	39.5%	44.5%
Bruntál	70,538	0.2%	1.2%	75.7%	22.9%
Frýdek-Místek	61,370	2.0%	15.8%	54.5%	27.7%
Jeseník	42,328	0.2%	1.3%	32.5%	66.0%
Jihlava	37,050	2.4%	22.9%	34.8%	39.9%
Jindřichův Hradec	75,750	1.0%	18.6%	64,3%	16.1%
Prostějov	15,494	1.2%	20.8%	27,6%	50.4%
Trutnov	53,754	0.4%	7.5%	68.8%	23.4%
Třebíč	39,474	1.8%	22.0%	59.5%	16.7%
Vsetín	61,984	3.1%	34.3%	31.0%	31.6%

According to the data of the Ministry of Agriculture (MZe, 2015, 2020), the above mentioned district of Bruntál belonged to the most affected districts in the Czech Republic in 2014 from the point of view of registered spruce bark wood, it was 378,000 m³. The culmination of the volume of timber harvesting in this district occurred in 2017 (1.68 million m³ harvested) and in 2018 (1.60 million m³ of spruce bark wood), in 2019 it was 1.06 million m³. For comparison, the total amount of timber harvested in the Czech Republic was 15.48 million m³ in 2014 (the share of salvage cutting was 29%) and 32,58 million m³ in 2019 (the share of salvage cutting was 95%). The forest ownership structure of the most affected districts has no common features. In half of them, the state is the largest owner (either for historical reasons or for nature protection reasons), in four legal persons (LP) and in one case of individuals. Also in the districts where LP are the biggest owners, the situation is not uniform. In the Jeseník district, 88% of LP are churches. In the district of Prostějov, 57% of LP are owned by business companies. However, the forest area is the smallest among all analysed districts. In the Blansko district, municipalities are represented by the largest share, but the largest owner is the Mendel University in Brno (with its school forest training enterprise). In the Jihlava district, 86% of the LP are municipalities owners. The specific situation is in Vsetín district, where the

largest share of forests is owned by individuals. The largest owner (apart from the state) is Opatství Staré Brno Řádu sv. Augustina (Old Brno Abbey of the Order of St. Augustin; 4 129 ha) followed by company B.F.P., Lesy a statky Tomáše Bati, spol. s r.o. [Forests and Estates of Tomas Bata], 2 836 ha. The individual who owns the biggest forest area in this district is a woman born in 1950 living in the United Kingdom.

The problem is the ownership fragmentation. Table 2 shows the case of ownership fragmentation of individuals and NSCOS in the Vsetín district. Almost half of the owners has assets of area less than 0.5 hectare, 56% of the area is in size category of 5-50 hectares.

Table 2: Forest ownership structure according to the forest property area (individuals) in Vsetín district.

Tabelle 2: Struktur des Eigentums natürlicher Personen nach der Größe der Waldgrundstücken im Bezirk Vsetín.

Forest property size (ha)	Number of individuals (I)+NSCOS	Share from the number	Area (ha)	Share from the area
>250	1	0.01%	331.89	1.43%
>100 and <=250	6	0.04%	983.77	4.25%
>50 and <=100	8	0.06%	637.77	2.76%
>10 and <=50	269	1.93%	4,650.34	20.09%
>5 and <=10	700	5.03%	4,718.14	20.38%
>3 and <=5	958	6.88%	3,650.47	15.77%
>1 and <=3	3,106	22.30%	5,528.06	23.88%
>0,5 and <=1	2,153	15.46%	1,558.53	6.73%
>0,1 and <=0,5	3,638	26.12%	969.65	4.19%
<=0,1	3,090	22.18%	120.58	0.52%
In total	13,929	100.00%	23,149.20	100.00%

Small owners in this region represent more than 99%, in area 91%. These results underline the significant share of small forest owners both in terms of their number and in terms of their share on the forest area. The results of economic modeling below therefore have the opportunity to be utilized by the target group of small forest owners.

3.2 Economic modeling

The initial results of economic modeling in CZK are recalculated and presented in EUR (rounded to entire numbers, EUR 1 = CZK 26.33; source: CNB, 2017).

Table 3 shows the gross yield of forest production results for the six economic models (GYFP, green colour in Figure 2) and alternatively for the other six models, with the difference that direct seeding costs are considered (GYFP S, yellow in Figure 2).

Table 3: Gross yield of forest production (GYFP) models of birch stands models (in EUR on average per year and 1 ha).

Tabelle 3: Bruttogewinn (GYFP) der Waldproduktion von Birkenbestandmodellen (in EUR im Durchschnitt pro Jahr und 1 ha).

	Rotation period 20 years			**Rotation period 60 years**		
	A/acid	**A/nutr.**	**A/stagn.**	**B/acid**	**B/nutr.**	**B/stagn.**
	Average EUR/year/1 ha					
GYFP	-25	58	15	149	259	204
GYFP S (incl. seeding)	-240	-157	-200	78	188	132

The comparison and at the same time the differences between the individual results of economic models are better expressed in Figure 2.

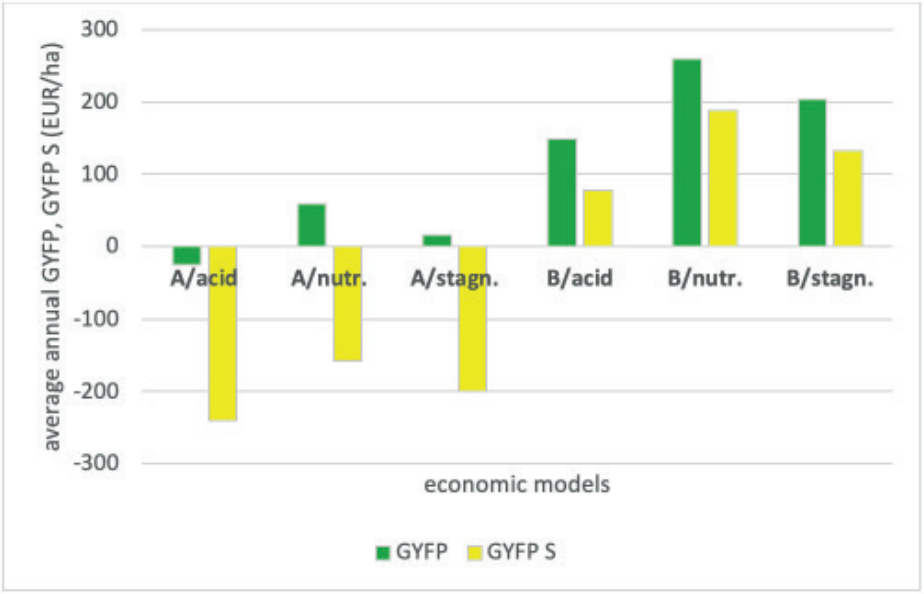

Figure 2: Comparison of the gross profit of the forest production (GYFP) of birch stand models (in EUR on average per year and 1 ha).

Abbildung 2: Vergleich des Bruttogewinns (GYFP) der Waldproduktion von Birkenbestandsmodellen (in EUR im Durchschnitt pro Jahr und 1 ha).

Figure 2 shows that in terms of economic efficiency, the short rotation period of birch stands (established by natural regeneration) is on the edge of acceptance in water-affected sites, where the average annual gross yield of forest production per hectare is 15 EUR. In the case of nutrient sites, the result is better (58 EUR) and worse for acidic sites (loss of 25 EUR). If artificial seeding is considered in economic models, then in the case of a short rotation period, the result is always a loss that reaches the highest level in acidic habitats (loss of 240 EUR). The low volume of wood production during a short rotation period of 20 years causes low efficiency of these models, in the acidic site we get at a loss due to the lowest volume of production compared to the other sites. The effectiveness of this group of models in short rotation is fundamentally influenced by the alternative use of artificial seeding instead of natural regeneration. Thanks to this, we get into a loss for all three "A" models and the gross yield of forest production taking into account the cost of artificial seeding (GYFP S) becomes a loss.

If a long rotation period is considered, then the average annual gross yield of forest production per hectare always reaches a positive value. The biggest influence on the differences between the efficiency of "B" models in different sites is again the

different volume of production. Furthermore, it is also the expected quality of raw wood assortments. In nutrient sites, these indicators reach the best values. The most economically favorable results are achieved with naturally established model stand on nutrient sites (EUR 259). At the same time, it is the highest achieved value of the average annual gross yield of forest production per hectare for the presented models. On the contrary, the lowest achieved value of the average annual gross yield of forest production per hectare (for long rotation period) is again in acidic sites when using seeding for forest regeneration (78 EUR).

Another interesting finding is the information on the impact of artificial regeneration on the economic results of modeling. This impact is the highest for short rotation period, because the level of revenues from wood-production function from model stands is low. In this case, the average annual gross yield of forest production per hectare is reduced by up to 215 EUR when considering artificial regeneration. A smaller effect of artificial regeneration is found in the case of long rotation period of model stands. The average annual gross yield of forest production per hectare is reduced "only" by around 71 EUR when considering artificial regeneration.

The relative expression of the differences in economic results between the models in the case of an economically viable variant of the long rotation period is also interesting. Naturally established model stands at the water-affected site achieve cca. about 37% better results and at the nutrient site even about 74% better results compared to the average annual gross yield of forest production per hectare at the acid site.

Overall, it can be said that the use of birch in the regeneration of declining spruce stands can provide small forest owners with an economically interesting alternative when deciding on the use of the tree composition of regenerated tree species.

4. Discussion

The significance of the article also lies in the fact that the results are applicable to large forest owners. When designing reforestation after calamities, in the field of economic efficiency, large forest owners have traditionally been based on a long-term perspective, which results from the "Forest Rent Theory". Large forest properties have a richer tree composition and calamities do not usually affect all forest stands of such property. The situation is different for small forest owners, where the calamity situation often affects the entire forest property. The long-term horizon of economic efficiency from the point of view of rotation period is too remote for an individual small forest owner. Such an owner prioritises forest regeneration at minimal cost, when the achievement of the main volume of revenues concern the future generations (Dudík *et al.*, 2020a). Besides other things this also was the reason why models with short rotation period (20 years) were considered. Another reason was to find out what possibilities there are (from the economic point of view and in the conditions of the Czech Republic) for birch cultivation more likely for the dendromass production than the

production of quality raw wood assortments.

With regard to the above mentioned, the article presents the results of models with the rotation period at maximum of 60 years. Within the projects solved for the state enterprise Lesy České republiky (Forests of the Czech Republic, see Introduction), there were also two other silvicultural frames created. In both of them, birch was used as a pioneer species. In the first case, birch was removed in a young age after fulfilling its function. In the second case birch was kept in the stand until its felling age as an admixture of target species. These models are less interesting in terms of achieving the first revenues for an individual small forest owner, who renew the stand. The rotation period of these stands is significantly longer. In addition to this, it is easier for small forest owners to tend a monocultural stand than (in a better case) to deal with two-phase forest regeneration. In a worse case also to raise a mixed-stand for a substantial part of the rotation period.

When evaluating the economic efficiency of forest management in forests owned by small forest owners, it is appropriate to mention another possible attitude. It is based on the modelling of net present value. This option allows to evaluate the efficiency of so-called one-time project. Project analysis contains procedures, methods and recommendations, which allows the investor (owner, forest manager) to best evaluate the economic impacts of the intended projects. The main meaning is how to maximize the effect of invested money.

A suitable method for financial valuation of long-term projects is the analysis of discounted "cash flows" - the expected cash costs and revenues in the individual years of the expected duration of the project. The net present value method provides an alternative view on the results from modelling obtained using the basis of "Forest Rent Theory" (see Table 3 and Figure 2). The algorithm used for calculation of the model net present value (NPVm and NPVm S) was the algorithm used by Pulkrab *et al.* (2008). Again, two alternatives for the establishment of a model birch stand were considered, namely natural regeneration (see NPVm results) and artificial regeneration (see NPVm S results). The compiled and calculated comparative models represent other results of the solved project, which are also usable for small forest owners. The use of the "Forest Rent Theory" and "Net Present Value" approaches corresponds to the methodological starting points used by Pulkrab *et al.* (2014).

In these calculations, the same sub-cost and revenue items (which arose during the rotation period of model stands) as in the GYFP and GYFP S calculations (see Table 3 and Figure 2) were used. The time level in this option is the time set for the rotation period of birch stands, while the wood production function of the forest is logically evaluated again. For the calculation, a discount rate of 2% was considered. The result of the calculation of the net present value of the model birch stand over the lifetime of the project (considering a long rotation period of 60 years) is always related to an area of 1 ha. The results of NPVm and NPVm S are shown in Table 4.

Table 4: Net present value (NPV) of the model birch stands.

Tabelle 4: Nettobarwert (NPV) der modellierten Birkenbestände.

	Rotation period 60 years		
	B/acid	**B/nutr.**	**B/stagn.**
	EUR/ha		
NPVm	2 646	5 320	3 567
NPVm S	-1 499	1 090	-578

The results in Table 4 again show a significantly positive effect of natural birch regeneration on the economic efficiency of the considered models. For models considering artificial regeneration (sows), the results of NPVm S in acidic and water-affected sites are even negative.

The gross yield of forest production of the birch management models becomes more apparent when compared to models of standard tree species management. In this comparison, a mixture of pine – *Pinus sylvestris* L. (70%), oak – *Quercus petraea* L. (20%), larch - *Larix decidua* Mill. (5%) and fir – *Abies alba* Mill. (5%) on acidic site reaches 32 EUR. Second model of standard tree species management, spruce – *Picea abies* L. (70%), beech – *Fagus sylvatica* L. (20%), larch (5%) and fir (5%), on acidic site reaches 144 EUR. Third model of standard tree species management, spruce (70%), beech (20%), larch (5%) and fir (5%), on sites affected by water reaches 193 EUR (Dudík *et al.*, 2018a). For all three models of standard tree species management, the share of natural regeneration of the stand in the amount of 30% was considered, artificial regeneration by plants was considered in the share of 70%. The price level of unit costs and revenues was used at the same level as in the calculation of birch stand models - the results of birch models are shown in Table 3. Comparison of birch and standard models results shows that if artificial regeneration is used, for both groups spruce is more economically advantageous, that they reach higher levels of gross yield of forest production (*e.g.* in water-affected sites, the spruce model was 46% more advantageous than birch).

Czech forestry has been facing the problem of declining stands, especially coniferous, in lower and middle locations in most parts of the Czech Republic in recent years. Currently, the problem concerns spruce, but also pine stands. As a result, there is a surplus of merchantable timber on the market, especially spruce timber from bark beetle salvage fellings, which causes a decrease in the selling price of all assortments

of spruce wood. In the period of 1st quarter of 2015 until 4rd quarter of 2020, the price of spruce wood in the assortment of quality class III.A/B (saw logs without bark beetle infestation) decreased by 42%, in the case of assortment quality class V. (pulpwood) it was up to 62%. This situation has a negative effect on the amount of receipts achieved from the sale of wood, which also has a negative effect on the cash flow of small and large forest owners, who have a significant proportion of spruce stands on their forest property (Dudík *et al.*, 2020a).

It is very important to take into account the optimal / telling price level of unit costs and revenues. As part of the solution of the second project for the state enterprise Lesy České republiky (Dudík *et al.*, 2021), the price level of 2020 was taken into consideration. That responded to the year of creation of new economic models, which followed the new structure of input information concerning the establishment, tending, and production possibilities of birch stands. I.e., also share of regeneration of birch stands with an artificial regeneration up to 50%, the attention was aimed at higher geographical locations than in the first project. An interesting finding was how the above-mentioned decline in the prices of spruce wood assortments was significantly projected in the comparison of the results of economic models of birch stands with models of standard tree species management. The result of the comparison of the mentioned models in the price level of 2020 was the opposite in comparison with the results of economic models in the price level of 2017. *E.g.* the spruce model in water-affected sites achieved a 28% lower level of gross yield of forest production than the birch model in the same site - both models were at the price level of 2020. It should be noted that this difference would be even greater if the price of birch roundwood did not fall by 8% between 2017 and 2020. The slump in wood prices in the Czech Republic occurred for both spruce and birch wood between 2017 and 2020. However, for spruce wood, this decline was significantly higher.

These published results provide a space for a future increase in the composition of birch in forest stands in the Czech Republic, while in 2019 the share of birch was 2.8% (MZe, 2020). However, it is important to communicate the possibilities of use of birch wood in wood-processing companies, because the attractiveness of birch wood products for customers can be increased by its heat treatment (Dudík *et al.*, 2020b). Higher consumption of wood on the domestic market, as well as a support for a higher degree of finalization of products, should be one of the key areas of interest in the wood-processing industry in the coming years (Palátová *et al.*, 2017). Another way to increase the demand for wood products in general is to use marketing tools working with information on forest certification and the related Chain-of-Custody system (Dudík and Riedl, 2015; Paluš *et al.*, 2017).

Equally important is to communicate the possibilities of using birch wood with forest owners. The motivation of forest owners to the forest management are very different (Takala *et al.*, 2017), especially for individual ownership. However, as the analysis has shown, among the districts which were hit mostly by bark beetle calamities, are those

where state or municipal ownership predominates. The state in its Concept of the state forest policy (Vláda, 2020) talks about the need to face climate change also with the change of species composition. As the analysis of a particular municipal forest owner (Jůza *et al.*, 2021) shows, such an owner may prefer ensuring the recreational forest function. Even in this case, birch can play an important role. In the Czech Republic, very popular are the collection of mushrooms (Sisak *et al.*, 2016) and other forest fruits (Riedl *et al.*, 2020), which are often tied to birch stands. To motivate small forest owners is relatively difficult, as Riedl *et al.* (2019) show, it is mostly the problem of properly chosen communication than technical matters.

5. Conclusion

Current economic calculations show that even from a long-term perspective, birch stands cultivated in a longer rotation period (up to 60 years) are an economically viable alternative to the commercial tree species in the Czech Republic, which include, among others, Norway spruce, Scots pine and European beech.

In the conditions of the Czech Republic, the use of alternative tree species in the regeneration of stands, such as white birch, provides lower costs for established stand, e.g. compared to European beech. In addition, significantly lower rotation period of birch enables to reach the receipts from timber sales earlier. And that can be interesting for small forest owners.

Based on the information provided in the sections Results and Discussion, it can be stated that in the long run, the relative differences between individual economic models are more significant result than the absolute expression of gross yield of forest production in EUR per year. At the same time, it is necessary to choose an appropriate and corresponding price level of unit cost and revenue inputs. This applies in particular to the comparison of the results of variant economic models of one tree species with the economic results of modelling of another tree species. If any of these woody species is in an extremely favourable or, conversely, in an extremely unfavourable situation on the wood market, it will significantly affect the results of the comparison of economic models.

Overall, it can be stated that the utilization and support of birch in the restoration and tending of forest stands in the conditions of the Czech Republic is becoming a competitive alternative to traditional commercial tree species, in our case spruce and pine. The economic efficiency of the birch management is enhanced by the use of natural regeneration. The reason is the greater sensitivity of the efficiency of the birch management to the level of spent costs. This is caused by a lower level of total sales of birch wood (in addition to the price, the lower achieved hectare production of birch stands also has an impact). However, this circumstance is positively compensated by the shorter rotation period of birch stands, which is positively reflected in the resulting gross yield of forest production in EUR per year.

The bioeconomic view of the possibilities of using birch confirmed the suitability of its use both in forestry and in the sector of wood-processing industry. Within this comprehensive view, based on the published works, the potential use of birch wood raw material in products with higher added value was also found, in the conditions of the Czech Republic.

Acknowledgments

Acknowledgement belong to the Grant service Forests of the Czech Republic, state enterprise, for the support of projects mentioned in Introduction, within which the initial data were collected. Composition of this article was supported by projects "Diversification of the Impact of the Bioeconomy on Strategic Documents of the Forestry-Wood Sector as a Basis for State Administration and the Design of Strategic Goals", grant No. QK1920391 and „Sustainable management in the forests of small owners", grant No. QK21020371; both funded by the Ministry of Agriculture of the Czech Republic.

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