forests

Article

Comparison of Economic Efficiency of Management Systems with Prevailing Representation of Sessile Oak (*Quercus petraea* (Matt.) Liebl.) in the Territory of Křivoklátsko Forest Park (Czech Republic)

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Abstract: The objective of the article was to model the economic efficiency of coppice and compare it with that of an oak high forest (primarily for the territory of Křivoklátsko Forest Park). The model calculations were based on actual expenses and revenues from the area of interest to the maximum possible extent. The calculations included methods both with time factor (dynamic methods, namely the method of net present value) and without time factor (static methods). For the area of Křivoklátsko Forest Park, the examined data showed that the economic efficiency of coppice could be greater than that of high forest or over-mature coppice.

Keywords: coppice; over-mature coppice; high forest; interest rate; sessile oak

1. Introduction

The advantage of the area of Křivoklátsko is that it remained almost untouched by the Neolithic revolution. Thus, it can be presumed that natural forests were preserved there as long as until the Early Middle Ages. The first colonization of the area took place in the 13th century, but only along watercourses and old roads. By then, a large part of the area was already protected as of the prince's and later the King' hunting district [1]. As for the ownership, the area of Křivoklátsko was divided into two dominions: Křivoklátsko and Zbirožsko. Originally owned by the King, the dominion of Křivoklátsko was sold to The House of Waldstein in 1685 and was passed on to the House of Fürstenberg by marriage in 1735. Since 1992, the territory has been administered by Lesy České republiky (State Enterprise). The dominion of Zbirožsko was purchased by the Colloredo-Mannsfeld family in 1879. Since then, the family has been managing the territory, except for years 1948–1992, when the territory was administered by the State through the Forest State Enterprise, national fisheries, and agricultural cooperatives [2]. The industrial revolution of the late 18th and early 19th century mainly led to the development of steel, metallurgical, and glass industry in the region. With its large iron ore deposits, ample water sources, and deep forests, Křivoklátsko was an important industrial area. As a result, it is sometimes referred to as the cradle of the Czech iron and steel industry [3]. Historically, there were mainly mixed forests. The predominating woody plant was oak accompanied by limes and birches. The quality of oaks declined over time. Around 1800, there are said to have been low-grade standard trees or poor-quality undergrowth [4]. The years 1750 through 1850 saw a loss of oaks and limes, followed by an important decrease in beeches and firs. Mixed forests were replaced with purely coniferous monocultures, mainly with pure pine or larch plantations, but also with pure spruce forests. Forest management then concentrated on transforming coppice forests, the traditional form of management, to high forests, which resulted in further reductions in the portion of broadleaf trees in the overall species composition. In the second half of the 19th century, the economic importance of oak felling dropped to its minimum. The proportional representation of broadleaf plants amounted to up to 10% [4]. It was not until the 1920s when the proportional representation of oak started to slowly increase, as can be supported by several authors (e.g., References [4–7]). The management of coppices, i.e., of forest stands mainly originating from the sprouting (vegetative) ability of woody plants, was traditionally used throughout the territory of the Czech Republic over hundreds of years. This management was characterized by intensive felling of stands aged 7–40 years [8]. Trunks were cut, preferably the nearest to the ground possible and during the dormancy. During the next growing season, stumps (also known as stamp heads) or roots and trunks automatically started to grow secondary trunks called sprouts. Coppice wood of up to 40 years of age shows very intensive growth and production thanks to nutrient reserves cumulated in the roots (as compared to a high forest of the same woody plant of seed origin growing in the same site). However, coppice forest management was gradually abandoned during the late 18th and whole 19th century due to economic reasons and coppice forests were transformed into high forests [9]. This was done through tending felling or generative regeneration of coppices, i.e., by their felling and replacement by means of planting mainly coniferous species of woody plants (spruces, pines, and larches). In the places where the conversion of coppices into high forests was not economically beneficial, the coppice forests were left unattended. This led to the formation of over-mature coppice forests, which persist in some places (e.g., References [10,11]).

It is crucial for a comparison of these different management systems whether the time factor is considered or not because of the length of the economic cycle (rotation period). In the case of the school of highest net forest yield, a forest is seen as something that has been around since ancient times and has been passed down through generations. A forest owner annually (periodically) takes some benefit from the forest and invests some costs in it while achieving annual regular and balanced profit. If the management is good, a forest does not lose its value since only the annual increment is felled while all silvicultural operations are performed. The next generation inherits the forest in the same condition as the previous one, so no high one-off investments are necessary. Another important aspect is that forests are not seen as investment projects. There are no start-up costs related to the acquisition of forests. Therefore, the calculations disregard the time factor (interest rate), which would normally express the cost of time of return on the investment. This school, however, requires several fundamental prerequisites to work. Above all, the forest estate must be sufficiently large to allow for balanced management. Regarding age classes, a "standard proportional representation" of age classes is required. The school of highest net land yield adopts a completely different approach. It sees a forest as an investment project. The interest rate and the length of a production cycle (rotation period) are crucial for the calculations that take into account the time factor. Investments into forests are often negative with longer rotation periods (ca over 100 years) and with the interest rate of approximately 3% or more. If a forest is purely seen as an investment project, such an investment should be rejected, or the investor should accept a lower interest rate.

These days, climate changes lead to reflections on the need of finding and employing functional forest management adaptation measures capable of effective elimination of the anticipated negative effects of global climate changes, as can be supported by several authors (e.g., References [12,13]). Climate change models predict an increase in temperature from 2.3 to 5.3 °C in central Europe in the 21st century Europe, accompanied by roughly a half of the total rainfall during spring and summer [14]. Thus, the focus of forest management on growing mixed stands with oak would likely be beneficial for the area of Křivoklátsko in the future. The question is which management system or systems should be adopted for forest regeneration and management? The possibilities include the traditional method of managing coppice or over-mature coppice forests as well as typical high forest management, which is the most widespread in the area. This article works with the hypothesis that economically, the most beneficial method of forest stand management in the given area is currently the high forest management [15]. This article aims to either confirm or reject this hypothesis, particularly from the economic perspective. We assume that the contribution will be an inspiration and guidance on how to manage the expected negative effects of climate change in Central Europe in areas with predominant winter oak.

2. Materials and Methods

2.1. Characteristics of the Analyzed Area

Křivoklátsko Forest Park (LP Křivoklátsko, Czech Republic) covers the area of the natural forest area of Křivoklátsko and Český kras and extends over the surface area of approximately 17,000 ha. The area lies about 60 km to the southwest of the City of Prague (red point on the map). Figure 1 shows the exact geographic location of the interest area in which the research was carried out.

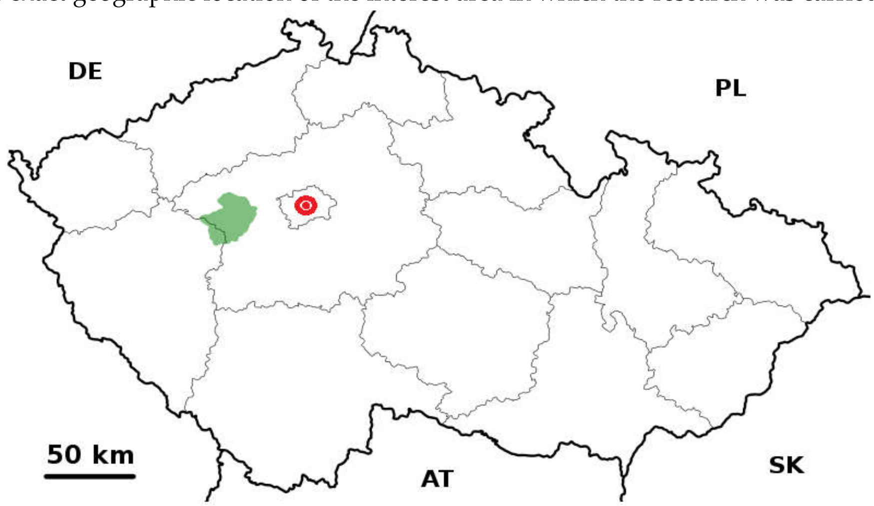


Figure 1. Geographic location of the interest area (green area on the map) of Křivoklátsko (Czech Republic).

LP Křivoklátsko was established in 2010 when the founding owners decided to manage the area in line with the so-called forest park standard [2,16] in the future. It can be said that a large part (about two thirds) of the respective area is administered by the State (Lesy České republiky, State Enterprise), while a smaller part is managed by private subjects (by the Colloredo-Mannsfeld family in particular). The average annual temperature in the area fluctuates between 7.1 and 8.8 °C, and the average annual precipitation is 480–617 mm, or 320–380 mm during the vegetation period [4]. An overview of the current composition of commercial woody plant species is provided in Table 1. It shows that broadleaf species (oak and beech) prevail in the woody plant composition. The most widespread coniferous woody plant is spruce.

Table 1. Current woody plant composition of the area of Křivoklátsko LP in % [4].

Woody plant	Spruce	Pine	Larch	Fir	Other conifers	Conifers total	Oak	Beech	Hornbeam	Other broadleaf species	Broadleaf species total
Conifers	27	9	9	1	1	47	-	-	-	-	-
Broadleaf species	-	-	-	-	-	-	18	18	8	9	53

2.2. Work Methodology

In the course of history, two basic approaches (so-called schools) have arisen, which conceive the benefits of forest (revenues) and deposits in it (costs) in terms of calculations quite differently. The authors come out from the "School of the highest net yield from the soil" when the forest is understood as an investment project. The basic international method that is used to assess the effectiveness of investments in the calculation of the net present value of the investment (NPV), which works with a time factor. The evaluation of profitability (NPV) is based on the prediction of monetary expenditures and income from the investment, not on estimates of accrued (accounting) costs and revenues. Investments are assessed through three criteria: return on investment, risk, and repayment (liquidity) of the investment. In calculating that take into time-factor, interest rates and the length of the production cycle (rotation period) play a crucial role. At a higher rotation period (over about 100 years) and interest rates of about 3% and above, investment in forests often results in a negative outcome. If we consider a forest as a pure investment project, such an investment should be rejected, or the investor would have to settle for a lower interest rate.

The modeling of cost and revenue of the management systems of oak coppice, high oak forest, and over-mature oak coppice took actual economic figures achieved in the area of LP Křivoklátsko in 2008–2017 as its basis. Complete lists of cost and revenue items performed in the individual forest stands were available. The economic efficiency of the compared management systems was evaluated using the calculation of net present value (NPV).

The general Formula (Formula (1)) for the NPV calculation can be expressed as follows:

$$NPV = SHP - SHN = \sum_{t-1}^{n} \frac{Pt}{(1+i)t} - \sum_{t-1}^{n} \frac{Nt}{(1+i)t} \quad (1)$$

where: NPV—net present value of the investment, t—individual decennia, SHP—present value of revenue, SHN—present value of costs, P—revenue, n—total time (regeneration), N—costs, and i—interest rate.

The following six options of oak stand management were evaluated and compared:

1: High forest—with a game-proof fence,
2: High forest—without a game-proof fence,
3: Over-mature coppice—with a game-proof fence,
4: Over-mature coppice—without a game-proof fence,
5: Coppice—site interclass I/II [16], with a game-proof fence,
6: Coppice—site interclass I/II [16], without a game-proof fence.

The input data for the evaluation of economic efficiency of the individual examined options are provided in Tables 2–4. Only the options without a game-proof fence are provided due to the extensive nature of the data. Should the variants with the game-proof fence also be considered for all the three compared variants, the costs would rise in each variant by CZK 94,000 (approximately $3760 USD) in the age class I.

Table 2. Variant: Oak high forest without game-proof fence.

Age class	Stand age (years)	Time since beginning (years)	Action	Unit	Quantity	Costs (CZK/unit)	Costs (CZK total)	Revenues (CZK/unit	Revenues (total in CZK)
1	1–10	1	*1	ths.	10.000	8936	89,360	-	-
1	1–10	1	*2	ha	1.00	4329	4329	-	-
1	1–10	1	*3	ha	1.00	9474	9474	-	-
1	1–10	2	*4	ths.	5.000	10,087	50,435	-	-
1	1–10	2	*2	ha	1.00	4329	4329	-	-
1	1–10	2	*3	ha	1.00	9474	9474	-	-

1	1–10	3	*2	ha	1.00	4329	4329	-	-
1	1–10	3	*3	ha	1.00	9474	9474	-	-
1	1–10	4	*3	ha	1.00	9474	9474	-	-
1	1–10	5	*3	ha	1.00	9474	9474	-	-
1	1–10	6	*3	ha	1.00	9474	9474	-	-
							209,626	**0**	**0**
2	11–20	15	*5	ha	1.00	5525	5525	-	-
2	11–20	15	*6	km	0.50	3184	1592	-	-
							7117	**0**	**0**
3	21–30	25	*7	m^3	13	216	2808	548	7124
							2808	**548**	**7124**
4	31–40	35	*7	m^3	20	211	4220	520	10,400
							4220	**520**	**10,400**
5	41–50	45	*8	m^3	20	170	3400	523	10,460
							3400	**523**	**10,460**
6	51–60	55	*8	m^3	21	203	4263	562	11,802
							4263	**562**	**11,802**
7	61–70	65	*8	m^3	20	125	2500	636	12,720
							2500	**636**	**12,720**
8	71–80	75	*8	m^3	19	119	2261	643	12,217
							2261	**643**	**12,217**
9	81–90	85	*8	m^3	18	108	1944	1207	21,726
							1944	**1207**	**21,726**
10	91–100	95	*8	m^3	19	118	2242	1553	29,507
							2242	**1553**	**29,507**
11	101–110	105	*9	m^3	0	98	0	1586	0
							0	**1586**	**0**
12	111–120	115	*9	m^3	0	98	0	1586	0
							0	**1586**	**0**
13	121–130	125	*9	m^3	44	70	3080	1663	73,172
							3080	**1663**	**73,172**
14	131–140	135	*9	m^3	98	84	8232	1736	170,128
							8232	**1736**	**170,128**
15	141–150	150	*9	m^3	268	93	24,924	1759	471,412

15	141–150	150	*10	m³	268	52	13,936	-	-
15	141–150	150	*11	ha	1.00	4685	4685	-	-
							43,545	**1759**	**471,412**

Legend: *1 Artificial regeneration—first planting of oaks in a clearing; *2 Protection of plantations against forest weed—chemically over the entire area; *3 Protection of plantations against forest weed—mechanically over the entire area; *4 Artificial regeneration—repeated planting of oaks; *5 Thinning of broadleaf plants; *6 Access—skidding trail; *7 Tending felling from thinning up to 40 years of age; *8 Tending felling from thinning over 40 years of age; *9 Regeneration felling for artificial regeneration *10 Slash cleaning—heaping up; *11 Site preparation for regeneration—fine cleaning.

Table 3. Variant: Oak over-mature coppice without game-proof fence.

Age class	Stand age (years)	Time since beginning (years)	Action	Unit	Quantity	Costs (CZK/unit)	Costs (total in CZK)	Revenues (CZK/unit)	Revenues (total in CZK)
1	1–10	1	*1	ha	1.00	4329	4329	-	-
			*2				**4329**	**0**	**0**
2	11–20	15	*3	ha	1.00	5525	5525	-	-
2	11–20	15	*4	km	0.50	3184	1592	-	-
							7117	**0**	**0**
3	21–30	25	*4	m³	35	723	25,305	1250	43,750
							25,305	**1250**	**43,750**
4	31–40	35	*4	m³	26	723	18,798	1250	32,500
							18,798	**1250**	**32,500**
5	41–50	45	*5	m³	21	610	12,810	1250	26,250
							12,810	**1250**	**26,250**
6	51–60	55	*5	m³	19	470	8930	1250	23,750
							8930	**1250**	**23,750**
7	61–70	65	*5	m³	17	386	6562	1250	21,250
							6562	**1250**	**21,250**
8	71–80	75	*5	m³	15	302	4530	1250	18,750
							4530	**1250**	**18,750**
9	81–90	85	*5	m³	14	243	3402	1250	17,500
							3402	**1250**	**17,500**
10	91–100	95	*5	m³	14	243	3402	1250	17,500
							3402	**1250**	**17,500**
11	101–110	105	*5	m³	0	243	0	1250	0
							0	**1250**	**0**
12	111–120	115	*5	m³	0	243	0	1532	0

							0	**1532**	**0**
13	121–130	125	*5	m^3	31	243	7533	1532	47,498
							7533	**1532**	**47,498**
14	131–140	135	*5	m^3	68	243	16,524	1532	104,190
							16,524	**1532**	**104,190**
15	141–150	150	*6	m^3	182	225	40,950	1673	304,541
15	141–150	150	*7	m^3	182	52	9464	-	-
15	141–150	150	*8	ha	1.00	4685	4685	-	-
							55,099	**1673**	**304,541**

Legend: *1 Protection of plantations against forest weed—chemically over the entire area; *2 Thinning of broadleaf plants (sprout singling); *3 Access—skidding trail; *4 Tending felling from thinning up to 40 years of age; *5 Tending felling from thinning over 40 years of age; *6 Regeneration felling for artificial regeneration; *7 Slash cleaning—heaping up; *8 Site preparation for regeneration—fine cleaning.

Table 4. Variant: Oak coppice forest, without game-proof fence.

Age Class	Stand Age (Years)	Time Since Beginning (years)	Action	Unit	Quantity	Costs (CZK/Unit)	Costs (Total n CZK)	Revenues (CZK/unit)	Revenues (Total in CZK)
1	1–10	1	*1	ha	1.00	4329	4329	-	-
							4329	**0**	**0**
2	11–20	15	*2	ha	1.00	5525	5525	-	-
							5525	**0**	**0**
4	31–40	37.5	*3	m^3	173.5	470	81,545	1250	216,875
							81,545	**1250**	**216,875**

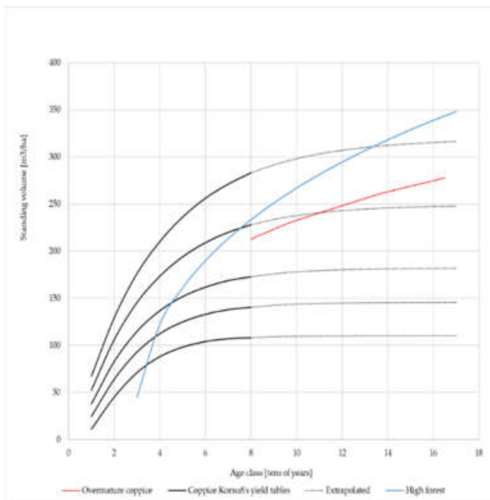
Legend: *1 Protection of plantations against forest weed—chemically over the entire area; *2 Thinning of broadleaf plants (sprout singling); *3 Regeneration felling.

In order to objectively compare the economic efficiency of coppice and high forest or over-mature coppice, it was necessary to employ models but with the use of actually achieved prices of silvicultural and felling operations and actual exercise prices of timber. The rotation period of 150 or 40 years used in the area was employed in the case of high forest and over-mature coppice. The net present value with the interest rate of 1% and 2% was calculated, as well as the difference between costs and revenues for the period of 150 years. The rotation period of 150 years was used in options 1 through 4. Options 5 through 6 (coppice) were calculated with the rotation period of 37.5 years (4 × 37.5 years = 150 years of a high forest). Forest growth tables were used in the case of coppice forests as there are currently no coppices managed in the area of LP Křivoklátsko. The tables were analyzed for their compliance with the figures of actually achieved over-mature coppice stock in the area of LP Křivoklátsko to assess their appropriateness for the application to oak coppice. Therefore, the values of hectare growing stock of over-mature coppice were classified according to the scale of available coppice tables (e.g., References [16,17]). Since the tables only include values of stocks with the stand age of up to 80, the curves of the individual site indexes in the respective tables were extrapolated as you can see in figure 2. The extrapolation was performed using the generalized Chapman–Richards function [18], as in Formula (2):

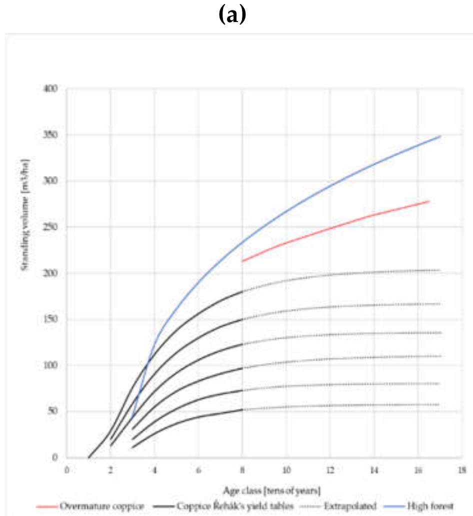
$$y = a \times (1 - e^{-b \times x})^{c} \quad (2)$$

where: y—explained variable, e—natural logarithm with the base in Euler's number, x—independent variable (age), and a, b, c—regression coefficients.

The site index of Řehák's tables lies outside the values of the actual stock of over-mature coppices and high forests in LP Křivoklátsko. The situation is different in the case of Korsuň's tables. The values of over-mature coppices are linked to the interclass I/II according to Korsuň's tables, see Figure 2. As there are no actively managed coppices in the interest area, a volume yield of interclass I/II according to Korsuň's tables [16] was used for coppices. For the high forest and over-mature coppices, actual oak growing stock achieved in the given area until the rotation period (150 years) was used. The calculations did not take account of the smallwood volume and branch biomass, also because the market with these raw materials is highly unstable and depends on support from the State (subsidies) and current prices of other fuels to a large extent.



(a)



(b)

Figure 2. Comparison of site index curves according to Korsuň (**a**) and Řehák (**b**) of real values of actual hectare stock of over-mature oak coppices and high oak forests in LP Křivoklátsko.

3. Results

The results of the comparison of the individual options of oak stand management in the territory of LP Křivoklátsko are presented in Figure 3 below.

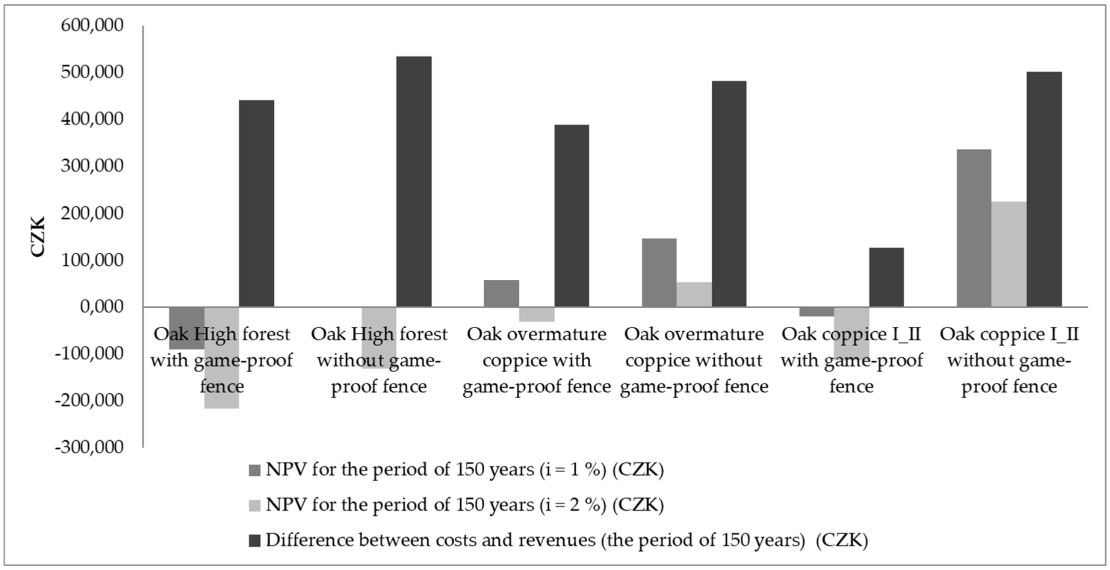
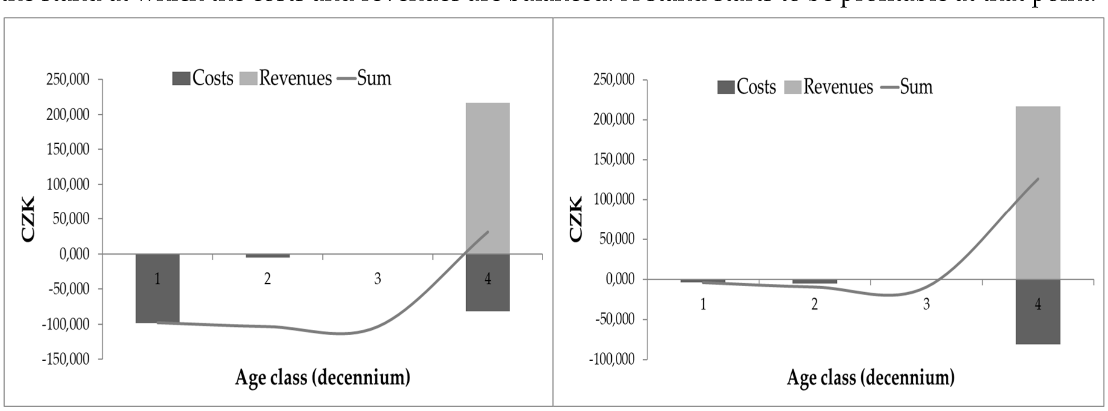


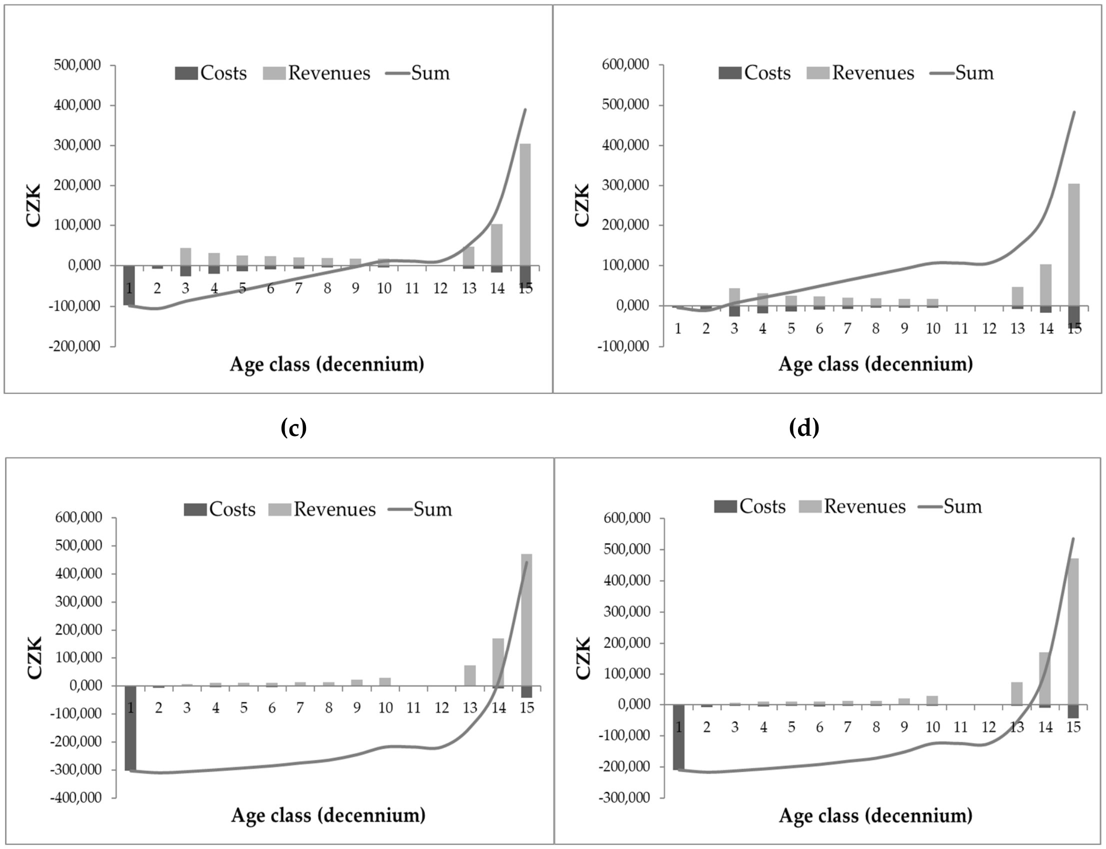
Figure 3. Economic comparison of oak stand management options in LP Křivoklátsko.

The results indicate that when the time factor is not incorporated into the calculation, the model of a high oak forest without game-proof fence is the most beneficial from the economic perspective, with 535,430 CZK/ha. The oak coppice without game-proof fence in the interclass I/II (without the effect of game) shows almost the same value, with 501,904 CZK/ha. To the contrary, the least beneficial model is the oak coppice with game-proof fence of the interclass I/II (126,960 CZK/ha). Calculating the net present value of the investment with the interest rate of 2%, the most beneficial option is the coppice without game-proof fence of interclass I/II (225,497 CZK/ha) and the least beneficial one is the high forest with game-proof fence (−216,979 CZK/ha). The use of over-mature coppices without game-proof fence also seems to be interesting from the economic point of view (NPV of 53,633 CZK/ha with i = 2%).

Figure 4a–f shows the courses of costs and revenues for the entire rotation period for the individual examined options (without taking into account the time factor). The point where the curve of the sum of revenues and costs since the stand establishment intersects the x-axis shows the age of the stand at which the costs and revenues are balanced. A stand starts to be profitable at that point.



(a) (b)



(c) **(d)**

(e) **(f)**

Figure 4. Course of costs and revenues through the whole rotation period for the individual examined variants (without regard to time factor). (**a**) Course of costs and revenues—coppice I_II with game-proof fence, (**b**) course of costs and revenues—coppice I_II without game-proof fence, (**c**) course of costs and revenues—over-mature coppice with game-proof fence, (**d**) course of costs and revenues—over-mature coppice without game-proof fence, (**e**) course of costs and revenues—high forest with game-proof fence, (**f**) course of costs and revenues—high forest without game-proof fence.

The above-mentioned results also show a considerable influence of costs of the forest protection against damages caused by game on the overall economy of the management. In the calculations involving the time factor, this is further amplified by the necessity to take these protective measures at the beginning of the production cycle and hence, by very long-term interest rates applied on the transferred capital over the entire rotation period. Moreover, the results suggest that with better site indexes, the economic efficiency of coppice could be better than that of high forest or over-mature coppice. With the interclass I/II [16] of the option without game-proof fence, the calculated difference between costs and revenues of four rotation periods of 37.5 years is 501,904 CZK/ha. This option achieved the second-best result of all the six examined options and the very best in the case of calculations involving the time factor. With i = 1%, the value of NPV for four rotation periods is 337,226 CZK/ha, with i = 2%, the result is 225,497 CZK/ha. The results for coppice with game-proof fence are much worse. The difference between costs and revenues is only positive with the coppice without time factor [16] (126 960 CZK/ha). The calculations including time factor [16] with i = 2% reached negative values (−114,102 CZK/ha). Consequently, coppice cultivation is only economically viable in the case of better site indexes or at localities with reasonable cloven-hoofed game population, where a game-proof fence is not necessary, or in the case of adopting other means of protection against damages caused by game.

Another economically interesting alternative could be the cultivation of over-mature coppices. The biggest advantage, in this case, is the very low costs on establishing new stands. Only the option with game-proof fence and i = 2 % reached a negative level (−31,267 CZK/ha). The difference between costs and revenues in the case of the option without game-proof fence is 483,138 CZK/ha. The calculations for high forests involving the time factor generally reached negative values. This was mainly due to the high initial costs of establishment and potential protection of the new stand as well as due to the relatively long rotation periods (150 years in the case of the examined options). Both options of high oak forest cultivation (with and without game-proof fence) reached negative values, with both i = 1% and i = 2%. In the case of the option with game-proof fence, the revenues less the costs are 441,694 CZK/ha, while without game-proof fence, they are 535,430 CZK/ha.

4. Discussion

This article compared the economic efficiency of forest management systems in the case of forest stands with a predominance of sessile oak in the territory of Křivoklátsko Forest Park. A major challenge is the anticipated negative effects of climate changes on the forest stands in the Czech Republic (e.g., References [12,19]). Although management of oak in the Czech Republic might appear beneficial for the future [20], the question is, which management system or combination of management systems shall be used for the said purpose in the examined area? It is possible to say that today's forest stands with a predominance of sessile oak are a result of the transformations of coppices into high forests in the form of over-mature coppices exercised in the past or of intentional forest regeneration that gave rise to high forests. These days, there are no actively managed coppices in the area. Coppices and their economic comparison with other management systems were included into the study to introduce the results of studies on the potential effectiveness of the use of coppices with regard to the anticipated negative effects of global climate changes, to drought in particular.

Results of studies (e.g., References [21–24]) suggest that coppice is a promising forest management adaptation alternative with a better adaptation strategy at extreme localities, mainly in conditions with limited availability of water. However, the observed advantage probably lasts only during the first two decades and then gradually declines [21]. This fact (if generally confirmed) could substantially limit the recommendation for the use of coppices in a normal forestry operation. Nevertheless, it will probably not apply to very extreme and drying sites.

Interesting results were produced by a study concentrated on the relation between climate and growth of over-mature oak coppices and high forests [24]. The results show a positive effect of precipitation during the period from May to April on trees of both generative and vegetative origin. The temperatures of the previous autumn and June of the given year seem to negatively correlate with the radial increment of coppice forests in a statistically significant way. Nevertheless, trees from generatively propagated stands showed higher sensitivity to drought (in comparison with over-mature coppice). During the 20th century, they also tended to increase the radial growth thanks to higher temperatures of the previous autumn. The authors of the study believe that the positive effect of warmer autumns, which was confirmed in high forests, could be linked to a prolonging growing season. This could signify an improved capacity to adapt to the forthcoming warmer environment. This fact (if generally confirmed) would considerably favor high forests against over-mature coppice.

The growth and yield prediction, as well as the economic assessment of coppice presented in this paper, was done with the help of growth tables for oak coppices, called Korsuň's tables [16], which were historically used for the given purpose in the territory of the Czech Republic. Apart from those, other tables were also used, such as Korsuň's tables as adjusted by Řehák [17]. It should be noted that there is no officially approved growth chart in the Czech Republic these days to be used for coppice forests.

The determination of the expected forest yield, i.e., of the utility value, requires an appropriately set interest rate. However, setting the interest rate for forest valuation is a difficult task. The main reason is that the rate is not determined by revenues and market forces only, but that other factors also apply which are specific for this type of asset [25]. There are several different schools in setting the proper interest rate. In various publications, its value ranges from 0% to 8%, which is a wide range from the perspective of forest asset valuation. Besides, the purpose of valuation matters. For example, supporters of the net land yield method have long been trying to enforce the interest rate for forest management of 3% as a generally valid interest rate for calculations [26]. In the Czech Republic, the interest rate of 2% is generally used for all groups of woody plants [27]. For example, several authors (e.g., References [28–30]) mention the use of other interest rates in forest management.

As for the economy of coppices, they dominated the specter of forest management systems over a long period and were profitable under the conditions that were used then [31]. Yet, the scale of utilities covered by forests was considerably wider in those days and, consequently, the possibilities to apply the findings about their profitability to today's forests is limited. From today's point of view, historical materials can rather provide us with a summary of the advantages of coppices with a link to the economy of management, including a better-balanced management thanks to a shorter production period and hence earlier "harvest", lower costs in comparison with high forests, and minor production risk levels [32]. No firm conclusions regarding the profitability of such forests can be established due to their absence in the Czech Republic. The few sources dealing with this issue include papers that compare coppice (or medium forest) as an economic alternative with other types of management (e.g., References [33,34]). However, the results of those studies differ based on the local conditions regarding sales or growth, as can be supported by several authors (e.g., References [35–40]).

Unfortunately, there are only a few sources [41], which could provide us with information that could help answer the question of which of the examined forest stand management systems can be used for the specific area. It is probably linked with the historical departure from the coppice management, the conversion of coppices to high forests, and with probably more beneficial management of high forests than of coppices from the economic perspective. The biggest amount of information of economic nature relates to the conversion of coppices to high forests, for example in the form of assessed costs linked with the actual conversion procedure (e.g., References [42–44]), assessments of conversion productivity (e.g., References [43–45]) or return on investments (e.g., References [46,47]), and calculations of the resulting financial value of the applied conversion to a high forest [48].

5. Conclusions

Based on the examined options and results, the following facts were found about the area of LP Křivoklátsko:

- In better site indexes, the economic efficiency of a coppice could be higher than that of a high forest or over-mature coppice.
- The option number 6 with the time factor, i.e., coppice—interclass I/II [16], without a game-proof fence, gives the best results.
- Coppice cultivation is economically viable only in the best site indexes or at localities with reasonable cloven-hoofed game population, where game-proof fences are not necessary, or where other means of protection against damages caused by game are used.
- Cultivation of over-mature coppices might become an economically interesting alternative.
- In the case of high forests, the values reach negative levels (calculations with time factor) due to the high initial costs of establishment or protection of the new forest stand as well as due to the use of a relatively long rotation period (150 years in the examined options).

Although the results of this study show that it is economically beneficial for the area of LP Křivoklátsko to manage the oak stands in the form of coppices or over-mature coppices, several facts should be pointed out. Recently, several studies concentrating on the relation between the growth of high oak stands and the climate were carried out in central Europe (e.g., References [49–51]), as well as studies pointing out coppice forests as a promising adaptation alternative for extreme localities, namely in the areas with limited availability of water, as can be supported by several authors (e.g., References [21–24]). On the other hand, there are also studies which call the advantageousness of coppices as an adaptation alternative into question concerning its long-term functioning [21] and studies which rather favor high oak forests to over-mature coppices because of the changing climatic conditions [24]. It is obvious that relatively little information is available about the comparison of the growth of oak coppices, over-mature oak coppices, and high oak forests in the period of the anticipated future scenarios of climate development. Therefore, we believe that it is necessary to look at the results of this study from more perspectives than just from the economic point of view.

We see the management of oak stands in the form of coppices or over-mature coppices in central Europe as a potential alternative to the current method of high forest management, in particular, for extreme sites with limited availability of water.

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References

1. Žák, K.; Majer, M.; Hůla, P.; Cílek, V. *(Křivoklátsko—Příběh Královského Hvozdu [Křivoklátsko: The Story of King's Forest]*, 1st ed.; Dokořán: Prague, Czech Republic, 2016; 318p, ISBN 978-80-7363-762-0.
2. LP Křivoklátsko. [Křivoklátsko Forestry Park] (KFP). Available online: http://www.lpkrivoklatsko.cz/summary.html (accessed on 15 March 2020).
3. Kopecký, M. Křivoklátsko—Sledování Vývoje Krajiny na Starých Mapách [Křivoklátsko: Tracking of Landscape Evolution Using Old Maps. Bachelor's Thesis, Czech Technical University in Prague, Prague, Czech Republic, 2011; 52p.
4. *LHP Křívoklátsko [Forest Management Plans of owners from area Forest Park Křivoklátsko*]; Private source of information from LP Křivoklátsko. Private communication, 2019.
5. Maděra, P.; Buček, A.; Úradníček, L.; Slach, T.; Friedl, M.; Machala, M.; Řepka, R.; Lacina, J.; Černušáková, L.; Volařík, D. *Starobylé Výmladkové Lesy, Jejich Význam a Udržitelnost v Kulturní krajině [Ancient Sprout Forests: Importance and Sustainability in Cultivated Landscapes].* Mendel University in Brno: Brno, Czech Republic, Certified methodology; 2016.
6. Skopeček, J. Dynamika a Příčiny Hospodaření s Křivoklátskými Lesy od Poloviny 18. Století do Roku 1939 [Dynamics and Causes of Management of Krivoklat Forests from the Mid. 18th Century to 1939]. Master's Thesis, Charles University in Prague, Prague, Czech Republic, 2008; 103p.
7. Lesprojekt Hradec Králové s. r. o. *Lesní Hospodářský Plán Křivoklát 2005–2014 [Forest Management Plan Křivoklát 2005–2014]*; Textual part; Lesprojekt Hradec Králové s.r.o.: Hradec Králové, Czech Republic, 2004.
8. Müllerová, J; Szabó, P.; Hédl, R. The rise and fall of traditional forest management in southern Moravia: A history of the past 700 years. *For. Ecol. Manag.* **2014**, *331*, 104–115.
9. McGrath, M.J.; Luyssaert, S.; Meyfroidt, P.; Kaplan, J.O.; Bürgi, M.; Chen, Y.; Erb, K.; Gimmi, U.; McInerney, D.; Naudts, K.; et al. Reconstructing European forest management from 1600 to 2010. *Biogeosciences* **2015**, *12*, 4291–4316.
10. Matthews, J.D. *Silvicultural Systems*; Oxford University Press: Oxford, UK, 1991.
11. Buckley, G.P. *Ecology and Management of Coppice Woodlands*; University Press, Cambridge, UK, 1992.
12. Lindner, M.; Fitzgerald, J.B.; Zimmermann, N.E.; Reyer, C.; Delzon, S.; van der Maaten, E.; Schelhaas, M.-J.; Lasch, P.; Eggers, J.; van der Maaten-Theunissen, M.; et al. Climate change and European forests: What do we know, what are the uncertainties, and what are the implications for forest management? *J. Environ. Manag.* **2014**, *146*, 69–83.
13. Puettmann, K.J.; Wilson, S.M.G.; Baker, S.C.; Donoso, P.J.; Drössler, L.; Amente, G.; Harvey, B.D.; Knoke, T.; Lu, Y.; Nocentini, S.; et al. Silvicultural alternatives to conventional even-aged forest management—What limits global adoption? *For. Ecosyst.* **2015**, *2*, 2–16.
14. IPCC. *Climate Change 2013, the Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK, 2013.

15. IMFN. International Model Forest Network: What is a Model Forest? Available online: https://imfn.net/model-forest/ (accessed on 15 March 2020).
16. Korsuň, F. Život dubových pařezin v číslicích [Life of Oak Coppices in Figures]. *Pap. Czechoslov. For. Res. Inst.* **1954**, *6*, 154–190.
17. Řehák, J. *Úprava Růstových Tabulek Pro Výmladkový Dub, Olši a Habr [Adjustment of Growth Tables for Oak, Alder, and Hornbeam Sprouts]*; Final report; VŠZ in Prague. Forest Research Instute in Kostelec Nad Černými Lesy: Prague, Czech Republic, 1981; 41p.
18. Pienaar, L.V.; Turnbull, K.J. The Chapman-Richards generalization of von Bertalanffy's growth model for basal area growth and yield in even-aged stands. *For. Sci.* **1973**, *19*, 2–22.
19. Hlásny, T.; Barcza, Z.; Fabrika, M.; Balázs, B.; Churkina, G.; Pajtík, J.; Sedmák, R.; Turčáni, M. Climate change impacts on growth and carbon balance of forests in Central Europe. *Clim. Res.* **2011**, *47*, 219–236.
20. Mikita, T.; Čermák, P.; Trnka, M.; Jurečka, F. Modelování Podmínek pro Pěstování Smrku, Buku a Dubu [Modelling Conditions for Spruce, Beech, and Oak Cultivation]. FRAMEADAPT—Frameworks and Possibilities of Forest Adaptation Measures and Strategies Connected with Climate Change. Technical Report 1.4. 2016. Available online: https://www.researchgate.net/publication/337276121_Modelovani_podminek_pro_pestovani_smrku_buku_a_dubu (accessed on 18 February 2020).
21. Pietras, J.; Stojanović, M.; Knott, R.; Pokorný, R. Oak sprouts grow better than seedlings under drought stress. *iForest Biogeosci. For.* **2016**, 552, doi:10.3832/ifor1823-009.
22. Stojanović, M.; Čater, M.; Pokorný, R. Responses in young Quercus petraea: Coppices and standards under favourable and drought conditions. *Dendrobiology* **2016**, *76*, 127–136, doi:10.12657/denbio.076.012.
23. Stojanović, M.; Szatniewska, J.; Kyselová, I.; Pokorný, R.; Čater, M. Transpiration and water potential of young Quercus petraea (M.) Liebl. coppice sprouts and seedlings during favourable and drought conditions. *J. For. Sci.* **2017**, *63*, 313–323.
24. Stojanović, M.; Sánchez-Salguero, R.; Levanič, T.; Linares, J.C.; Szatniewska, J.; Pokorný, R.; Linares, J.C. Forecasting tree growth in coppiced and high forests in the Czech Republic. The legacy of management drives the coming Quercus petraea climate responses. *For. Ecol. Manag.* **2017**, *405*, 56–68.
25. Matějíček, J.; Šafařík, D.; Vala, V.; Sebera, J.; Lenoch, J. *Úroková Míra v Lesnictví. [The Forestry Interest Rate]*; Lesnická práce, s. r. o., Kostelec Nad Černými Lesy: 2013; 160p.
26. Endres, M. *Lehrbuch der Waldbewertrechnung und Forststatik*; 4. Auflage; Berlin, Germany, 1923. Available online: https://docplayer.cz/69182702-Trzni-realizace-mimoprodukcnich-funkci-lesa.html (accessed on 31 December 2016).
27. DECREE NO. 441/2013 COLL., Implementing the Property Valuation Act (Valuation Decree), as Amended. Available online: https://www.zakonyprolidi.cz/cs/2013-441 (accessed on 15 March 2020).
28. Moog, M.; Bösch, M. Interest rates in the German forest valuation literature of the early nineteenth century. *For. Policy Econ.* **2013**, *30*, 1–5.
29. Mantel, W. *Waldbewertung, Einführung und Anleitung. 5. Neubearbeitete Auflage*; Bayerischer Landwirtshaftsverlag München Basel: Wien, Austria, 1968; 308p.
30. Tutka, J.; Vilček, J.; Kovalčík, M. *Oceňovanie Lesa. [Forest Valuation]*; The Insitute for Education and Training for Staffs of the Forest and Water Management: Zvolen, Czech Republic, 2003; 254p.
31. Jančík, A. *Dějiny lesního závodu VŠZ v Brně. A) Adamovské lesy. 2. Od Smrti Aloise I. Liechtenštejna 1805 do nastoupení Jana II. Liechtenštejna 1858. [History of Forest Enterprise VŠZ in Brno. A) Adamov Forests. 2. From the Death of Aloys I, Prince of Liechtenstein, to the Beginning of Reign of John II, Duke of Liechtenstein, in 1858]*; VŠZ Brno. Křtiny Forest Enterprise: Mendel university in Brno, Brno, Czech Republic, 1960; 201p.
32. Frič, J. *Zařízení lesů [Forest Management]*; Československá Matice Lesnická: Písek, Czech Republic, 1947; 516p.
33. Styles, D.; Thorne, F.; Jones, M. Energy crops in Ireland: An economic comparison of willow and Miscanthus production with conventional farming systems. *Biomass Bioenergy* **2008**, *32*, 407–421.
34. Gasol, M.C.; Brun, F.; Mosso, A.; Rieradevall, J.; Gbarrell, X. Economic assessment and comparison of acacia energy crop with annual traditional crops in Southern Europe. *Energy Policy* **2009**, *38*, 592–597.
35. Le Goff, N.; Garros, L.; Canta, R. Indice de productivité des tailis sous futaie de chene dans la région centre. *Ann. Sci. For.* **1984**, *41*, 1–34.
36. Dubourdieu, J. L'intéret de la conversion des tailis-sous-futaie en futaie et ses limites. *Rev. For. Fr.* **1991**, *43*, 146–161.

37. Schütz, J.P.; Rotach, P. Mittelwaldbetrieb: Nostalgische Illusion oder zukunftsträchtiges Waldbaukonzept? *Wald Und Holz* **1993**, *74*, 8–12.
38. Suchant, R.; Opeker K.; Nain, W. Der Kirschen—Mittelwald: Ökonomische und ökologische Alternative für den Niederwald. *Allg. Forst-Und Jagdztg.* **1995**, *167/7*, 139–148.
39. Hochbichler, E. Fallstudien zur Struktur, Produktion und Bewirtschaftung von Mittelwäldern im Osten Österreichs (Weinviertel). Band 20. Österreichische Gesellschaft für Waldökosystemforschung und Experimentelle Baumforschung. Ph.D. Thesis, Universität für Bodenkultur, Wien, Austria, 2008; 245p.
40. Kneifl, M.; Kadavý, J. Modelové srovnání výnosovosti nízkého a vysokého dubového lesa [Model Comparison of Oak Coppice and Oak High Forest Profitability]. [CDROM]. In *Nízké a střední lesy v krajině [Coppice and High Forests in Landscape]*; Mendel university in Brno, Brno, Czech Republic, **2009**; ISBN 978-80-7375-292-7.
41. Kneifl, M.; Kadavý, J.; Knott, R. Gross Value Yield Potential of Coppice, High Forest and Model Conversion of High Forest to Coppice on Best Sites. *J. For. Sci.* **2011**, *57*, 536–546.
42. Amorini, E.; Fabbio, G.; Gambi, G. Thinning regime for coppice stands for conversion to high forest. Experimental trials for multiple use with grazing. *Ann. Dell'ist. Sper. Selvic. Italy* **1979**, *10*, 1–23.
43. Piegai, F.; Fabiano, F. Harvesting of firewood at coppice clearcutting and at first thinning for coppice conversion into high forest. *Ann. Dell'ist. Sper. Selvic.* **2002**, *33*, 51–62.
44. Piegai, F. Utilization and conversion in oak coppice: Productivity compared. *Sherwood For. Alberi Oggi* No.117, **2005**, 5–8. Available online: https://www.cabdirect.org/cabdirect/abstract/20063011218 (accessed on 1 March 2020).
45. Picchio, R.; Maesano, M.; Savelli, S.; Marchi, E. Productivity and energy balance in conversion of a Quercus cerris L. coppice stand into high forest in Central Italy. *Croat. J. For. Eng.* **2009**, *30*, 15–26.
46. Marca, O. Research into the exploitation of Turkey oak woods in Italy. *Cellul. Carta* **1992**, *43*, 28–32.
47. Vassilev, Z. On the economic effectiveness of reconstructions of low productivity coppice forests. In Proceedings of a Jubilee Symposium Marking 125 Years of the Bulgarian Academy of Sciences and 65 Years of the Forest Research Institute Sofia Bulgaria, Sofia, Bulgaria, 22–23 September **1994**; pp. 126–130.
48. Durkaya, A.; Durkaya, B.; Cetin, M. Conversion possibilities of oak (Quercus sp. L.) coppices into high forests in Bartin, Turkey. *Bartin Orman Fak. Derg.* **2009**, *11*, 51–59.
49. Doležal, J.; Mazůrek, P.; Klimešová. J. Oak decline in southern Moravia: The association between climate change and early and late wood formation in oaks. *Preslia* **2010**, *82*, 289–306.
50. Mérian, P.; Bontemps, J.-D.; Bergès, L.; Lebourgeois, F. Spatial variation and temporal instability in climate-growth relationships of sessile oak (Quercus petraea [Matt.] Liebl.) under temperate conditions. *Plant Ecol.* **2011**, *212*, 1855–1871, doi:10.1007/s11258-011-9959-2.
51. Rybníček, M.; Čermák, P.; Prokop, O.; Žid, T.; Trnka, M.; Kolář, T. Oak (Quercus spp.) response to climate differs more among sites than among species in central Czech Republic. *Dendrobiology* **2016**, *75*, 55–65.