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Growth Response of Sessile Oak and European Hornbeam to Traditional Coppice-with-Standards Management

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Abstract: *Research Highlights:* The influence of litter raking and livestock grazing on the development of juvenile sessile oak and European hornbeam sprouts as well as on sessile oak standards were studied. Such experiments are very rare, especially in central Europe where these activities have been prohibited for several decades. Little is known on how these ancient management activities affect tree growth. *Background and Objectives:* Traditional management practices in coppice forests such as grazing and litter raking have been abandoned, but have recently been studied as to whether these practices can substantially contribute to an increase in the species diversity of coppices. The important question is, however, how these practices influence the growth of coppice-with-standards. Therefore, this study focused on the effect of grazing, litter raking, and their combination on both sprouts and adult trees in a coppice-with-standards system one year after harvest. *Materials and Methods:* The experiment was carried out in the area of the Training Forest Enterprise Masaryk Forest Křtiny, Czech Republic, in a forest stand dominated by sessile oak and European hornbeam. We analyzed 132 oak polycormons, 132 hornbeam polycormons, and 163 oak standards. *Results:* The number of sprouts per stump was affected by the stump size and management practice: (A) coppice-with-standards, litter raking, and sheep grazing; (B) coppice-with-standards and sheep grazing; (C) coppice-with-standards and litter raking; and (D) coppice-with-standards), but not by tree species. The number of the sprouts as well as their height increased with the stump size. In contrast, grazing resulted in a smaller height of the sprouts while thinner sprouts were found under a combination of grazing and raking. When comparing the species, the oak sprouts were higher and thicker when compared to the hornbeam sprouts. The increment of standards increased after stand harvest. This, however, was not the result of grazing or raking, but the response to the reduction of tree number and thus of competition between neighboring trees. *Conclusions:* The results showed that there were rather negative impacts from the implemented traditional management practices on the growth of sprouts. This may lead to the question of whether ecological diversity resulting from the traditional practices may prevail their negative effect on the growth of the coppices.

Keywords: litter raking; grazing; sheep; standard; sprout

1. Introduction

In the past, coppicing was a traditional forest management applied across almost the whole of the Czech Republic. In the coppices were dominant easily resprouting species such as hornbeam, oak, and lime [1]. Aside from coppicing, practices like livestock grazing, litter raking, hay harvest, old grass burning, stump digging, etc. were frequently used in forests. Most of these practices have been abandoned and some of them have even been prohibited due to their presumed negative effect on forest ecosystems [2]. The active practice of such activities resulted in devastated forests (coppices) and soil degradation. On the other hand, the effect of practices like litter raking and livestock grazing have recently been studied and recommended as a tool of meadow maintenance in protected areas (for instance, grass mowing and grazing in the protected landscape area Bílé Karpaty in the Czech Republic). The application of litter raking and livestock grazing have also been evaluated in forests with a prevailing protective function in the Podyjí National Park, Czech Republic [3,4]. Results of these experiments showed that restoration of traditional management (raking and grazing) can increase the species' floristic diversity of coppices [5].

Coppices utilize the advantages of the rapid vegetation regeneration of broadleaf tree species that are periodically cut [6]. Coppices are characterized by intensive harvest measures applied every 7–40 years [7]. Rotation length depends on the site quality (the better the site quality, the shorter the rotation). Stems are cut as close to the ground level as possible, preferably in the winter. Most central European broadleaved tree species have the ability to create (either from the stump or from roots) secondary stems, so called sprouts. It has been documented that the growth and wood production of a coppice is more intensive during the first 40 years after harvest when compared to seed origin trees growing on the same site due to assimilation reserves allocated in the coppice root system preserved from the previous generation [8]. Coppicing is being reintroduced for many reasons, but mainly as a source of renewable energy (biomass production) [9], increasing biodiversity [10], or urban forestry [11]. Coppice-with-standards is a management type where a certain density of quality trees of generative origin (so called standards) are not harvested in order to enhance the coppice regeneration with seeds [12]. The standards are cut at the end of the next harvest period and the whole process is repeated again and again. This system provides wood for fuel (coppice) and timber (standards).

Tree harvesting reduces forest floor shading and accelerates the growth of herbaceous plants. Therefore, coppice stands used to also serve as pasture for cattle. The grazing of livestock has shaped the European countryside since Neolithic times. A wide range of biotopes have been created and maintained in this way (for instance, floodplain forests, steppes and forest steppes, moors, juniper pastures, etc.) [13]. A typical example of the historic influence of pasture on the countryside is that of Great Britain, where cattle grazing contributed to the preservation of semi-natural forests [14,15]. Pasture abandonment started at the beginning of 18th century and peaked in the second half of the 20th century as a result of intensified agriculture and the transition to stable cattle breeding. The biodiversity of abandoned pastures has decreased due to natural succession. From this point on, grazing has no longer been considered as harmful, but as a maintaining measure [16].

Tree litter raking has been a widespread way of forest utilization in Central Europe since the 12th century. Tree litter is a layer of organic material of tree origin (especially leaves) in various degrees of decomposition and humification on the forest ground. As such, it is the main source of humus in forest soils. Humus composition is substantially affected by canopy species composition [17,18]. Primarily, the tree litter has been utilized as bedding for livestock and then mixed up with excrement and used as fertilizer. Around the 1800s, tree litter utilization peaked and became indispensable for small farms [19]. The first tree litter yield ranged between 6 and 15.6 t ha^{-1} per year [20–22]. Approximately since 1850, the first experiences of the negative consequences of litter raking were documented such as a decline in the nutrient content and an overall negative impact on forest soils [20]. Therefore, this activity was considered undesirable and substantially limiting for the production of fuel wood and valuable timber assortments. During the 19th century, tree litter raking was essentially reduced and, from the beginning of the 20th century, was almost abandoned [23]. Recently, tree litter raking has been applied rarely on a limited number of areas in southern Europe, and is still declining [24].

Therefore, there is only limited information on the influence of the above-mentioned activities on commercial coppice woodland biotopes. This coincides with the drop in fuel wood demand and conversions of coppices to high forests during the last approximately 60 year [25].

The main goal of this paper was to explore (i) whether and to what extent the grazing, litter raking, and stump cross sectional area affected the growth of sprouts (number, diameter, and height of sprouts) of two different species (sessile oak and European hornbeam) in the coppice-with-standards (C-W-S), and (ii) whether and to what extend the traditional managements and their combinations affect the growth at the standards.

2. Materials and Methods

2.1. Site Description

The study site is located at the Training Forest Enterprise Masaryk Forest Křtiny, Bílovice forest district, in the southeastern part of the Czech Republic (49°25′ N, 16°68′ E), 340 m a.s.l. with a mean annual temperature of 7.5 °C and mean annual precipitation of 550–650 mm. The soil at the site is classified as Dystric Cambisol [26] with Dysmull and Hémimoder [27] as the dominating humus form (organic horizons predominantly 2.5–4.5 cm thick on average, composed of OLn, OLv, and OF horizons and discontinuous or absent OH horizon). The predominating tree species are sessile oak (*Quercus petraea* [Matt.] Liebl.), European hornbeam (*Carpinus betulus* L.), and European beech (*Fagus sylvatica* L.) with an average representation of 58.0%, 20.3%, and 14.0%, respectively, with the average site index (SI) of 22, 18, and 24, respectively (expected height in meters for 100 years old stand) [28]. A small admixture of *Tilia cordata* Mill., *Prunus avium* (L.) L., *Larix decidua* Mill., and *Pinus sylvestris* L. in the tree layer was also present.

2.2. Experimental Design

In 2017, three small (30 × 40 m) and six larger plots (60 × 40 m) were established at the Training Forest Enterprise "Masarykův les" Křtiny, Czech Republic, where the age range of the forest stands was between 26 to 40 years. The small plots were left undisturbed as a control, while trees on the remaining plots were cut, except for the standards, and harvest was done by chainsaw. Harvesting was also carried out within a 20 m buffer belt around each plot in March 2018. All nine plots were then fenced to exclude wild game grazing. The harvest intensity was 88% of the standing stock volume. On each harvested plot, 92 sessile oak standards (per hectare) were left in regular spacing (distance between the standards was about 11 m). The harvested plots were divided into halves (30 × 40 m); the litter was raked and completely removed from one half of each harvested plot in April 2018. The total amount of the raked litter was 30.5 t ha^{-1} (sd 8.7). A herd of six sheep (breed Šumavka, 3.75 livestock units/ha) grazed successively in three of the six harvested plots in two-week intervals from June to September 2018. Figure 1 and Table 1 present the arrangement and characteristics of the individual plots.

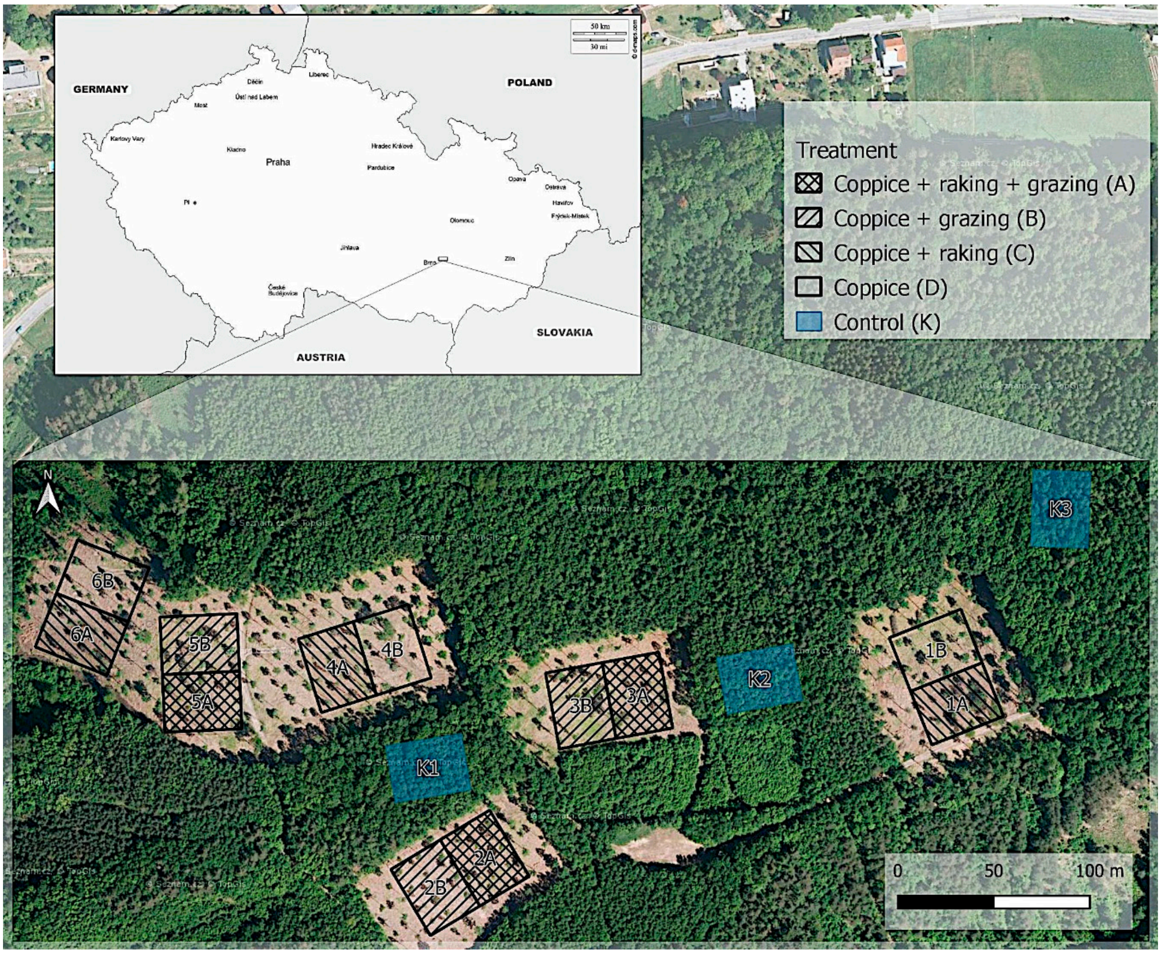

Figure 1. Arrangement of the experimental plots (aerial map (orthophotomap), © Seznam.cz, a.s., © TopGis, s.r.o.).

Table 1. Plot characteristics in 2017 prior to harvest.

Label	Harvest	Treatment	Age (years)	Slope (°)/Exposition (°)	Density (tree ha^{-1})	SDI	Volume (m^3 ha^{-1})
K1	Not harvested	Control (K)	52	7.0/245	1467	589	186
K2			40	10.5/350	1875	552	152
K3			66	13.0/270	1433	613	209
2A	Harvested	C-W-S + raking + grazing (A)	38	8.0/200	1933	569	129
3A			40	6.0/0	1433	490	149
5A			38	10.5/270	1733	599	149
2B		C-W-S + grazing (B)	38	7.0/210	2042	459	76
3B			40	5.5/0	1283	522	177
5B			38	12.5/290	1225	516	148
1A		C-W-S + raking (C)	40	5.5/345	1583	507	146
4A			38	9.0/270	1325	510	156
6A			26	21.0/290	1792	542	124
1B		C-W-S (D)	40	16.0/340	1833	603	177
4B			38	8.0/330	1233	465	147
6B			26	19.0/270	1467	513	110

C-W-S: coppice-with-standards, SDI: stand density index [29].

2.3. Measurements

Eleven randomly selected stumps for each species were recorded on each half of the six harvested plots. The following characteristics were acquired for each stump: (a) the number of the sprouts on a stump or in its immediate vicinity, (b) the average diameter of the five thickest sprouts (above the root collar), (c) the average height of the five thickest sprouts, and (d) the cross sectional area of a parent stump (circle area from the average of two perpendicular directions, stump heights were 10 cm). This design was used to avoid the pseudoreplication issue during the statistical analyses.

We also recorded the characteristics of all 163 standards (11 standards for every plot except for plots 1A and 5B where there were only 10 standards per plot) in larger harvested plots with variable management types: (A) C-W-S, litter raking, and sheep grazing; (B) C-W-S and sheep grazing; (C) C-W-S and litter raking; and (D) C-W-S as well as in smaller control plots (K). The circumference of each standard was measured three times: (1) in March 2017 during the establishment of the experiment; (2) prior to harvest in March 2018; and (3) in November 2018. It was therefore possible to evaluate the circumference increments in both 2017 (without the influence of management) and 2018 (with management influence).

2.4. Statistical Analyses

Statistical analyses of sessile oak and European hornbeam sprouts were carried out for four management types (A–D). Management type D was set as a reference management.

To model the number of sprouts per stump as a function of stump cross sectional area, the management type and species generalized linear model (GLM) with negative binomial (NB) distribution and log link function was used [30]:

$$E(Y_i) = e^{\beta_0+\beta_1 X_{1i}+\beta_2 X_{2i}+\ldots\beta_j X_{ji}} \quad (1)$$

where $E(Y_i)$ is the mean value of distribution (fitted count) of sprout number on stump i; β_0, β_1, β_2, β_j are the estimated parameters; and X_{1i}, X_{2i}, X_{ji} are the independent variables j of stump i.

This approach is suitable for the analysis of data with a discrete distribution. Moreover, the GLM model with a negative binomial distribution is recommended for experiments with a data overdispersion issue [30]. The numbers of the sprouts per stump showed a high rate of overdispersion in the primal data analysis. Overall model significance was assessed by the χ^2 likelihood ratio test and the Z-test was used for the significance analysis of the model parameters. Goodness of fit was evaluated using the Akaike's information criterion (AIC) [31] and pseudo R^2 [32].

Average sprout diameter and height per stump were modeled by the linear regression model because both diameter and height had a continuous normal distribution:

$$E(Y_i) = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots \beta_j X_{ji} \quad (2)$$

where $E(Y_i)$ is the mean value of the distribution (fitted average height or diameter) of the average sprout height or diameter on stump i; β_0, β_1, β_2, β_j are the estimated model parameters; and X_{1i}, X_{2i}, X_{ji} are the explanatory variables j of stump i.

This model contained the following explanatory variables: stump cross sectional area, tree species, and management type. Overall model significance was tested using the F-test. The significance of the model parameters was assessed using the t-test. Goodness of fit was evaluated using AIC and R^2.

The circumference increment of the standards was then converted to relative growth rate (RGR) [33]:

$$RGR = \frac{x_i - x_{i-1}}{x_{i-1}} * 100 \quad (3)$$

where x_i is the tree circumference at breast height in time i (end of growing season) and x_{i-1} is the tree circumference at breast height in time $i-1$ (beginning of growing season).

We applied the one-way analysis of variance (ANOVA) with the consequent Tukey HSD multiple comparison test to compare the differences in RGR between the five management variants (A–D) and the control (K).

All analyses were done in R software [34] on an $\alpha = 0.05$ significance level.

3. Results

3.1. Growth of Sprouts

The GLM model (Tables 2 and 3) revealed that the stump cross sectional area and management type significantly influenced the number of sprouts per stump while the anticipated effect of tree species was not confirmed.

Table 2. Goodness of fit characteristics of the selected models.

Dependent Variable	DF	χ^2	F	p	AIC	R^2	Pseudo R^2
N	4	24.11		<0.0001	2385.3		0.0886
d	5; 254		15.55	<0.0001	1124.25	0.2344	
h	5; 254		24.93	<0.0001	2321.41	0.3292	

DF: degree of freedom; χ^2: value of χ^2 likelihood ratio test; F: F test value; p: p value; AIC: Akaike's information criterion; R^2: coefficient of determination; N: number of sprouts per stump; d: average diameter of five thickest sprouts on a stump; and h: average height of the five thickest sprouts on a stump.

Table 3. Estimated values of the parameters for the selected models.

Dependent Variable	Independent Variable	Parameter	ESTIMATION	SE	t	z	p
N	INT	β0	3.4801	0.0810		42.977	<0.0001
	SA	β1	0.0006	0.0001		4.101	<0.0001
	C	β2	0.2792	0.0982		2.844	0.0045
	B	β3	0.1915	0.0999		1.917	0.0552
	A	β4	0.2718	0.0984		2.760	0.0058
d	INT	β0	10.5928	0.3493	30.327		<0.0001
	SA	β1	0.0018	0.0006	3.213		0.0015
	SH	β2	−1.3821	0.2705	−5.108		<0.0001
	C	β3	−0.0724	0.3605	−0.201		0.8411
	B	β4	−0.5319	0.3663	−1.452		0.1477
	A	β5	−1.5259	0.3615	−4.220		<0.0001
h	INT	β0	96.2987	3.4916	27.580		<0.0001
	SA	β1	0.0127	0.0057	2.237		0.0262
	SH	β2	−6.0598	2.7045	−2.241		0.0259
	C	β3	2.4656	3.6038	0.684		0.4945
	B	β4	−23.4180	3.6619	−6.395		<0.0001
	A	β5	−26.4539	3.6141	−7.320		<0.0001

SE: standard error; t: *t*-test value; z: *z*-test value; p: *p* value; N: number of sprouts per stump; d: average diameter of the five thickest sprouts on a stump; h: average height of the five thickest sprouts on a stump; INT: intercept (corresponds to coefficient of management type D: coppice-with-standards not grazed, not raked); SA: stump cross sectional area; SH: species hornbeam; C: coppice-with-standards + raking; B: coppice-with-standards + grazing; A: coppice-with-standards + raking + grazing.

The number of sprouts per stump increased with the increasing sectional area of the stump (Table 3, Figure 2). Management types A and C (both with applied raking) also resulted in significantly more sprouts per stump than the reference management type D, with no significant differences between the A and C types. The difference in the number of sprouts per stump between plots with management type B (grazing) and D (without raking and grazing) was insignificant ($p = 0.055$). However, from a practical point of view, the fitted numbers of sprouts per stump on B management type plots can be considered higher than those on management type D plots (Figure 2). Grazing and raking led, therefore, to higher numbers of sprouts per stump.

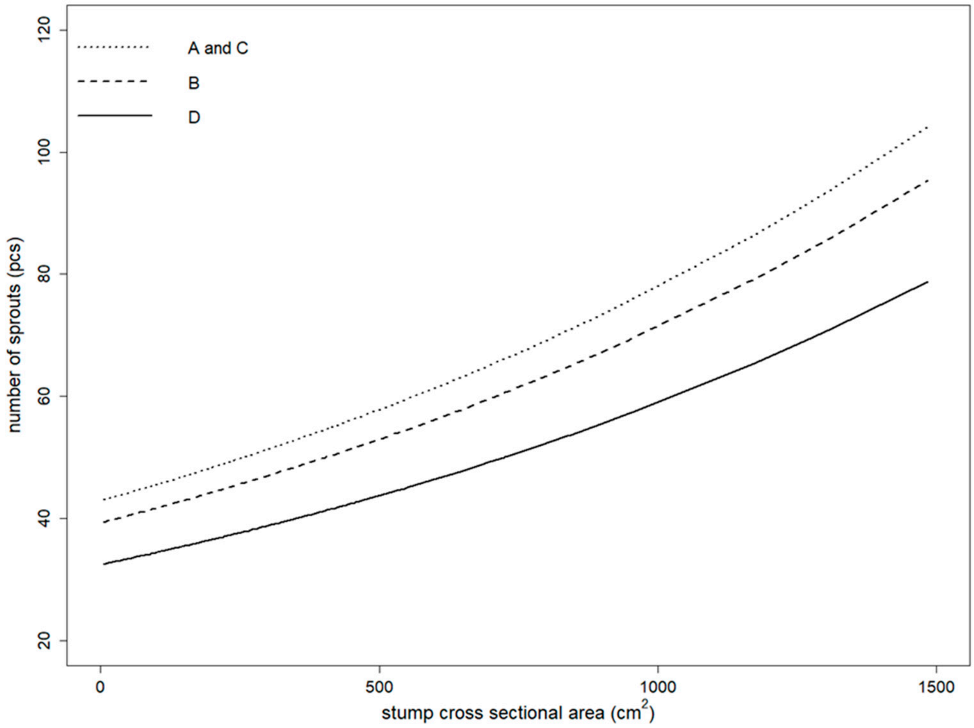

Figure 2. Fitted values of the number of sprouts per stump (species not taken into account) in relation to the stump cross sectional area and the management type (A: coppice-with-standards + raking + grazing; B: coppice-with-standards + grazing; C: coppice-with-standards + raking; and D: coppice-with-standards).

The linear model applied to model the average sprout diameters explained more than 23% of its variability (Table 2). All observed variables, i.e., the stump cross sectional area, species and management type, significantly affected average diameter of the sprouts (Table 3). The sprout diameter increased with the increasing stump sectional area, and was significantly lower in the European hornbeam when compared to the sessile oak; moreover, this was significantly lower on plots with management type A (grazing and raking) compared to the B, C, and D plots (Figure 3). The average sprout diameters in management types B, C, and D did not differ significantly. The negative effect of raking and grazing was observed only when the plots were grazed and raked simultaneously.

As far as the average sprout height model is concerned, all three explanatory variables were significant here (Table 3) and the model explained 33% of the variability of heights (Table 2). The average sprout height increased with the increasing stump cross sectional area. European hornbeam sprouts were significantly lower than those of sessile oak (Table 3, Figure 4). The difference between the sessile oak and European hornbeam average sprout heights were about 25 cm (Figure 4). The biggest differences accounted for different management types. The heights of sprouts on plots with management types A and B (both with applied grazing) were significantly lower than those on D plots, while no significant difference was found in sprout heights between plots with management types A and B. Moreover, the were no significant differences between the average sprout heights of management type C (only raking) and type D. To sum up, grazing significantly decreased the sprout height while raking had no effect.

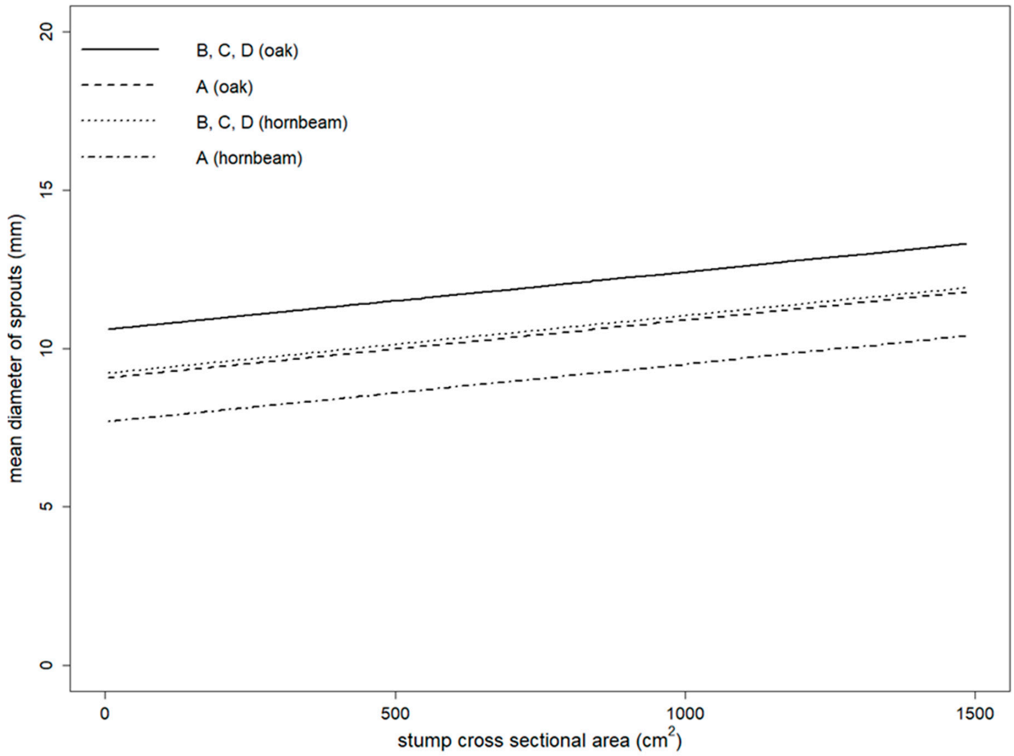

Figure 3. Fitted values of the average sprout diameter in relation to the stump cross sectional area, the species, and the management type (A: coppice-with-standards + raking + grazing; B: coppice-with-standards + grazing; C: coppice-with-standards + raking; and D: coppice-with-standards).

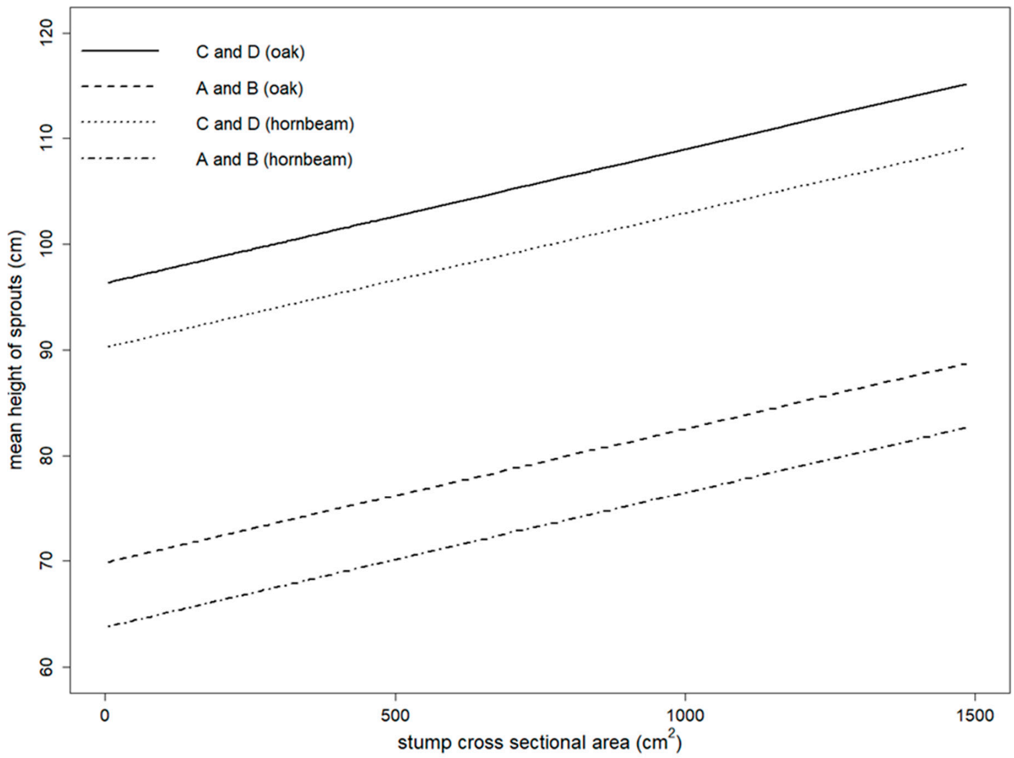

Figure 4. Fitted values of the average sprout height in relation to stump cross sectional area, species, and management type (A: coppice-with-standards + raking + grazing; B: coppice-with-standards + grazing; C: coppice-with-standards + raking; and D: coppice-with-standards).

3.2. Growth of Sessile Oak Standards

Prior to harvest and applied managements, differences in the circumference increment of oak standards (expressed as RGR) between individual plots (A–D and K) were statistically insignificant ($F(4, 158) = 1.889$, $p = 0.115$) in 2017. The average RGR of all standards in 2017 was 1.01% (standard error = 0.06). In 2018, after the harvest and management measures were applied, significantly lower values of RGR were recorded on the control (K) plots when compared to plots with applied harvest (A–D) (Figure 5) ($F(4, 158) = 11.3$, $p < 0.0001$). Furthermore, standards on plots with management type A (raked and grazed) had significantly lower RGR than those on management types B and D (both with absence of raking). Moreover, despite the statistically significant differences, the circumference increment on A management type plots was very close to that on the K plots (control). To sum up, the additive effect of raking and grazing already negatively affected the circumference increment of standards in the first year of experiment.

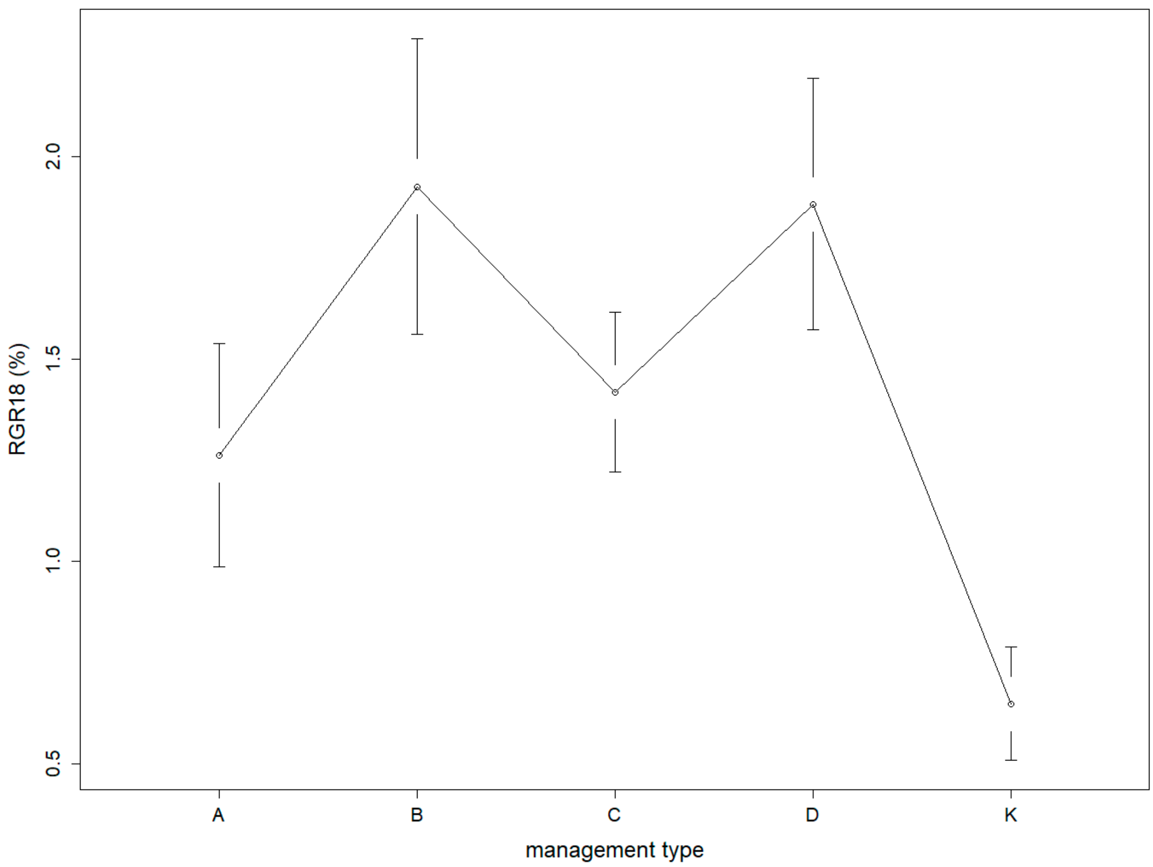

Figure 5. Mean values (with 95% confidence intervals) of the RGR of the circumference of the oak standards according to the applied management type in 2018 (A: coppice-with-standards + raking + grazing; B: coppice-with-standards + grazing; C: coppice-with-standards + raking; and D: coppice-with-standards, K–control, RGR 18 (%) is the circumference RGR of oak standards in 2018).

4. Discussion

4.1. Impact of Livestock Grazing and Litter Raking on Coppices and Landscape Development

Grazing fundamentally shapes the structure and species composition of plants. Nutrient content enrichment, soil surface disturbances, and selective grazing are the main shaping factors [16]. Aside from herbs, tree seedlings and young sprouts represent the main food of livestock. On the other hand, numerous studies revealed have that low or mid intensity grazing pressure (<0.25 livestock units/ha/year) is suitable for maintaining a landscape mosaic of grasslands and woods [35,36]. In our experiment, a higher grazing pressure was used (3.75 livestock units/ha). Nevertheless, thanks to the application of rotation grazing (two weeks grazing cycle) in our experiment, the stumps were able to resprout between cycles and their bark remained intact, so that plots could be grazed repeatedly during the growing season.

The influence of livestock grazing (cattle and sheep) on the development of oak coppices of various ages was studied in Greece [37]. In this study, forest stands were thinned and grazing was consequently applied. The results indicated that cattle strongly preferred herbs by 97%, whereas goats preferred feeding on oak sprouts (41%) and herbs (34%). The remaining 25% involved grazing of other woody species. Almost half of the plant vegetation was consumed and a severe reduction in sprout growth and development was documented after goat grazing. Therefore, goats are not recommended for grazing in coppices [37]. Moreover, [38] stated that goats in particular undoubtedly caused damage to sprouts and their bark. Among the livestock species, goats are assigned as "black sheep" because of the fact that they consume almost everything edible and are, therefore, blamed as a site degradation factor [39]. The above-mentioned facts contributed to our decision to use sheep in our experiment. Sheep consume plant vegetation selectively [40], therefore, grazing by sheep controls the distribution of dominant plant species and their population dynamics [41]. Sheep have been commonly used in silvo-pastoral systems [42] as they can feed on grasslands as well as woodlands; nevertheless, compared to goats, sheep prefer the lower vegetation layer [43].

The effect of litter raking on the condition of coppice soils was found to be indifferent in the short-term experiment [4], however, in the case of long-term exposure it was mainly associated with the risks of nutrient and organic matter loss and with the change of humus or soil water regime [44]. In our experiment, it was discovered that thinner sprouts were found under a combination of grazing and raking. When comparing the species, the oak sprouts were higher and thicker in comparison to the hornbeam sprouts.

4.2. Growth of Sprouts in Coppices

Individual tree species differ in their capacity to create sprouts after cutting [45]. The resprouting probability decreases with both increasing tree age and increasing stump size [45–48]. If the stump has already sprouted, the stump sprouting capacity is affected by the stump size and root system. Compared to seed origin trees, coppices grow faster in youth due to the nutrient and water reserves in roots preserved from the previous generation [49–51]. The root system size and growth intensity of juvenile sprouts can also be related to the stump size. We can, therefore, assume that the bigger the stump, the thicker and higher the sprouts created after disturbance. Matula et al. [47] observed the relationships between the stump size, the number of the sprouts per stump, and the sprout heights and diameters in sessile oak, European hornbeam, and small leaved lime (typical central European coppice tree species) in the Czech Republic. The authors in [47] confirmed the significance of the relationship between the stump diameter–number of sprouts for juvenile sprouts of all three species. In contrast, no relationship between the stump size and the diameter of the sprouts was confirmed for hornbeam and oak, and no relationship between the stump diameter and height of the sprouts was confirmed for oak. This experiment [47], however, did not involve any effect of livestock or wild game grazing, or litter raking.

Our results indicate that the number of the sprouts per stump increased both with the stump size and after grazing and raking, while tree species had no influence. We can conclude that traditional management with high pressure (management types A–C) on coppice biotopes lead to higher numbers of the sprouts per stump. The higher the pressure, the higher the number of sprouts that can be expected, regardless of the tree species (sessile oak and European hornbeam in our case). This finding supports the fact that trees under higher stress pressure resprout more spontaneously, longer, and in a bigger extent [45]. Grazing and litter raking can be considered as a prominent stress factor.

The mean diameter and height of the sprouts were affected by all involved explanatory variables (stump cross sectional area, management type, and tree species). The stump across the sectional area correlated positively with both the sprout diameter and height, whereas the management affected these parameters negatively. The additive effect of raking and grazing (management type A) decreased sprout heights the most, while the effect of individual management types (only raking or only grazing) was smaller. This was probably due to the shortness of our experiment. We assumed, however, that the effect of both individual raking and grazing would significantly affect the growth of sprouts during a longer period of observation.

Simultaneous raking and grazing also resulted in the significantly smaller diameter of the sprouts one year after harvest, while the sprout height was significantly reduced only on grazed plots (management types A and B). This is supported by the fact that, primarily, grazing decreased the height of the sprouts. As far as the tree species as the explanatory factor is concerned, European hornbeam showed lower diameters and heights of sprouts when compared to sessile oak. We can explain this finding as follows: The resprouting capacity and growth of sprouts are affected by (a) the age of the parent tree (stump), (b) size of the parent tree (stump), and (c) the site quality [45,49,52]. In our experiment, both the European hornbeam and sessile oak had similar nature conditions and sizes. Therefore, the observed difference in the sprout diameters and heights between oak and hornbeam can be related to the biological differences of both species. Sessile oak, as a light demanding tree species, exhibits earlier and more intense growth compared to European hornbeam. This is supported by the different site indices of oak (22) and hornbeam (18) [28] at the experimental site. Thus, the higher mean diameter and height of oak sprouts can be related to the higher production capacity of oak on this site.

If we omit the positive effect of traditional management systems on the number of sprouts per stump, we can state that we found no positive effect of litter raking and livestock grazing on the growth of the sprouts. Papachristou and Platis [37] published similar results for oak sprouts under grazing management in Greece. According to [53], it is difficult to find positive effects simply because they are covered by negative effects. However, the positives of traditional management practices have been proven in terms of higher biological diversity (e.g., [5,14,54]).

4.3. Growth of the Standards in the Coppices

The standards on the plots with applied management types (A–D) showed higher RGR when compared to the control plots (K) in the second year of the experiment. This can be explained by a substantial reduction of tree competition after harvest [49,55–58]. Raking (management types A and C) significantly decreased the RGR (compared to the management type B and D plots with the absence of raking) while grazing had no effect on RGR. The decreasing growth of the standards after the removal of litter by raking can be explained by the loss of nutrients and acidification of soil [18,59,60]. However, the RGR of stem circumference was significantly reduced only on plots with simultaneous grazing and raking (type A). This can be related to the short term character of the experiment. We expect that the individual application of grazing or raking will affect the RGR in the long term. Similarly, the simultaneous effect of both raking and grazing would increase in the future as long term litter removal can lead to a drastic decrease of soil fertility and wood production in the past [17,20].

5. Conclusions

This study assessed the growth of sessile oak and European hornbeam one year after the application of livestock grazing and litter raking as traditional management practices in a coppice with oak standards. Based on our results, we can conclude that:

1. the number of sprouts per stump was positively affected by the stump cross sectional area and applied management types; species had no effect on the number of sprouts.
2. the mean diameter and the mean height of the sprouts were correlated with all of the involved factors, i.e., stump cross sectional area, applied management, and tree species as
    - bigger stumps produced thicker and higher sprouts;
    - the influence of traditional management types on sprout dimensions was significant as

        i. only the simultaneous application of raking and grazing decreased the mean sprout diameter, and
        ii. the application of grazing (either individual or combined with raking) reduced the mean heights of sprouts; and

    - European hornbeam produced thinner and lower sprouts than sessile oak.

3. Standards responded to harvest by increased relative circumference increment. Only the simultaneous effect of grazing and raking decreased the circumference increment significantly.

We did not observe any positive effects of traditional management types (litter raking and livestock grazing) on the growth of the sprouts in a coppice with oak standards (regardless of the positive effect of traditional management on the number of sprouts per stump). The oak standards responded to the harvest by increasing the relative growth rate of stem circumference, but this, however, can be assigned to decreased competition due to the removal of neighboring trees). It is therefore possible, that the commonly advocated positive effect of traditional management on biological diversity has been devalued by the negative effects of traditional management on coppice growth.

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References

1. Szabó, P.; Müllerová, J.; Silvie Suchánková, S.; Kotacka, M. Intensive woodland management in the Middle Ages: spatial modelling based on archival data. *J. Hist Geogr.* **2015**, *48*, 1–10. [CrossRef] [PubMed]
2. Pfeffer, A. *Hrabání steliva v lesích a lesní pastva v Normálních Dobách: Studie Lesnická, Národohospodářská a Vodohospodářská*, 1st ed.; Masarykova Akademie Práce: Praha, Czech Republic, 1948; p. 32.
3. Vild, O.; Stejskal, R. Vliv experimentální pastvy na lesní podrost v Národním Parku Podyjí. *Thayensia* **2013**, *10*, 27–38.
4. Vild, O.; Kalwij, J.M.; Hédl, R. Effects of simulated historical tree litter raking on the understorey vegetation in a central European forest. *Appl. Veg. Sci.* **2015**, *18*, 569–578. [CrossRef] [PubMed]
5. Debussche, M.; Debussche, G.; Lepart, J. Changes in the vegetation of *Quercus pubescens* woodland after cessation of coppicing and grazing. *J. Veg. Sci.* **2001**, *2*, 81–92. [CrossRef]
6. Evans, J. Coppice forestry–an overview. In *Ecology and Management of Coppice Woodlands*, 1st ed.; Buckley, G.P., Ed.; Chapman & Hall: London, UK, 1992; pp. 18–27.
7. 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.
8. Zhu, W.Z.; Xiang, J.S.; Wang, S.G.; Li, M.H. Resprouting ability and mobile carbohydrate reserves in an oak shrubland decline with increasing elevation on the eastern edge of the Qinghai-Tibet Plateau. *For. Ecol. Manag.* **2012**, *278*, 118–126. [CrossRef]
9. Carl, Ch.; Lehmann, J.R.K.; Landgraf, D.; Pretzsch, H. *Robinia pseudoacacia* L. in Short Rotation Coppice: Seed and Stump Shoot Reproduction as well as UAS-based Spreading Analysis. *Forests* **2019**, *10*, 235. [CrossRef]

10. Vild, O.; Roleček, J.; Hédl, R.; Kopecký, M.; Utinek, D. Experimental restoration of coppice-with-standards: Response of understorey vegetation from the conservation perspective. *For. Ecol. Manag.* **2013**, *310*, 234–241. [CrossRef]
11. Rydberg, D.; Falck, J. Urban forestry in Sweden from a silvicultural perspective: A review. *Landsc. Urban. Plan.* **2000**, *47*, 1–18. [CrossRef]
12. Van Calster, H.; Baeten, L.; Verheyen, K.; De Keersmaeker, L.; Dekeyser, S.; Rogister, J.E.; Hermy, M. Diverging effects of overstorey conversion scenarios on the understorey vegetation in a former coppice-with-standards forest. *For. Ecol. Manag.* **2008**, *256*, 519–528. [CrossRef]
13. Buček, A. Krajina České republiky a pastva. *Veronica* **2000**, *14*, 1–7.
14. Mitchell, F.J.G.; Kirby, K.J. The Impact of Large Herbivores on the Conservation of Semi-natural Woods in the British Upland. *Forestry* **1990**, *63*, 333–353. [CrossRef]
15. Hester, A.J.; Mitchell, F.J.G.; Kirby, K.J. Effects of season and intensity of sheep grazing on tree regeneration in a British upland woodland. *For. Ecol. Manag.* **1996**, *88*, 99–106. [CrossRef]
16. Mládek, J.; Pavlů, V.; Hejcman, M.; Gaisler, J. *Pastva jako prostředek údržby trvalých travních porostů v chráněných územích*, 1st ed.; Výzkumný ústav rostlinné výroby: Praha, Czech Republic, 2006; p. 104.
17. Mitscherlich, G. Untersuchungen über das Wachstumder Kiefer in Baden. 2. Teil: Die Streunutzungs- und Düngungsversuche. *Allgemeine Forst- und Jagdzeitung* **1955**, *126*, 193–204.
18. Glatzel, G. The impact of historic land use and modern forestry on nutrient relations of Central European forest ecosystems. *Fert. Res.* **1991**, *27*, 1–8. [CrossRef]
19. Kilian, W. Forest site degradation-temporary deviation from the natural site potential. *Ecol. Eng.* **1998**, *10*, 5–18. [CrossRef]
20. Ebermayer, E. *Die gesammte Lehre der Waldstreu mit Rücksicht auf die chemische Statik des Waldbaues*, 1st ed.; Springer: Berlin, Germany, 1876; p. 416.
21. Tschermak, L. Buchenlaubstreunutzung im Lande Salzburg. *Centralblatt für das Gesamte Forstwesen* **1926**, *52*, 336–349 & 577–663.
22. Kreutzer, K. Über den Einfluss der Streunutzung auf den Stickstoffhaushalt von Kiefernbeständen (*Pinus silvestris* L.). *Forstwiss. Cent.bl.* **1972**, *91*, 263–270. [CrossRef]
23. Bürgi, M. A case study of forest change in the Swiss lowlands. *Landsc. Ecol.* **1999**, *14*, 567–575. [CrossRef]
24. Šilc, U.; Čarni, A.; Košir, P.; Marinšek, A.; Zelnik, I. Litter-raking forests in SE Slovenia and in Croatia. *Hacquetia* **2008**, *7*, 71–88. [CrossRef]
25. Kadavý, J.; Kneifl, M.; Knott, R.; Hurt, V.; Flora, M. Možnosti a limity hospodaření s nízkým a středním lesem a jejich vliv na biodiverzitu. In *Ochrana Přírody a Krajiny v České Republice*; Vybrané aktuální problémy a možnosti jejich řešení. I. díl, Olomouc, Česká republika; Machar, I., Drobilová, L., Eds.; Univerzita Palackého v Olomouci: Olomouc, Czech Republic, 2012; pp. 290–300.
26. IUSS Working Group WRB. World Reference Base for Soil Resources 2014. In *International Soil Classification System for Naming Soils and Creating Legends for Soil Maps*, 1st ed.; World Soil Resources Reports No. 106; FAO: Rome, Italy, 2014; p. 203.
27. Jabiol, B.; Brêthes, A.; Ponge, J.F.; Toutain, F.; Brun, J.J. *L'humus sous toutes ses forms*, 1st ed.; École Nationale du Gńie Rural, des Eaux et des Forêts: Nancy, France, 1995; p. 63.
28. ÚHÚL; VÚLHM. *Taxační tabulky (Forest Taxation Tables)*, 1st ed.; Forest Management Institute and Forestry and Game Management Research Institute: Jíloviště-Strnady, Czech Republic, 1990; p. 32.
29. Pretzsch, H.; Biber, P. A Re-Evaluation of Reineke's Rule and Stand Density Index. *For. Sci.* **2005**, *51*, 304–320.
30. Zuur, A.F.; Ieno, E.N.; Walker, N.J.; Savaliev, A.A.; Smith, G.M. *Mixed Effects Models and Extensions in Ecology with R*; Springer: New York, NY, USA, 2009; p. 574.
31. Akaike, H. Information theory and an extension of the maximum likelihood principle. In Proceedings of the 2nd International Symposium on Information Theory, Budapest, Hungary, 2–8 September 1973; Petrov, B.N., Csaki, F., Eds.; Akademiai Kiado: Budapest, Hungary, 1973; pp. 268–281.
32. Nagelkerke, N.J.D. A note on a general definition of the coefficient of determination. *Biometrika* **1991**, *78*, 691–692. [CrossRef]
33. Cotillas, M.; Sabaté, S.; Gracia, C.; Espelta, J.M. Growth response of mixed mediterranean oak coppices to rainfall reduction: Could selective thinning have any influence on it? *For. Ecol. Manag.* **2009**, *258*, 1677–1683. [CrossRef]

34. R Core Team. *R: A Language and Environment for Statistical Computing*; R Foundation for Statistical Computing: Vienna, Austria, 2017; Available online: http://www.R-project.org/ (accessed on 18 February 2019).
35. Van Uytvanck, J.; Hoffmann, M. Impact of grazing management with large herbivores on forest ground flora and bramble understorey. *Acta Oecol.* **2009**, *35*, 523–532. [CrossRef]
36. McEvoy, P.M.; Flexen, M.; McAdam, J.H. The effects of livestock grazing on ground flora in broadleaf woodlands in Northern Ireland. *For. Ecol. Manag.* **2006**, *225*, 39–50. [CrossRef]
37. Papachristou, T.G.; Platis, P.D. The impact of cattle and goats grazing on vegetation in oak stands of varying coppicing age. *Acta Oecol.* **2011**, *37*, 16–22. [CrossRef]
38. Hart, S.P. Recent perspectives in using goats for vegetation management in the USA. *J. Dairy Sci.* **2001**, *84* (Electronic Suppl.), E170–E176. [CrossRef]
39. Peacok, C.; Sherman, D.M. Sustainable goat production. Some global perspectives. *Small Rumin. Res.* **2010**, *89*, 78–80. [CrossRef]
40. Cochillo-Hilario, M.; Wrage-Moenning, N.; Isselstein, J. Forage selectivity by cattle and sheep co-grazing swards differing in plant species diversity. *Grass Forage Sci.* **2018**, *73*, 320–329. [CrossRef]
41. Onatibia, G.R.; Aguiar, M.R. Grasses and grazers in arid rangelands: Impact of sheep management on forage and non-forage grass populations. *J. Environ. Manag.* **2019**, *235*, 42–50. [CrossRef]
42. Flota-Banuelos, C.; Rivera-Lorca, J.A.; Candelaria-Martinez, B. Importance of sheep social hierarchy on feeding behavior and parasite load in silvopastoral and grass monoculture grazing systems. *Rev. Mex. Cienc. Pecu.* **2019**, *10*, 52–67.
43. Bojkovski, D.; Štuhec, I.; Kompan, D.; Zupan, M. The behavior of sheep and goats co-grazing on pasture with different types of vegetation in the karst region. *J. Anim. Sci.* **2014**, *92*, 2752–2758. [CrossRef] [PubMed]
44. Gimmi, U.; Poulter, B.; Wolf, A.; Portner, H.; Weber, P.; Bürgi, M. Soil carbon pools in Swiss forests show legacy effects from historic forest litter raking. *J. Landsc. Ecol.* **2013**, *28*, 835–846. [CrossRef]
45. Del Tredici, P. Sprouting in temperate trees: A morphological and ecological review. *Bot. Rev.* **2001**, *67*, 121–140. [CrossRef]
46. Vesk, P.A.; Westoby, M. Sprouting ability across diverse disturbances and vegetation types worldwide. *J. Ecol.* **2004**, *92*, 310–320. [CrossRef]
47. Matula, R.; Svátek, M.; Kůrová, J.; Úradníček, L.; Kadavý, J.; Kneifl, M. The sprouting ability of the main tree species in Central European coppices: implications for coppice restoration. *Eur. J. Forest. Res.* **2012**, *131*, 1501–1511. [CrossRef]
48. Šplíchalová, M.; Adamec, Z.; Kadavý, J.; Kneifl, M. Probability model of sessile oak (*Quercus petraea* (Matt.) Liebl.) stump sprouting in the Czech Republic. *Eur. J. Forest. Res.* **2012**, *131*, 1611–1618. [CrossRef]
49. Johnson, P.S.; Shifley, S.R.; Rogers, R. *The Ecology and Silviculture of Oaks*, 2nd ed.; CAB International: Wallingford, UK, 2009; p. 580.
50. Pietras, J.; Stojanović, M.; Knott, R.; Pokorný, R. Oak sprouts grow better than seedlings under drought stress. *iForest* **2016**, *9*, 529–535. [CrossRef]
51. 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.
52. Weigel, D.R.; Peng, C.-Y.J. Predicting stump sprouting and competitive success of five oak species in southern Indiana. *Can. J. For. Res.* **2002**, *32*, 703–712. [CrossRef]
53. Reimoser, F.; Armstrong, H.; Suchant, R. Measuring forest damage of ungulates: what should be considered. *For. Ecol. Manag.* **1999**, *120*, 47–58. [CrossRef]
54. Bullock, D.J.; Grabrovaz, M. The impact of goat farming on upland vegetation in Scotland—A preliminary survey. In *Rural Development Report*, 1st ed.; Nature Conservancy Council: Edinburgh, UK, 1990; Volume 1, pp. 1–28.
55. Dale, M.E. *Growth Response from Thinning Young Even-Aged White Oaks Stands*; USDA Forest Service Research Paper NE-112; USDA Forest Service, Northeastern Forest Experiment Station: Newtown Square, PA, USA, 1968; p. 20.
56. Hilt, D.E. *Diameter Growth of Upland Oaks after Thinning*; USDA Forest Service Research Paper NE-437; USDA Forest Service, Northeastern Forest Experiment Station: Newtown Square, PA, USA, 1979; p. 12.

57. Hilt, D.E. *Individual-Tree Diameter Growth Model for Managed, Even-Aged, Upland Oak Stands*; USDA Forest Service Research Paper NE-533; USDA Forest Service, Northeastern Forest Experiment Station: Newtown Square, PA, USA, 1983; p. 15.
58. Mitchell, R.J.; Dwyer, J.P.; Musbach, R.A.; Garrett, H.E.; Cox, G.S.; Kurtz, W.B. Crop tree release of a scarlet-black oak stand. *North. J. Appl. For.* **1988**, *5*, 96–99.
59. Dzwonko, Z.; Gawroński, S. Effect of litter removal on species richness and acidification of a mixed oak-pine woodland. *Biol. Cons.* **2002**, *106*, 389–398. [CrossRef]
60. Sayer, E.J. Using experimental manipulation to assess the roles of leaf litter in the functioning of forest ecosystems. *Biol. Rev.* **2006**, *81*, 1–31. [CrossRef] [PubMed]