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An Efficient Tool for the Maintenance of Thermophilous Oak Forest Understory—Sheep or Brush Cutter?

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Abstract: *Research Highlights:* Thermophilous oak forests are among the most species-rich forest ecosystems in Central Europe. In the temperate zone, they evolved from mixed deciduous forests due to centuries-long livestock grazing. The abandonment of traditional forms of landscape use resulted in a constant decline in the number of patches of these communities, their area and species richness, which has been ongoing for decades and calls for their urgent conservation. The commonly used approaches to the conservation of this community are the reestablishment of grazing or mechanical removal of undergrowth. However, there are a limited number of works comparing their effects on the forest herb layer separately and in combination. *Background and Objectives:* The purpose of our research was to evaluate the effectiveness of grazing, mechanical brush removal and their combination for the conservation of the oak forest herb layer. *Materials and Methods:* Our work was based on a fully crossed experimental design set in a 60-year-old oak forest. The individual and combined influences of sheep grazing and brush cutting on forest floor vegetation were compared to control plots. We surveyed plant species twice—before the application of treatments and one year later on 600 one-square-meter subplots selected randomly in the limits of twelve fenced 20 m × 20 m treated and untreated study plots. *Results:* Both grazing by sheep and mechanical removal served well for total plant species richness and their cover, if applied separately. But these effects were not additive—plant species richness and plant cover on plots with combined treatment did not differ from plots, where just a single treatment was applied. Application of both treatments (but separately) had positive influence on species cover of the target group of plants typical to xerothermic oak forests and non-target species of mixed deciduous forests. Mechanical removal allowed also for successful control of woody species. Active conservation measures resulted also in negative effects—we observed increase in the species richness and cover of ruderal species on grazed plots. *Conclusions:* Both tested methods can be used for active conservation of open oak forest understorey vegetation. The method of active conservation should be chosen depending on the goal and the species composition of the forest floor and undergrowth found at the beginning of the restoration process, however, combining of these treatments does not bring any extra advantage. In our opinion a monitoring of the reaction of vegetation on treatments is of paramount importance.

Keywords: forest conservation; nature conservation; habitat restoration; ecological groups

1. Introduction

Thermophilous oak forests, among the most species-rich forest ecosystems in Central Europe, are currently one of the most endangered forest communities in the temperate zone. In the European Union they are among the Natura 2000 priority habitats. In Central Poland they are represented by the subcontinental and Mediterranean forms of oak forests [1–4]. The high species richness of the herb layer of these communities stems from the diversity of niches suitable for the development of a large number of species with a very diverse spectrum of habitat requirements—from grasslands and meadows, via thermophilous bushes, to forest generalists and stenotopic forest specialists, specific to thermophilous oak forests [5]. Patches of thermophilous oak forests, often surrounded by arable fields, are refuges for rare and endangered plant and invertebrate species listed on regional and/or national red lists (in Poland these are, for example, *Adenophora liliifolia* (L.) Besser, *Cyprypedium calceolus* L., *Thesium ebracteatum* Hayne, *Cerambyx cerdo* L., *Osmoderma eremita* (Scopoli)/*O. barnabita* Motsch.). Unfortunately, a constant decline in the number of patches of these communities, their area and species richness has continued for decades [6–10]. The high species richness of the thermophilous oak forest understory is maintained due to the specific calcareous substrate on which this type of vegetation develops and thanks to relatively low canopy density, ensuring access of sun radiation to the forest floor [11–13]. In the past these specific conditions were maintained in the temperate climate zone mainly by high pressure from domestic herbivores [14,15]. Large herbivores also played an important role as seed vectors for several hundred plant species, supporting their migration between spatially isolated forest patches [16,17].

The abandonment of traditional forms of livestock farming that were carried out for centuries in these open woodlands led to a decrease in the intensity of light on the forest floor, which resulted in the spread of shade-tolerant trees and shrubs [18]. As a result, a drastic decline in the species richness of the herb layer took place, manifested mainly by a reduction in the share of light-demanding, stenotopic species [19–21]. Moreover, the decrease of grazing has a negative effects on floristic diversity because the most competitive species dominate [18]. The influence of herbivores on the herb layer of deciduous forest is the subject of many works [22–30], in which the authors emphasize the impact of animals on the frequency of various functional groups of forest herb species and the role of herbivores in the stabilization of late-successional communities [15]. Many authors discuss the influence of the mechanical removal of undergrowth on the restoration of flora specific to open forests [31–35]. Very often the evaluation of such treatment is difficult, because after the first positive effects bushes and young trees intensively redevelop by vegetative means and cast even deeper shade on the forest floor than before the start of active conservation activities [36]. There is only a limited number of works considering the combined effects of grazing and undergrowth removal in comparison to the influence of each of these single factors alone as a tool to manage herb layer diversity [37], thus, we found it important for nature conservation practice to study the interplay between these treatments, their combination and biodiversity of thermophilous forests. Our work was based on a fully crossed experimental design, where the individual and combined influences of sheep grazing and brush cutting on forest floor vegetation were studied in a 60-year-old oak forest. To date, no comparative studies have been conducted to examine how the herb layer of a temperate oak forest reacts to sheep grazing, mechanical removal of undergrowth and the cumulative impact of these two treatments. Due to the high natural value of thermophilous light oak forests—one of the priority forest habitats in the European nature protection system Natura 2000, finding the most effective tool to maintain this habitat in a proper state of conservation is very important.

Therefore, the purpose of our research was to check the response of the oak forest herb layer to commonly used treatments in the field of active nature conservation and in particular to answer the following research questions—(1) how do grazing, removal of undergrowth and grazing combined with the removal of undergrowth affect the species diversity of oak forest patches? (2) can grazing, which in the past contributed to the creation of high floristic richness of light oak forest patches, be replaced by mechanical removal of the undergrowth? (3) does the combined effect of grazing and brush cutting better contribute to the development of typical oak forest flora than each of these treatments separately?

We hypothesized that—(1) the combined effect of both treatments should serve in the best way for all kinds of plant species typical of thermophilous oak forest because of the cumulative effect. In effect, the patches with a combined treatment would be characterized by the highest amount of light reaching the forest floor, which would be reflected in the highest species diversity of the herb layer. Grazing and removal of undergrowth applied in isolation would, due to different pressure mechanisms, promote some ecological groups of plants but not others. (2) Mechanical removal would result in rapid redevelopment of woody species, which due to rapid vegetative regrowth would limit light access to the forest floor and negatively affect target light- demanding forest floor species. This effect is accelerated by mechanical treatment of mainly higher individuals, ignoring the juvenile, which, owing to increased light access right after the treatment, may quickly dominate treated patches.

2. Materials and Methods

2.1. Study Area: History and Location

The study was conducted in a 60-year-old oak stand, covering an area of 3.30 ha, within a larger fenced forest area of 7.70 ha in the Pińczów Forest District (Central Poland), sub-department 93a (50.4761°N, 20.4939°E, altitude 200–230 m a.s.l.), within the Kozubowski Landscape Park. The Niecka Nidziańska upland (200–300 m a.s.l.), where the study site was located, is one of the warmest areas in Poland. The mean temperature of July is about 18 °C and of January −2 °C and vegetation period is about 10 days longer than in the neighboring regions. The mean annual rainfall is 550 to 650 mm and is lower than in the neighboring uplands. The average annual relative humidity is approximately 80% [38]. The studied forest occupied typical brown rendzina soils made of limestone and chalk marl. Due to calciferous parent rock the soil pH is high (>6.55 in KCl) and the content of $CaCO_3$ in the humus horizon is significantly high (>10%) [39], increasing site soil fertility.

The place of our research was a strip of oak forest planted on post-arable land, at the edge of an mixed deciduous forest (Figure 1). According to 19th century forest maps, this piece of land was over hundred years ago occupied by an oak forest as well. According to the historical type of use of such forests, it could have been a place of livestock grazing in the past [40]. However, it should be emphasized that the ban on grazing of domestic stock in forests have been introduced to Polish forestry act in 1950s, therefore, grazing never took place in the studied stand since its establishment 60 years ago.

The investigated oak forest was characterized by an even canopy density of around 60%. In 2015, a year before the study, about 30% of the trees and a similar share of the undergrowth layer were removed during stand thinning. The treatment intensity was even within the entire forest (7.70 ha), increasing the light amount reaching the forest floor.

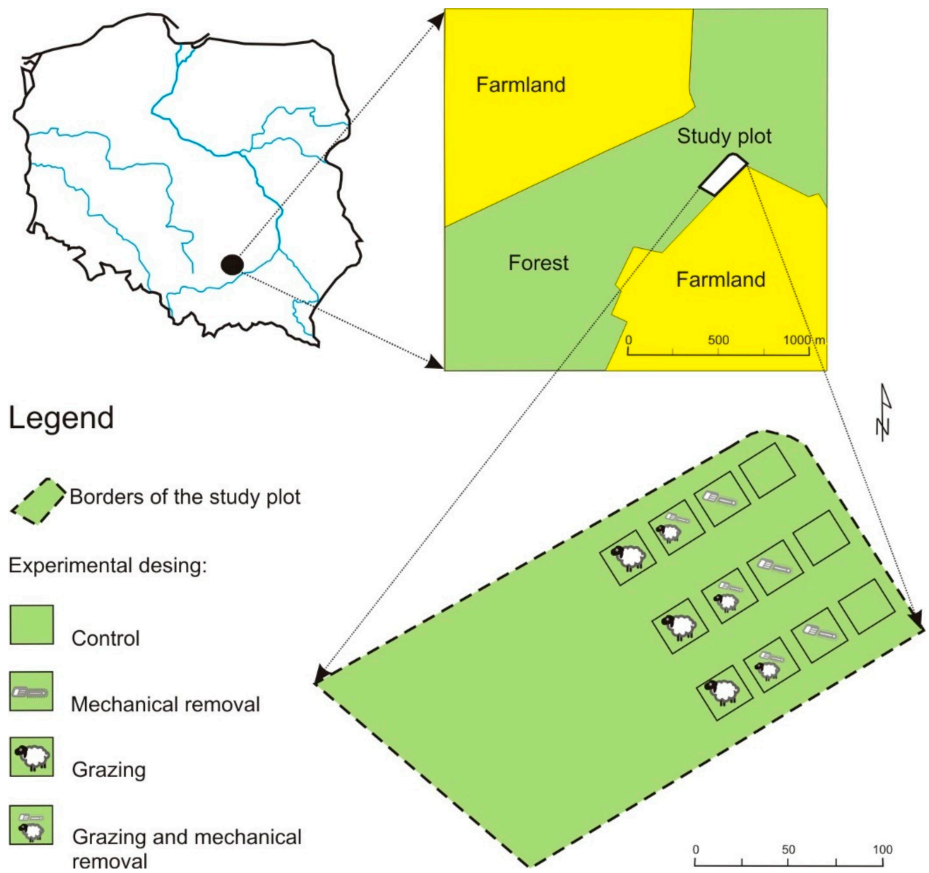

Figure 1. Study site location and study plot design. The area delimited as the study plot is part of the bigger (7.70 ha) fenced forest treated by sheep grazing.

2.2. Methods

We examined the species richness and herb layer structure in May–June 2016 (before the application of experimental treatments) and in May–June 2017 (one year after the treatments) on 12 permanent plots 20 m × 20 m (Figure 1) set in a homogenous oak stand. The whole study site (7.70 ha) was fenced with a 2.2 m high mesh to eliminate the impact of large wild herbivores and allow easy control over the sheep herd. The experiment consisted of the control and the two treatments applied individually and in combination in July 2016, with three replications (plots) within each treatment. Altogether, we established—three control plots (C)—without any intervention, three plots where all bushes and trees lower than 50 cm were mechanically removed using brush cutter with circular saw blade (R), three plots where sheep were grazed (G) and three plots RG, where sheep grazing was combined with mechanical removal of all remaining bushes and trees lower than 50 cm (Figure 1). Mechanical removal of trees and bushes took place after sheep grazing season was over, during late autumn 2016. Plots (series) C and R were fenced by 2.2 m high mesh to keep sheep out, while plots (series) G and RG were only permanently marked on the corners and sheep utilized them equally to the rest of the area.

Thirty sheep of the local Polish breed (black-headed sheep) were grazed in the enclosure from turn of May and June till half of October 2016. This specific breed is suitable for long term extensive grazing in forest ecosystems because they tolerate harsh environmental conditions and are resistant to diseases. The body weight of adult sheep does not exceed 35–42 kg for ewes and 45–55 kg for rams. The sheep stayed in the fenced area throughout the whole grazing season, spending nights in a shelter. The sheepherder directed sheep every 2–3 days through the experimental plots G and RG, to make sure that they are evenly grazed during the whole season.

On each inventory date, we carried out a vascular plant survey of the herb layer on 50 one-square-meter subplots randomly selected at the limits of each permanent plot. The herb layer in this paper is defined as all vascular plants, including tree and bush species, with a height <50 cm. The inventory included the estimation of the cover of each species in a four-step scale (1—cover <10%, 2—cover 10%–40%; 3—cover 40%–70% and 4—cover >70%) and overall plot cover by herb layer vegetation according to a ten-step Londo scale [41]. Due to uneven width of the four-step scale, we converted it to percent values, using a middle of each class, for calculation of means and so forth. (1 = 5%, 2 = 25%, 3 = 55%, 4 = 85%).

In total, on each research date, we surveyed 600 one-square-meter research subplots (4 treatments (series) × 3 replications × 50 subplots). Each of the recorded plant species was classified to one of the five non overlapping ecological groups—A, B, C, D, E, F, defined according to Matuszkiewicz [42]:

A—species of thermophilous oak forests—stenotopic species whose occurrence defines the priority habitat "thermophilous oak forest (91I0)" from the list of natural habitats of Community importance.
B—species of temperate deciduous forests—species with a wide ecological range growing in eutrophic and mesotrophic deciduous forests, mainly in oak-lime-hornbeam mixed deciduous forests and beech forests.
C—species of meadows and xerothermic grasslands, typical of open habitats—xerothermic grasslands, ecotone communities between xerothermic grassland and forest, thermophilus bush communities and forest clearings.
D—species with a wide ecological range, associated mainly with wet places, growing in alluvial forests and nitrophilic riverside thickets in shaded places.
E—weeds (plants associated with agriculture) and alien species.

These groups can be treated as indicators of the state of preservation of the forest floor's biological diversity. Species from groups A and C are typical for floristically rich, open warm forests on moderately fertile habitats, thus, they were the target groups for treatments. Group B contains species typical of dense and dark deciduous forests, so it is an ecological counterweight to the previous two groups. Group E comprise species building non-forest anthropogenic communities. They appear in forests after serious natural or anthropogenic disturbances, that is, sign of degradation of forest ecosystem.

Additionally we considered trees and shrubs as separate woody species group, because they grow much higher than average herb plant species and influence growth conditions of herb plants by casting shade on a forest floor. Due to their woodiness, trees and shrubs differ from herb plants by a nutritious value, which may influence grazing effect on their species richness and cover. The plant species nomenclature follows Mirek et al. [43].

2.3. Statistical Analyses

We analysed changes in plant coverage and plant species richness in reaction to conservation treatments with the help of generalised linear mixed models (GLMM) implemented in *lme4* package [44] in R [45] using *RStudio* [46]. In total, 15 GLMMs were performed and in all models single one-square-metre research subplot were used as a separate data record (n = 1200) while plot identity was inserted as random categorical factor, to account for possible dependency in plant coverage and richness among research subplots belonging to the same plot.

First, we performed seven models (GLMM 1–7) with negative binomial error distribution analysing coverage of different plant groups as a response variable (all species, A–E ecological groups, woody species). Plant coverage reflects abundance and is thus often treated as a count-like variable and modelled using Poisson or similar structure of errors [47]. In these models we included three explanatory variables—application of grazing (yes vs. no), application of mechanical removal of understorey (yes vs. no) and year (before vs. after treatments). Moreover, as we expected temporal changes of plant coverage to depend on treatment (and also interaction between the two treatments) we considered three-way interaction and three two-way interactions in GLMMs. Second, we analysed species richness of plant species groups (all species, A–E species, woody species) following the same procedure (GLMMs 8–14). Finally, we analysed influence of the treatments on the vegetation Shannon-Wiener diversity index (GLMM 15). The Shannon-Wiener index was calculated from species cover using package *vegan* [48]. The same package was used to calculate Sørensen vegetation similarity index. We carried out the detrended correspondence analysis (DCA) for species cover on data from all 1200 subplots summed up to the plot level (n = 24), to check if there are any directional changes in species composition of vegetation and to find out change of cover of which species were driving these changes. We executed DCA analysis for species cover, because plant cover reacts on environmental changes (caused for example, by treatments) faster due to vegetative expansion, than species frequency or species richness, which depend on propagule dispersal.

3. Results

There were 135 species of vascular plants registered in total on all plots in both surveys (Tables S1 and S2) and species richness varied between 80 and 86 species 100 m^{-2}. In three out of six plant groups considered (group A, B, E) and for all species pooled, grazing positively interacted with year indicating that at grazed sites the increase in plant coverage over time was larger than at non-grazed sites. Similarly, for plants belonging to group A and all plants pooled (and group B on the verge of significance) we recorded positive interaction between year and mechanical removal, thus indicating that removal leads to an increase in coverage of plants from these ecological groups as compared to sites without removal. In case of woody species, however, we obtained negative interaction, so for this group removal reduced coverage (Table 1 and Figure 2). We did not confirm any positive 3-way interaction among grazing, removal and year, while in case of two species groups (A and B) the interaction was even negative (marginally insignificant in two other cases, Table 1). This means that the two treatment types applied together have lower effect on temporal change of plant coverage than expected by the effects of removal and grazing applied separately (Table 1).

Table 1. Generalised linear mixed models with negative-binomial error structure analysing coverage of plant groups in reaction to conservation treatments (mechanical removal and grazing) and over time. For each model parameter estimates accompanied by SE in brackets are given, symbols indicating significance level are explained below the table, significant effects are bolded. Plant ecological groups considered: A—thermophilous oak forest species, B –deciduous forest species, C—meadow, xerothermic grassland and clearing species, D—wet-demanding and shadow-tolerant species, E—weeds and alien species, of herb layer in the studied oak forest, wood—trees and shrubs.

Model:	**GLMM1**	**GLMM2**	**GLMM3**	**GLMM4**	**GLMM5**	**GLMM6**	**GLMM7**
Response:	All Species	Group A	Group B	Group C	Group D	Group E	Wood
Main effects							
Intercept	**1.95 (0.03) *****	**2.93 (0.08) *****	**4.31 (0.06) *****	**0.80 (0.21) *****	**0.81 (0.47) ^**	0.56 (0.41)	**2.56 (0.10) *****
Year: after	0.01 (0.03)	0.10 (0.08)	**0.07 (0.04) ^**	0.21 (0.20)	−0.05 (0.26)	**0.42 (0.18) ***	**0.17 (0.06) ****
Removal: yes	−0.02 (0.04)	−0.16 (0.12)	0.01 (0.08)	**0.63 (0.30) ***	−0.14 (0.67)	0.38 (0.58)	−0.11 (0.14)
Grazing: yes	**−0.07 (0.04) ^**	**−0.22 (0.12) ^**	−0.06 (0.08)	0.38 (0.30)	−0.85 (0.67)	0.37 (0.58)	−0.16 (0.14)
2-way interactions							
Year * Removal	**0.11 (0.05) ***	**0.23 (0.11) ***	**0.09 (0.05) ^**	−0.14 (0.28)	0.28 (0.37)	0.07 (0.25)	**−0.18 (0.09) ***
Grazing * Removal	0.07 (0.06)	**0.38 (0.16) ***	−0.05 (0.11)	**−0.69 (0.42) ^**	1.07 (0.95)	−0.00 (0.82)	0.13 (0.20)
Year * Grazing	**0.18 (0.05) *****	**0.33 (0.11) ****	**0.19 (0.05) *****	0.31 (0.28)	0.48 (0.38)	**0.69 (0.25) ****	−0.08 (0.09)
3-way interaction							
Year * Grazing * Removal	**−0.19 (0.06) ****	**−0.43 (0.16) ****	**−0.14 (0.07) ^**	0.18 (0.39)	−0.57 (0.53)	**−0.65 (0.35) ^**	0.13 (0.13)

Significance levels: ^ −0.1; * −0.05, ** −0.01, *** −0.001.

We did not confirm any interactions among independent variables explaining species richness of all six plant groups considered (Figure 3). However, for all species pooled positive significant interaction between year and grazing was recorded and marginally insignificant positive interaction between year and removal. This shows that overall species richness of plant community is increasing faster at sites with grazing and with removal as compared to sites without these treatments. The two treatments, however, do not interact with time, indicating that at sites with both treatments the increase in species richness is not larger than at sites with each treatment applied separately. Finally, in all except two groups we observed a general increase of species richness between two study years and this increase was independent on the two treatments considered (Table 2 and Figure 3).

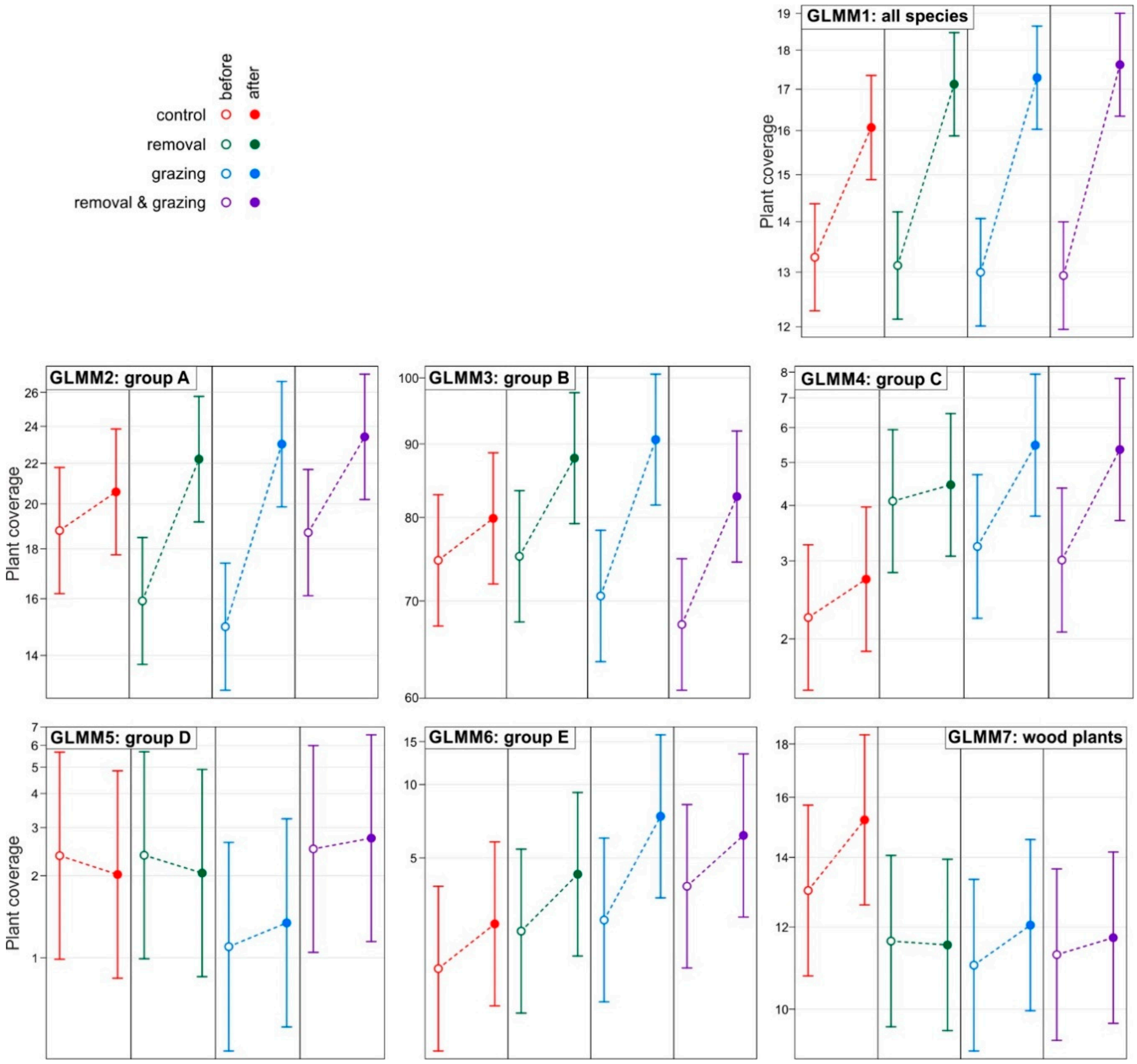

Figure 2. Coverage (and 95% confidence intervals) of all plant species and species belonging to studied ecological groups (all species, A—thermophilous oak forest species, B–deciduous forest species, C—meadow, xerothermic grassland and clearing species, D—wet-demanding and shadow-tolerant species, E—weeds and alien species, of herb layer in the studied oak forest, wood—trees and shrubs) in relation to treatment type (grazing and mechanical removal of understorey and their combination) over time, as predicted by models summarized in Table 1.

Variation in Shannon-Wiener plant diversity index showed significant increase over time (GLMM 15, Figure 3; intercept: 2.53 ± 0.04 SE, $p < 0.001$; year effect: 0.21 ± 0.02, $p < 0.001$) but main effects of removal and grazing were not significant ($p > 0.8$ in both cases). However, at sites with removal and at sites with grazing, the increase in the plant diversity was larger than at sites without these treatments (year*removal interaction: 0.07 ± 0.03, $p = 0.017$; year * grazing interaction: 0.07 ± 0.03, $p = 0.014$). Interaction between grazing and removal as well as 3-way interaction among year, removal and grazing had no effects on the plant diversity index ($p > 0.4$ in both cases).

The species composition of the herb layer did not change significantly after the treatments. Sørensen species similarity coefficients on individual plots before and after the treatment were high and ranged between 0.83 and 0.91. All plots were characterized by a similar species structure, with several dominant species occurring with a frequency of over 75%: *Anemone nemorosa* L., *Convallaria majalis* L., *Viola reichenbachiana* Jordan ex Bor., *Asperula odorata* L., *Quercus robur* L. and several common species, with a frequency higher than 50%: *Geum urbanum* L., *Poa nemoralis* L., *Lathyrus vernus* (L.) Bernh., *Milium effusum* L. and *Moehringia trinervia* L. As many as 87 (64%) of 135 recorded species had a frequency of less than 5% (Table S1).

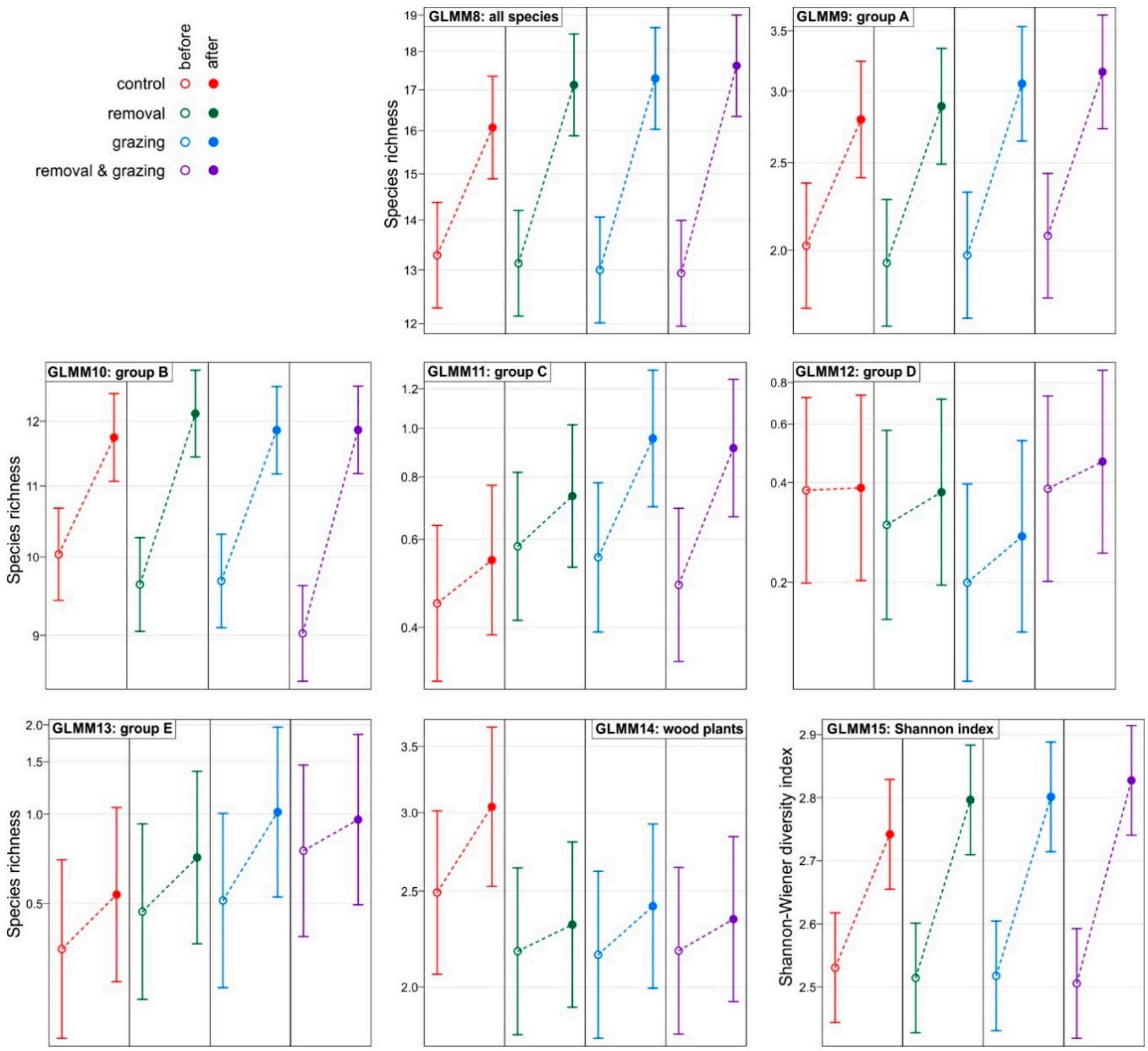

Figure 3. Species richness and Shannon-Wiener diversity index (and 95% confidence intervals) of all plant species and species belonging to studied ecological groups (all species, A—thermophilous oak forest species, B–deciduous forest species, C—meadow, xerothermic grassland and clearing species, D—wet-demanding and shadow-tolerant species, E—weeds and alien species, of herb layer in the studied oak forest, wood—trees and shrubs) in relation to treatment type (grazing and mechanical removal of understorey and their combination) over time, as predicted by models summarized in Table 2.

Despite the high value of the Sørensen species similarity coefficient, DCA analysis revealed clear directional shift of most plots on the DCA scatter, which was correlated with the DCA2 axis (Figure 4). This shift was associated with an increase in cover of species from the ecological groups A (*Campanula persicifolia* L.), B (*Brachypodium sylvaticum* (Huds.) *p.* Beauv., *Carex sylvatica* Huds., *Cruciata glabra* (L.) Ehrend., *G. urbanum*, *Isopyrum thalictroides* L., *Lilium martagon* L., *Luzula pilosa* (L.) Willd., *Oxalis acetosella* L., *Pulmonaria obscura* Dumort., *Viola riviniana* Rchb.), C (*Fragaria vesca* L.) and E (*Cerastium* *arvense* L., *Plantago major* L., *Veronica hederifolia* L.) and with decrease in cover of species from groups A (*Vincetoxicum hirudinaria* Medik.), B (*Sanicula europaea* L., *Tilia cordata* Mill., *Valeriana officinalis* L., *Viola mirabilis* L.) and D (*Chaerophyllum temulum* L.) (Figure 4).

Table 2. Generalised linear mixed models with Poisson error structure analysing species richness of plants groups in relation to conservation measures (mechanical removal and grazing) and over time. For each model parameter estimates accompanied by SE in brackets are given, symbols indicating significance level are explained in Table 1, significant effects are bolded. Plant ecological groups considered: A—thermophilous oak forest species, B—deciduous forest species, C—meadow, xerothermic grassland and clearing species, D—wet-demanding and shadow-tolerant species, E—weeds and alien species, of herb layer in the studied oak forest, wood—trees and shrubs.

Model:	GLMM8	GLMM9	GLMM10	GLMM11	GLMM12	GLMM13	GLMM14
Response:	All Species	Group A	Group B	Group C	Group D	Group E	Wood
Main effects							
Intercept	**2.59 (0.04) *****	**0.70 (0.08) *****	**2.31 (0.03) *****	**−0.81 (0.18) *****	**−0.97 (0.33) ****	**−1.05 (0.35) ****	**0.91 (0.10) *****
Year: after	**0.19 (0.03) *****	**0.32 (0.08) *****	**0.16 (0.04) *****	0.20 (0.16)	0.02 (0.18)	**0.42 (0.17) ***	**0.20 (0.07) ****
Removal: yes	−0.01 (0.06)	−0.04 (0.12)	−0.04 (0.05)	0.26 (0.25)	−0.24 (0.47)	0.29 (0.50)	−0.14 (0.14)
Grazing: yes	−0.02 (0.06)	−0.02 (0.12)	−0.04 (0.05)	0.21 (0.25)	−0.64 (0.48)	0.38 (0.50)	−0.14 (0.14)
2-way interactions							
Year * Removal	**0.08 (0.04) ˆ**	0.08 (0.11)	0.07 (0.05)	0.03 (0.21)	0.21 (0.26)	−0.00 (0.22)	−0.14 (0.10)
Grazing * Removal	0.01 (0.08)	0.09 (0.16)	−0.03 (0.06)	−0.39 (0.36)	0.89 (0.67)	0.10 (0.69)	0.15 (0.20)
Year * Grazing	**0.10 (0.04) ***	0.12 (0.11)	0.05 (0.05)	0.35 (0.21)	0.30 (0.28)	0.26 (0.22)	−0.09 (0.10)
3-way interaction							
Year * Grazing * Removal	−0.05 (0.06)	−0.10 (0.15)	−0.00 (0.07)	0.05 (0.29)	−0.34 (0.37)	−0.44 (0.28)	−0.10 (0.15)

Significance levels: ˆ −0.1; * −0.05, ** −0.01, *** −0.001.

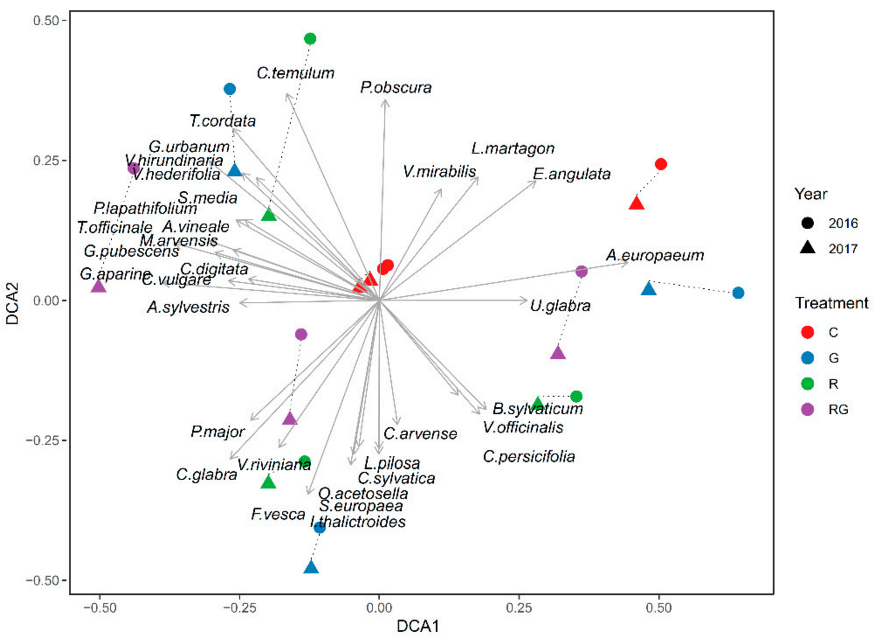

Figure 4. Detrended correspondence analysis (DCA) scatter plot of species covers summarized to plot level (n = 24). Vectors of species were passively fitted for species significantly correlated with DCA1 and DCA2 axes ($p < 0.02$; Pearson's $r > 0.300$). Treatments: C—control, G—grazing, R—mechanical removal of brush, RG—grazing followed by mechanical removal of brush, year 2016—before the treatment, year 2017—after treatment.

4. Discussion

The investigated oak forest, despite its young age and the post-agricultural origin of the site, was characterized by relatively high species richness of the herb layer and high biodiversity, which is typical for this kind of forest (see for example, Reference [49]). Research in Białowieża Forest, in some remnants of thermophilous oak forests, with good light access (density of crowns did not exceed 50%), yielded a similar level of herb layer species richness (77 to 82 species/100 m^2 in Białowieża forest [50] vs. 80 to 86 species/100 m^2 in our study). Most of the studied ecological groups of plants showed in the second year of the study an increasing trend in species richness, regardless of treatment or its lack (see Table 1). This was probably the effect of general silvicultural treatment carried out a year prior to our experiment's set up: relatively intensive stand thinning (30% of trees removed) and removal of approx. 30% of bushes, which resulted in increased light access to the forest floor. After such a strong thinning of the forest, the increase in species richness in the following years, especially light demanding species, was expected. Kwiatkowska et al. [51] and Kwiatkowska-Falińska et al. [52] reported that species richness and biodiversity indicators of the herb layer depend mainly on the species composition of the forest and the degree of canopy cover and therefore on the access of light to the forest floor. Other authors also showed that canopy shading in combination with the amount of soil phosphorus tend to be the most important factors influencing the species richness and productivity of the herb layer in oak forests [53–55]. The amount of light reaching the forest floor also depends on tree species' shade-casting ability, which for pedunculate oak is low in comparison to other European tree species [56], which enhances the species richness and cover of the herb layer [55]. Time and intensity of pre-experiment intervention, as well as intensity of the experimental treatments were similar on all plots and thus the differences between treatments revealed by our analysis were the effect of the application of active conservation measures.

Both active treatments—manual removal of shrubs (plots R) and grazing (plots G) caused an increase in the Shannon-Wiener diversity index and an increase of the species richness, if all species were taken into account, without dividing them into ecological groups. However, increase in total species richness on grazed plots was in our study on the verge of significance. McEvoy et al. [57] reported that grazing in seminatural woodlands of Northern Ireland caused an increase in botanical diversity, a reduction in the cover of dominant species, such as bramble *Rubus fruticosus* agg. and an increase in the share of ruderal species. However, the Irish study dealt with the long-term effect, which allowed migration of plant species into the study site from outside or possibly, it allowed also breaking of dormancy of seeds from the soil seed banks. Our short-term, only one-year long, monitoring did not allow to register changes in species richness, which takes longer time to occur due to limitations in plant dispersal but we observed significant changes in species cover. The general coverage of all species and cover of species from the ecological groups A (one of the two target groups) and B (species of dark forests) increased significantly on plots G (grazed) and R (with mechanical removal) but not on plots RG, where grazing was combined with mechanical removal. The increase in the species cover of plants from the group of forest species (group B) was not expected, neither demanded, as they are well thriving under forest canopy cover. Their reaction may be explained by their specific ecological needs—they are typical for mature natural and seminatural deciduous forests, whose dynamics are driven by small scale disturbances in the so-called gap dynamics scenario. Gap dynamics develop high complexity of forest patches [58,59] and in effect offer good conditions for development for both shade-tolerant plants under undisturbed canopy and moderately light- and warm-demanding species in the canopy gaps [20]. Consequently, their number and frequency or cover are used for evaluation of the effectiveness of active protection treatments in forests [20], which was well expressed on DCA scatter plot (Figure 4), where mostly species of the group B were responsible for shift in species composition of the studied plots. However, it must be stressed, that in large extent it was the effect of the increase in cover of light-demanding species from this group, for example, *I. thalictroides*, *L. martagon*, *P. obscura* and *V. riviniana*.

Grazing caused also increase in species cover of weeds and alien species (group E), which is in line with reports on increase in share of ruderal species in the grazed Irish woodlands [57]. It may be the combined effect of epi- and endozoochoric transport of weed seed by sheep and the creation of short plant cover due to grazing. The mechanical removal had a strong negative influence of cover of woody plants, which is contrary to our expectations (the second hypothesis) but may be explained by too short time for their regrowth. Interestingly, the combined treatment (RG) did not cause a significant reaction of species richness of any of the studied ecological groups and in case of plant coverage the target group A showed positive reaction but another target group C showed the opposite, which in general is against of our first hypothesis. We expected that grazing combined with mechanical removal will increase amount of light reaching the forest floor and promote development of light demanding species from the groups A and C. However, it could be that application of both treatments at the same space and time suppressed vegetation so strongly that positive effect of the increased light access did not take place. In our opinion this result suggests that not only the type of treatment but also its intensity should be taken into account during active nature conservation. The effect of our very short-term experiment indicates the need for introducing both treatments—controlled grazing and removal of shrubs but separately, as both approaches turned out to more successful than the control, with the mechanical removal more successful in suppressing woody plants.

We observed also some potential negative effects of treatments, for example, increase in abundance of weeds and alien species on grazed plots (group E) and increase in cover of typical forest species (group B), which must be considered, when deciding on the type of management in protected areas. On the other hand, taking into account post-agricultural character of the studied forest, relatively high number of typical forest species (group B) and their increase in cover in the studied oak forest shows its unexpectable quick restoration [60,61]. This was probably possible due to the close proximity of the continuously forested area, as well as the relatively short period of agricultural use, for only a few decades, too short to degrade forest soil and its soil seedbanks, which might serve as reservoirs of ancient forest species [62], which facilitated their quick recolonization of the forest floor. Many species of open oak forests are known to create permanent soil seed banks [52]. The results of our research strongly suggest that the method of active protection of oak forests should be chosen depending on the goal and the species composition and species cover of the herb layer and young trees and shrubs found at the beginning of the restoration process. Some species, such as blackthorn (*Prunus spinosa* L.), are not browsed by sheep due to thorns and in effect more open forest patches can be quickly colonized by these bushes if treatment does not include the mechanical removal of them. This is clearly confirmed by our results—blackthorn frequency increased on the C and G plots, where manual removal of the undergrowth was not applied but it decreased on the R and RG plots (Table S1). According to Vera [25], the resistance of blackthorn to browsing is so high that its clumps may serve as local regeneration safe places for trees in savannah-like landscapes heavily populated by large herbivores.

The positive reaction of the general vegetation cover (all species group) as well as ecological groups A and B on grazing suggests, that it is likely that livestock grazing in deciduous forests may have contributed in the past to the formation of the species-rich thermophilous oak forest communities (species from group A) by the establishment (seed transport and creation of favorable light conditions) of these light-demanding species in forest communities. The research on seed banks of such forests revealed that many species of oak forest have the ability to create permanent soil seed banks but their activation requires constant active protection involving the repeated removal of bushes and extensive grazing of domestic stock [52]. In such a short period of the study, however, no significant changes in species richness of thermophilous oak forest species (group A) was observed.

5. Conclusions

Our results revealed that both grazing by sheep and mechanical removal served well for total plant species richness and their cover, if applied separately but their combined effect can be negative or none. Thus, there is no need to combine these two treatments in the same place and time, unless some special circumstances, for example, presence of browsing resistance species, demand special combined treatment. Application of both treatments (but separately) had positive influence on species cover of plants typical to xerothermic oak forests (group A) and species of deciduous forests (group B), therefore, both can be used for active conservation of open oak forest understorey vegetation. Mechanical removal allowed also for successful control of woody species, which creates light conditions more suitable for light-demanding herb plants at the forest floor. This result is especially important in the context of more grazing- and browsing-resistant species, like thorny *P. spinosa*, where mechanical removal seems to be unavoidable to control them. Otherwise, they regenerate quickly and if not removed, benefit from decreased competition and higher light accessibility instead of the understory herb plants. Active conservation measures may result also in negative effects—we observed increase in the species richness and cover of ruderal species on grazed plots, which was probably the combined effect of epi- and endozoochoric seed transport by sheep and the creation of short lawn due to grazing, which reduced competition for light. Therefore, monitoring of the reaction of vegetation on treatments is of paramount importance and also negative side effects of treatments should be taken into account in this context.

Supplementary Materials: The following are available online at http://www.mdpi.com/1999-4907/11/5/582/s1: Table S1: Frequency (%) of the oak forest herb layer species before (2016) and after (2017) application of treatments, Table S2: Estimation of species cover in undergrowth of the oak forest in 2016 (prior to treatments) and 2017 (a year after treatments).

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