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Polish Pony Changes Lower Layer Biodiversity in Old Growth Scots Pine Stands

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Abstract: The study examines the influence of Polish primitive horse grazing on vegetation in deciduous and coniferous old forest stands in north-east Poland. It was conducted in both forest sites in two complexes located in: (i) the fenced area of the Popielno Research Station of the Polish Academy of Sciences, with free-living Polish pony [Polish primitive horse (*Equus ferus caballus* Linnaeus, 1758)] in 130-year-old stands, and (ii) in the open 116-year-old managed (harvested) Maskulińskie Forest District, without horses. In both areas the stands are inhabited by free-living red and roe deer. The impact of forest animals on ground cover layer as well as on understory shrub layer and undergrowth was compared. Very significant differences in the structure of the understory and undergrowth (above 0.5 m) layer vegetation communities between both areas and type of stands were found. The results suggest that the presence of the Polish horse substantially changed the species composition and increased the species diversity of the ground layer and shrub layer both in the coniferous forest and deciduous forest habitats. The height of the shrub layer trees was lower by 30% in the area with the Polish horse. The level of biodiversity of forest plants was dependent on the presence of the Polish horse, which in the past was one of the natural inhabitants of forests in the area of research.

Keywords: Polish primitive horse; forest site type; herb layer; undergrowth layer; understory layer; biodiversity

1. Introduction

A pro-ecological model of modern forestry in Poland, close-to-nature [1,2], provides local usage of natural forest farming methods [3], which have in the last half-century shaped the area where the Polish horse 'konik polski' (*Equus ferus caballus* Linnaeus, 1758) or tarpan (*Equus caballus gmelini* Antonius, 1912 or *Equus ferus ferus* Boddaert, 1785) can live [4–6]. It is assumed that adequate management of some animal populations will support the restoration of rare habitats, e.g., luminous oak stands, which occurred in large numbers in Poland in the past due to the existence of goats, pigs, and ponies in the forest. However, the impact of herbivorous megafauna on the biological diversity of forests, including natural complexes, has been debated for many years. In the opinion of some authors [7,8], large herbivorous mammals were the factor affecting the appearance of primary forest communities, and as a result of their pressure, forests were formed as a mosaic of patches dominated by trees and open grass areas. According to Vera [7], along with the development of farming, free-living aurochs (*Bos primigenius* Bojanus, 1827) and tarpans (*Equus gmelini* Boddaert, 1785) were replaced by domesticated animals, such as cows, horses, and pigs. Most studies describing the effect of large herbivores on forests focus on

ruminants—the red deer (*Cervus elaphus* Linnaeus, 1758), the roe deer (*Capreolus capreolus* Linnaeus, 1758), the fallow deer (*Dama dama* Frisch, 1775), the European bison (*Bison bonasus* Linnaeus, 1758), or the elk (*Alces alces* Linnaeus, 1758) [9]. However, little is known about the effect on free-living, non-ruminant ungulate species, such as the Exmoor pony (*Equus caballus* Linnaeus 1758), the Eurasian wild horse tarpan (*Equus caballus gmelini* or *Equus ferus ferus*), and the Przewalski's horse (*Equus ferus przewalskii* Poliakov, 1881). To the above-mentioned group of non-ruminants also belongs the Polish primitive horse, the 'konik Polski' (*Equus ferus caballus*) [10,11].

In Poland, Polish primitive horses are bred in two different systems, in stables and in nature reserves or in the wild. Breeding primitive horses in reserves is currently popular not only in Poland, but also in Germany, the Netherlands, and France [4,10,12–14]. The reintroduction to the forests of the Polish primitive horse, a mammal which lived in a wild state in the Białowieża Primeval Forest until about 1780 [5], has become a part of the activities undertaken for preserving the endangered species ex situ, e.g., by Vetulani in 1936 [15], but it requires evaluation of its impact on the environment, especially on plant communities. The Polish 'konik polski' was introduced recently as a natural component of some forests, facilitating the transformation of artificially established stands on post-agricultural lands towards an 'ecosystem' [16].

In general, *Equidae* contains species mainly related to open land structures, where they stay for most of the year (pastures and meadows), and they may also use available tree stands [17], where there can be seen mostly in winter and spring [18,19]. The diet of horses and cervids is significantly different, since the woody species (shrubs and trees) account for 40% to 90% in the deer diet [20], while primitive horses are first of all grass-eaters, and only to an insignificant degree feed on arborescent species [17,18,21,22]. As non-ruminants, horses obtain metabolic energy from both enzymatic digestion and bacterial fermentation [23,24]. The alimentary tract of horses is both anatomically and functionally adapted for small portions of woody plant food [19].

As mentioned before, equids use forest habitats relatively seldom [18,25–27]. In the case of the Polish primitive horse, it may use the forest not only as a feeding place, but also as protection against vexing insects or heat [12,25,28]. The grazing of the Polish primitive horse, like the Exmoor pony, is increasingly more frequently used as a natural means to maintain the non-forested status of the areas that are not agriculturally used. Free-living horses help to preserve vast meadow and pasture or dune areas, contributing to the preservation of semi-natural open communities, just like large herbivorous mammals in the past [18,29–32]. Polish primitive horses were used, for instance, not only to restrain the succession of forest species in grass areas and moors, but also to contribute to maintaining their biodiversity [33,34]. Grazing on mid-forest meadows in extensive conditions favors the diversity of the undergrowth structure, and the dispersed dung left by horses contributes to the herb layer diversification. This results in increasing the number of plant species [35,36].

Apparently, so far, the only place from which information has been provided concerning the diversification effect of herbivorous megafauna on the forest environment in Europe is the New Forest in England. However, this area, apart from the cervids and non-ruminants represented by the pony, is also inhabited by other mega-ruminants, i.e., cows [37]. At a moderate level of invasive or late-succession plant occurrence, large herbivores stop their expansion, which consequently promotes increasing biodiversity and structural variability of the landscape [3,38–42]. According to Borkowski [43] and Klich [10], the Polish primitive horse can affect trees and shrubs by nibbling shoots, browsing, and debarking seedlings and branches. However, the bark of trees and shrubs is a marginal component in the horse diet, used only in the winter period [18,26,44]. The mentioned authors reported that horses can only cause significant damage in tree stands while feeding with a large concentration of animals.

The aim of the research was to determine the level of biodiversity of forest plants depending on the presence of the Polish horse, which was in the past one of the natural inhabitants of forests in the area of research. The main hypothesis of the research undertaken is an assumption that depending on the composition of the tree species in the stand in deciduous or coniferous forests, the presence of free-living Polish primitive horses increases the degree of plant diversity in the forest ground cover

layer (forest vegetal cover, undergrowth, and understory) in comparison to the stand without horses in Maskulińskie Forest District (FD).

2. Materials and Methods

2.1. Research Areas

The research was carried out in 2013 in two adjacent areas: (i) the experimental forest of the Popielno Research Station of the Polish Academy of Science (RS) established in 1955, and (ii) managed (harvested) stands of Maskulińskie FD. Both forest complexes are located in the north-eastern part of Poland, in the area managed by the Regional Directorate of State Forests in Olsztyn, belonging to the Land of the Great Mazurian Lakes and Mazurian Plain mesoregions [45]. The examined areas are distinguished by a high number of pine stands, unique on the European scale for the age of the pine trees, which are even up to 230 years old.

A habitat of mixed coniferous-deciduous forest site (over 61%) prevails in the Popielno RS, with the Scots pine *Pinus sylvestris* L. as the dominant species (about 89%), with an average age of 131 years, and the addition of the European white birch *Betula peudula* Roth. and the European larch *Larix decidua* Miller. Other species growing here include the Norway spruce *Picea abies* (L.) Karst., the European oak *Quercus robur* L., the European beech *Fagus sylvatica* L., and a young generation of pine. The Popielno forest, with soil of higher fertility rate, is occupied by xeric mixed forest (16% share) and wet forest (2% share of the habitat). The neighboring Maskulińskie FD occupies more mesic biotope habitats, with prevailing wet coniferous (47%) and mixed coniferous stands (25%), while xeric mixed forests occupy 15% of the forest division area. The species composition is dominated by the pine (85%) with an average age of 116 years, and the share of other species (spruce, birch, alder, oak) does not exceed several percent.

The Popielno RS covers an area of 1628 ha (including 57 ha (3.5%) of meadows, pastures, and hunting grounds). This is a fenced-in 1955 (fence 2 m high) reserve, inhabited by four herds (46 animals) of free-living Polish primitive 'konik Polski' horses (*Equus ferus caballus*) [15]. The density of horses is about 3 animals per 100 ha. Control areas were established in the Maskulińskie FD, where the Polish primitive horse does not occur. The area of the Maskulińskie FD is characterized by similar natural and forest conditions. The objects under examination are inhabited by a natural community of ungulates, including red and roe deer as the only other large herbivores in the forest, and in the area of Popielno RS, additionally by the Polish primitive horse.

The deer were controlled and their density (estimated on the basis of pellet group counts) was similar in both areas, averaging around 7 ind. and 2 ind. of red and roe deer per 100 hectares, respectively [Borkowski Jakub, personal communication]. During winter, animals in both areas are fed with hay, which potentially reduces their impact on the vegetation available at this period.

2.2. Methods

In 38 sub-compartments in the Popielno RS and in 29 in the Maskulińskie FD, both in mesic coniferous (CF) and in xeric deciduous (DF) habitats, 67 sample plots were established, 40 × 40 m in size (the area of 1600 m^2). In each case an inventory of understory and undergrowth (higher 0.5 m) was carried out, describing number and species composition. Additionally, in each of the 67 sub-compartments in the tree stand canopy the five round plots, each of an area of 0.5 m^2, were distributed, with at least 5 m distance from large gaps (about 1000 m^2), where the inventory of undergrowth (lower 0.5 m) and the herb layer were carried out. All plants in the undergrowth were counted, specifying their species composition and height (to an accuracy of 1 mm). In the case of grasses, the percentage of surface coverage was specified instead of the number of individuals. We compared vegetation frequency in two adjoining areas with ungulate communities differing in the presence of the Polish primitive horse.

The Shannon-Wiener index of plant biodiversity [$H=-\Sigma(p_i \ln p)_i$; where p_i is the relative coverage of species i] was calculated for each sample plot with the use of BioDiversity Pro software [46].

The mean values of the index, as well as the height of plants for the research areas, were compared using ANOVA two-way analysis of variance, after testing the normality of distribution and evaluating the insignificance of differences for variances between the compared groups. In two cases, where differences between means were significant, the comparison was carried out using a post-hoc Tukey's test, taking into account two fertility groups of habitats (CF and DF) and the presence or absence of the Polish primitive horse (Horse and No Horse). Additionally, a Bray and Curtis [47] coefficient of qualitative and quantitative similarity of the community of plants was evaluated. Dendrograms which compared individual branches for each of the two layers of plants, taking into account plants of the herb layer and undergrowth, as well as the plants of the shrub and herb layer, were constructed in the BioDiversity Pro software.

3. Results

3.1. The Herb Layer and Undergrowth (Lower 0.5 m)

For the herb layer species, a certain variability of occurrence was observed, related to the type of the forest habitat and presence or absence, of the Polish primitive horse (Table 1).

Table 1. The share of species in the herb layer and undergrowth lower 0.5 m in the areas of various fertility, with the presence or absence of the Polish primitive horse. The '+' symbol denotes a percentage share of the entire number of existing species lower than 3%, the ++ symbol denotes the share between 3% and 6%, and the '+++' symbol denotes the number of the species exceeding 6%. The absence of the symbol means lack of the species. All species in the column account for 100%. Areas with horse were bold coded for ease of interpretation.

Species	Deciduous Forest (DF)		Coniferous Forest (CF)	
	No Horse	Horse	No Horse	Horse
Acer campestre L.				**+**
Acer platanoides L.	+	**++**		
Acer pseudoplatanus L.		**+**		
Aegopodium podagraria L.	+	**+**		
Anthericum ramosum L.	+		+	
Asarum europaeum L.	+			
Athyrium filix-femina (L.) Roth		**+**		
Betula pendula Roth.	+	**+**	+	**+**
Calamagrostis arundinacea L. Roth				**+**
Calluna vulgaris L.			+	**+**
Campanula rotundifolia L.		**+**		**+**
Carex digitata L.	+	**+**	+	**++**
Carpinus betulus L.	+++	**++**		**+**
Convallaria majalis L.	+	**++**	+	**++**
Corylus avellana L.		**+**		
Crataegus monogyna Jacq.		**+**		
Dactylis polygama Horv.		**++**		**+**
Daphne mezereum L.	+	**+**		
Deschampsia flexuosa L.	+	**+**	+++	**+++**
Dicranum polysetum Sw.		**+**		**+++**
Dicranum scoparium (L.) Hedw.	+	**+**	++	**+**
Dryopteris carthusiana (Vill.) H. P. Fuchs	+	**+++**		**++**
Dryopteris filix-mas (L.) Schott		**+**	+	
Equisetum sylvaticum L.	+			
Fagus sylvatica L.	+	**+**		
Ficaria verna Huds.	+	**+**		
Fragaria vesca L.	+	**+**	+	**+**
Fraxinus excelsior L.		**+**		
Geranium robertianum L.	+	**+**	+	

Table 1. *Cont.*

Species	Deciduous Forest (DF)		Coniferous Forest (CF)	
	No Horse	Horse	No Horse	Horse
Hepatica nobilis Mill.	++	**++**		**+**
Hylocomium splendens (Hedw.) Schin Bruch, Schimp. & W.Gümbel		**+**		**+++**
Impatiens noli-tangere L.	++	**+**		
Juniperus communis L.				**+**
Larix decidua Mill.				**+**
Luzula pilosa (L.) Willd.	+		++	
Lycopodium clavatum L.			+	
Maianthemum bifolium (L.) F. W. Schmidt	+++	**++**	+	**+**
Melampyrum pratense L.	+	**+**	+	**+**
Milium effusum L.			+	**+**
Mnium undulatum (L.) Hedw.		**+**		**++**
Mycelis muralis L.	+++	**+++**		**+**
Oxalis acetosella L.	+++	**+++**	+++	**++**
Paris quadrifolia L.	+	**+**		
Picea abies L.				**+**
Pinus sylvestris L.	+	**+**		**+**
Pleurozium schreberi (Willd.) Mitten.	+++	**++**	+++	**+++**
Poa nemoralis L.		**+**	+	
Polygonatum multiflorum (L.) All.		**+**		
Polygonatum odoratum (Mill) Druce		**+**	+	**+**
Polypodium vulgare L.				**+**
Polytrichum commune Hedw.	+		+	
Populus tremula L.	+			
Potentilla erecta (L.) Raeusch				**+**
Prunus serotina (Ehrh.) Borkh.		**+**		
Pteridium aquilinum (L.) Kuhn	+	**+**		**+**
Quercus robur L.	+	**+**	+++	**+**
Quercus rubra L.	+			**+**
Rubus caesius L.		**+**		
Rubus chamaemorus L.	+			
Rubus idaeus L.	++	**+**	+++	**+**
Rubus saxatilis L.		**++**	+	**++**
Sorbus aucuparia L.	+	**+**	+	**+**
Tilia cordata Mill.	+	**+**		**+**
Tilia platyphyllos L.	+			
Trientalis europaea L.	+	**+**	++	**+**
Ulmus minor Mill.	+	**+**		
Urtica dioica L.	+	**+**	+	
Vaccinium myrtillus L.	++	**+++**	+++	**+++**
Vaccinium vitis-idaea L.		**+**	+++	**++**
Veronica officinalis L.			+	
Vinca minor L.			+	
Viola hirta L.	+			
Viola reichenbachiana Jordan ex Bor.		**+++**		
Total	**42**	**51**	**30**	**40**

3.1.1. Deciduous Forests (DF)

In habitats with a xeric deciduous forest, where the Polish primitive horse did not occur (No H DF), 42 species in the layer of understory and undergrowth were observed. The most numerous (with the share of over 6%) included: *Carpinus betulus* L., *Oxalis acetosella* L., and *Pleurozium schreberi* (Willd.) Mitten. In DF, despite the absence of the horses, the least numerous (below 3%) included: *Asarum europaeum* L., *Equisetum sylvaticum* L., and *Luzula pilosa* (L.) Willd. It should be emphasized that the above-mentioned species were not found with the presence of the Polish primitive horse.

In deciduous forests with the presence of Polish horses (H DF), 51 species were observed, with the most numerous being *Dryopteris carthusiana* (Vill.) H. P. Fuchs, *Mycelis muralis* L., and *Oxalis acetosella* L. In the absence of Polish horses, the following species were not observed: *Dryopteris filix-mas* (L.) Schott, *Hylocomium splendens* (Hedw.) Schimp. in Bruch, Schimp. and W.Gümbel, *Poa nemoralis* L., and *Prunus serotina* (Ehrh.) Borkh. (the above-mentioned species scarcely occurred), *Viola reichenbachiana* Jordan ex Bor. (the species was numerous, above 6%).

3.1.2. Coniferous Forests (CF)

In mesic coniferous habitats (CF), without the presence of Polish horses (No H CF), 30 species were observed in the herb and undergrowth layer, including the most numerous: *Deschampsia flexuosa* L., *Pleurozium schreberi* (Willd.) Mitten., and *Vaccinium myrtillus* L. Species occurring in this habitat without the Polish horses (and absent where the Polish horse occurred) included: *Dryopteris filix-mas* (L.) Schott, *Luzula pilosa* (L.) Willd., *Poa nemoralis* L., and *Urtica dioica* L.

Coniferous forests where the Polish horse was present (H CF) were characterized by the occurrence of 40 species, including the following species observed in great numbers: *Deschampsia flexuosa* L., *Hylocomium splendens* (Hedw.) Schimp. in Bruch, Schimp. and W.Gümbel, and *Pleurozium schreberi* (Willd.) Mitten. The species growing in sub-compartments where the Polish horse was present (and non-occurring with the absence of Polish horse) include: *Calamagrostis arundinacea* L. Roth., *Juniperus communis* L., and *Potentilla erecta* [L.) Raeusch.

The differences between number of species observed in the herb layer on both habitats are presented in Figure 1.

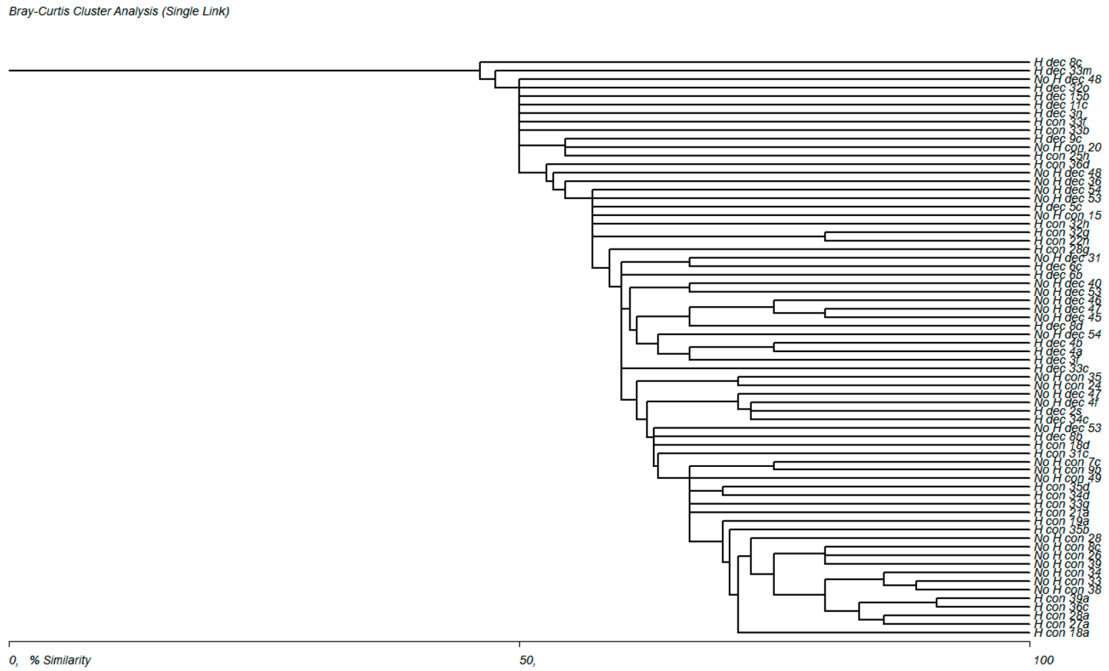

Figure 1. The similarity for clusters of species in herb layer and undergrowth lower than 0.5 m growing in all areas under examination; (H—horse present, No H—horse absent, con—coniferous forests (CF), dec—deciduous forests (DF); 7c, 54g—codes of the forest sub-compartment.

The evaluation of qualitative floristic similarity dendrogram indicates higher similarities for this layer of divisions according to the fertility groups of habitats than in relation to the presence and feeding of the Polish primitive horse. The upper part of the dendrogram shows more sub-compartments occupying deciduous sites, which means that more sub-compartments in those sites demonstrated a relatively low similarity of the species composition, while the lower part of the dendrogram tends to

present sub-compartments with coniferous forests, which proves a higher similarity between these areas as regards the species composition (Figure 1).

The average height of the herb layer depended on the habitat ($F_{1.64} = 5.249$, $p = 0.025$), while the herb layer growing in coniferous habitats was 20% taller than the herb layer occurring in deciduous habitats (Table 2). The presence of the Polish primitive horse did not affect the height of the herb layer ($F_{1.64} = 2.678$, $p = 0.106$) and the effect of integration of those two factors was also insignificant ($F_{1.64} = 0.006$, $p = 0.934$).

Table 2. The values of the Shannon-Wiener index (±SE) and average heights (±SE) calculated for the lower layers of forest vegetation (undergrowth higher than 0.5 m, and understory layers), in relation to the habitat fertility group and the presence of the Polish primitive horse. The means with statistically significant differences ($p < 0.05$) are marked with a different letter. The *ns* abbreviation means that statistically significant differences were not observed. Areas with horse were bold coded for ease of interpretation.

Effect	*N*	Shannon-Wiener Index (±SE)	Average Height of the Layer (±SE) [cm]
The herb layer and undergrowth (lower 0.5 m)			
Horse effect			
No H	29	0.823 ± 0.038ns	14.28 ± 0.98ns
H	**39**	**0.855 ± 0.031ns**	**17.07 ± 1.19ns**
Habitat effect			
DF	34	0.878 ± 0.035ns	13.95 ± 0.94b
CF	34	0.805 ± 0.033ns	17.70 ± 1.24a
Interaction horse × habitat			
No H × DF	18	0.879 ± 0.043ns	12.46 ± 1.26ns
H × DF	**15**	**0.865 ± 0.058ns**	**15.18 ± 1.32ns**
No H × CF	21	0.835 ± 0.045ns	16.22 ± 1.35ns
H × CF	**14**	**0.779 ± 0.047ns**	**18.69 ± 1.86ns**
Understory and undergrowth (higher 0.5 m) layer			
Horse effect			
No H	25	0.441 ± 0.034ns	80.02 ± 4.49a
H	**39**	**0.517 ± 0.036ns**	**56.35 ± 7.21b**
Habitat effect			
DF	32	0.414 ± 0.033a	68.96 ± 6.40ns
CF	32	0.561 ± 0.036b	62.23 ± 5.33ns
Interaction horse × habitat			
No H × DF	12	0.441 ± 0.053b	75.72 ± 12.19ns
H × DF	**19**	**0.397 ± 0.043b**	**64.91 ± 7.29ns**
No H × CF	12	0.441 ± 0.045b	83.99 ± 8.46ns
H × CF	**19**	**0.640 ± 0.045a**	**47.34 ± 4.41ns**

3.2. Understory and Undergrowth Layer Higher Than 0.5 m

The highest species diversity (21 species) was observed in deciduous forests [DF] where the Polish primitive horse was present and the lowest (13 species) was in coniferous sites without the presence of the horse (Table 3).

3.2.1. Deciduous Forests (DF)

In DF habitats where the Polish primitive horse did not occur (No H DF), 17 species were observed in the shrub and undergrowth (higher 0.5 m) layer, two of which were found in high numbers (above 6% of all the species occurring in this site and in this variant). These were: *Carpinus betulus* L. and *Corylus avellana* L. Three species occurred sparsely with the absence of the Polish primitive horse: *Acer pseudoplatanus* L., *Euonymus verrucosus* Scop., and *Prunus domestica* L.

In sites where the Polish primitive horse was present (H DF), 21 species in the shrub and understory layer were observed, with *Carpinus betulus* L., *Corylus avellana* L., and *Tilia cordata* Mill. occurring in the highest numbers. Species related only to the occurrence of the Polish primitive horse in this site included: *Acer campestre* L., *Alnus glutinosa* (L.) Gaertn., *Betula pendula* Roth., *Daphne mezereum* L., *Prunus cerasifera* Ehrh, *Robinia pseudoacacia* L., and *Ulmus glabra* Huds (all of them in small numbers).

Table 3. The share of species in the understory and undergrowth higher 0.5 m layer with the presence or absence of the Polish primitive horse. Abbreviations—see Table 1. Areas with horse were bold coded for ease of interpretation.

Species	Deciduous Forest (DF)		Coniferous Forest (CF)	
	No Horse	Horse	No Horse	Horse
Acer campestre L.		**+**		
Acer platanoides L.	++	**++**	+	**+**
Acer pseudoplatanus L.	+			
Alnus glutinosa [L.) Gaertn.		**+**		
Betula pendula Roth.		**++**	++	**+++**
Carpinus betulus L.	+++	**+++**	+++	**++**
Corylus avellana L.	+++	**+++**	+++	**+++**
Crataegus monogyna Jacq.				**+**
Daphne mezereum L.		**+**		
Euonymus verrucosus Scop.	+			
Fagus sylvatica L.	+	**++**		**++**
Frangula alnus Mill.	+	**+**	+	**+**
Juniperus communis L.			+	**+**
Larix decidua Mill.	+	**+**		**+**
Picea abies [L.) H. Karst	++	**+**	+++	**+++**
Pinus sylvestris L.	+	**+**	+	**++**
Populus tremula L.	+	**+**		**+**
Prunus cerasifera Ehrh.		**+**		**+**
Prunus domestica L.	+			
Quercus robur L.	++	**++**	+++	**+++**
Quercus rubra L.	+	**+**	+	
Robinia pseudoacacia L.		**+**		**+**
Rubus idaeus L.	+	**+**	+	**+**
Sorbus aucuparia L.	++	**++**	++	**+++**
Tilia cordata Mill.	++	**+++**	++	**+**
Ulmus glabra Huds.		**+**		
Total	**17**	**21**	**13**	**18**

3.2.2. Coniferous Forests (CF)

In CF habitats where the presence of the Polish primitive horse was not observed (No H CF), 13 species were recorded in the shrub and understory layer, of which *Carpinus betulus* L., *Corylus avellana* L., *Picea abies* (L.) H. Karst, and *Quercus robur* L. occurred in high numbers. Only one species in these habitats was exclusively related to the absence of the Polish primitive horse which was *Quercus rubra* L.

In sites with the presence of the Polish primitive horse (H CF), 18 species were found in the shrub and understory layer. The following species were observed in great numbers: *Betula pendula* Roth., *Corylus avellana* L., *Picea abies* (L.) H. Karst, *Quercus robur* L., and *Sorbus aucuparia* L. Five species occurred in sites inhabited by the Polish primitive horse (and did not exist when the horse was absent): *Crataegus monogyna* Jacq, *Fagus sylvatica* L., *Populus tremula* L., *Prunus cerasifera* Ehrh., and *Robinia pseudoacacia* L.

The dendrogram of qualitative floristic similarity (Figure 2) shows higher similarities of the shrub and undergrowth layer in tested habitats (CF or DF) than in relation to the presence or lack of feeding by the Polish primitive horse. The upper part of the dendrogram shows more areas occupying more fertile habitats (DF) and is characterized by a relatively lower similarity of the species composition of the shrub and understory layer. On the other hand, the lower part of the dendrogram tends to show areas with poorer habitats (CF), which proves a higher similarity of species composition between those areas (Figure 2). In this dendrogram four larger groups of similarities can be distinguished: (1) groups of stands in DF habitats with the presence of the Polish primitive horse (the upper part), (2) groups of stands in DF habitats without the occurrence of the Polish primitive horse (the upper and the central

part), (3) groups of stands in CF habitats without the presence of the Polish primitive horse (the central part), (4) a group of stands in CF sites with the presence of the Polish primitive horse (most often in the lower and the central part of the dendrogram). However, it should be noted that a certain irregularity as regards the cluster occurrence in the dendrogram was observed for some areas.

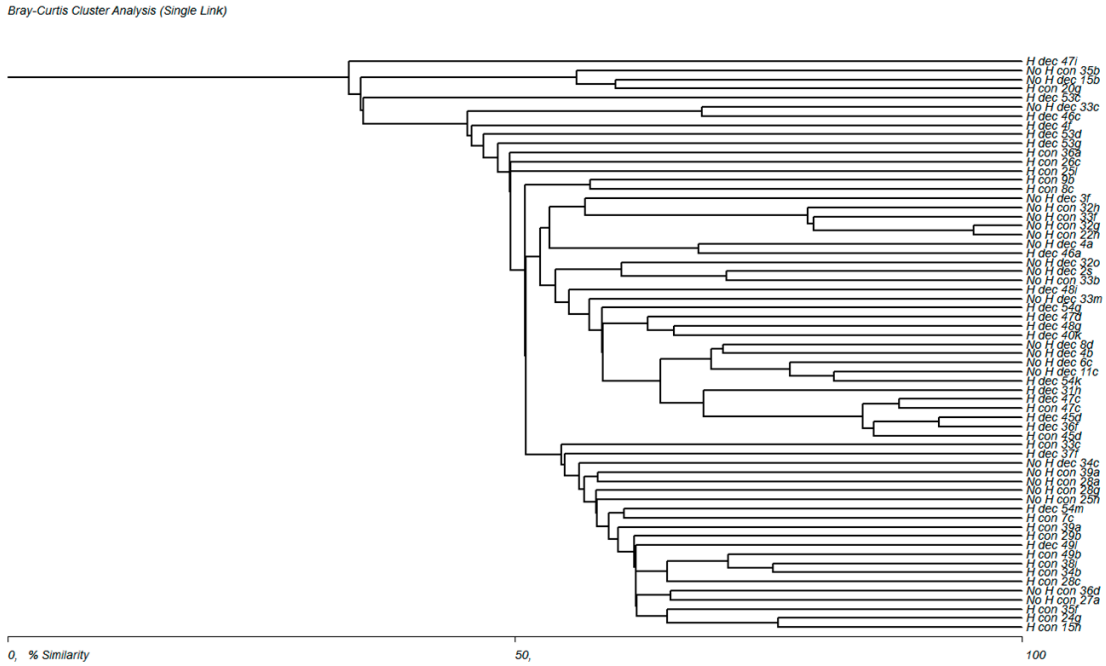

Figure 2. The similarity for clusters of shrub and understory layer species growing in all areas under examination; (H—horse present, No H—horse absent, con—coniferous forests (CF), dec—deciduous forests (DF); 7c, 54g—codes of the forest sub-compartment.

The average height of the woody understory vegetation >0.5 m was 30% lower in the stands with the horse, than in those without horse ($F_{1.58}$ = 8.913, p = 0.004) (Table 2). The quality of the habitat did not affect the height of the plant layer ($F_{1.58}$ = 0.341, p = 0.561) and the interaction between the effect of the habitat and the effect of the presence of the horse was not significant ($F_{1.58}$ = 2.644, p = 0.109).

Species that occurred in areas with the Polish primitive horse affected an increase in the biodiversity of the shrub and understory layer, including: *Acer campestre* L., *Alnus glutinosa* (L.) Gaertn., *Crataegus monogyna* Jacq., *Daphne mezereum*, *Prunus cerasifera* Ehrh., *Robinia pseudoacacia* L., and *Ulmus glabra* Huds. (Table 3).

3.3. Evaluation of the Frequency of Plant Communities

The evaluation of floristic complexes did not show a negative impact of the Polish primitive horse on the layer of herb and undergrowth (lower 0.5 m). The results of the two-way analysis of the Shannon-Wiener biodiversity index (S-W index) variance ($F_{1.64}$ = 0.523, p = 0.472) did not reveal significant differences between the areas (Table 2). The presence of the Polish primitive horse did not affect the biodiversity of the herbs and undergrowth (below 0.5 m) between habitats ($F_{1.64}$ = 1.718, p = 0.194), and the interaction between these two factors was not significant ($F_{1.64}$ = 0.826, p = 0.367).

In the understory and undergrowth (higher 0.5 m) layer, both in deciduous and coniferous habitats where the Polish primitive horse was present, a higher species diversity in comparison to the control areas was found. S-W index for understory and undergrowth was significantly higher in deciduous stands than in coniferous ones ($F_{1.58}$ = 6.221, p = 0.015). The interaction "habitat x horse presence" was also statistically significant ($F_{1.58}$ = 6.195, p = 0.016), and the higher value of the S-W index was calculated for coniferous sites with the presence of the Polish primitive horse (Table 2).

The values of the Shannon-Wiener index for the shrub layer ranged from 0.2 to 0.8 in the Popielno RS area and from 0.2 to 0.6 in the Maskulińskie FD. In this layer, the S-W index values were higher in the area inhabited by the Polish primitive horse (Figure 3). The spatial analysis of this index indicated that in the area inhabited by the horse it is (insignificantly) higher than in the control area, with the absence of the horse impact (Table 2).

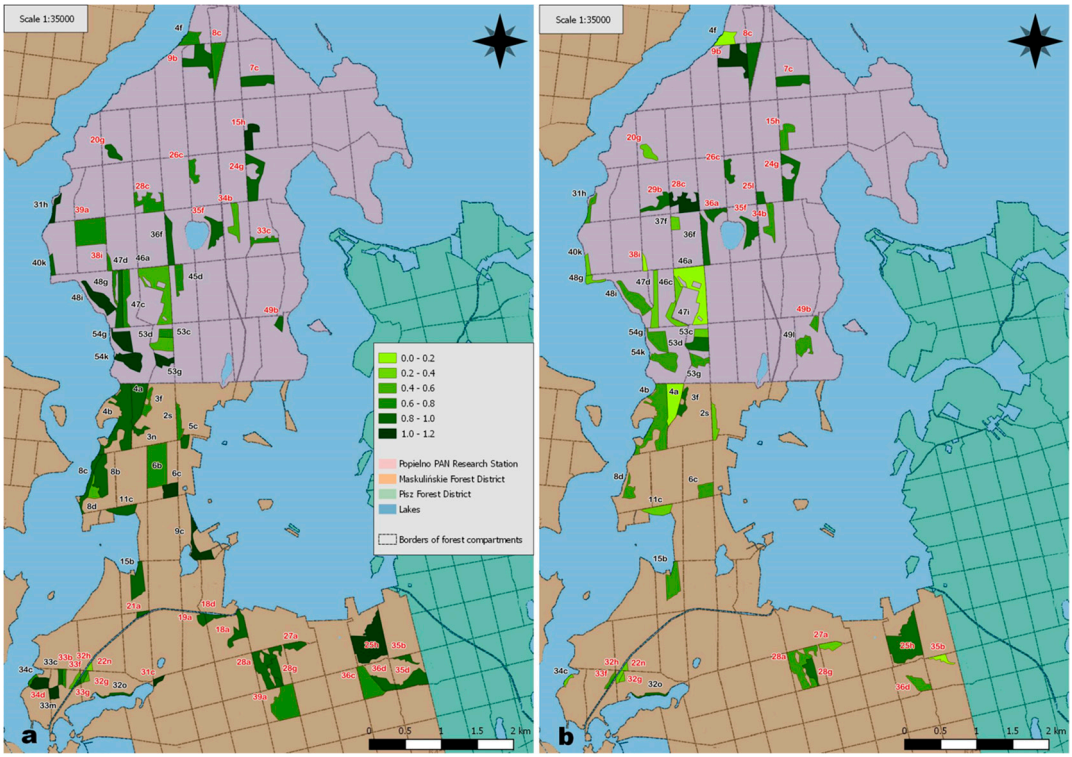

Figure 3. The location of evaluated forest sub-compartments and the graphical interpretation of Shannon-Wiener coefficient for undergrowth below 0.5 m, and herb layer (**a**), and undergrowth higher than 0.5 m shrub layer (**b**); description in the legend.

4. Discussion

The obtained results indicate some differences in the species composition as regards the vegetation in the herb layer and the undergrowth both below 0.5 m and higher then 0.5 m and the understory layer in the areas where the Polish primitive horse was present, in comparison to the tree stand without the horse. For the herb and undergrowth (below 0.5 m) layer in deciduous forests, the species diversity in areas with the horse was higher by 9 species, and in coniferous forests, by 10. Free-living horses, with forest and meadow communities situated within the boundaries of their habitat, do not demonstrate a negative pressure on natural restoration (undergrowth below 0.5 m), as they treat it first of all as a place of protection and rest. Since horses do not feed in dense forest, they also prefer habitats such as forest edges and areas of little density of trees. Skiwski and Klich [48] also show that the spatial use of forest by the Polish primitive horses is not only limited by the food base quality. Pépin et al. [49], Hanggi and Ingersoll [50], and Taraborelli et al. [51] indicated that a dense tree stand also does not provide an attractive environment for them in view of the strategy of avoiding predators and difficult escape and due to a longer period of adaptation to the dense forest conditions. In Popielno RS this situation did not take place due to loose old trees.

Chodkiewicz and Stypiński [14] reported that by biting the species forming the shrub and understory layer, the cervids create an opportunity for less numerous, often protected species to grow. As their food, horses use species of plants that are typically avoided by other species or breeds of animals. The alimentary tract of animals contributes to the distribution of diaspores of many species

of plants. This can affect the maintenance of species diversity in ecosystems of meadows and forest clearings. Sobczak et al. [52] found that in the period of full vegetation of plants (April-July), the Polish primitive horses take up 28.5-34.6 kg of plants a day. Although they inhibit the succession of forest plants, they also enrich the soil bank of meadow plant seeds. Dynowski [53] claims that in natural and semi-natural ecosystems, the Polish primitive horse can have a positive effect on the occurrence of many species rare in managed forests, e.g., *Acer campestre* L. and *Hylocomium splendens* (Hedw.) Schimp. This was also determined by the environment and tree stand conditions, for example, the *Ulmus glabra* Hunds. occurred only in the areas with the horse in DF habitats, and *Crataegus monogyna* Jacq. occurred only in coniferous forests in the presence of the horse.

Species of bushes and trees, such as *Betula, Salix, Alnus,* and *Sorbus,* found in the ecotone zone of meadows and forests are trampled and frequently used by horses [53]. Horses often use woody plants —willows, mountain ashes, maples, poplars, and alder trees [10,48]. The results showed the presence of aspen seedlings only in fertile habitats in the absence of the horse. *Acer platanoides* L. seedlings occurred in areas both with and without the horse, while *A.campestre* L. (both seedlings and shrub layers) and *A. pseudoplatanus* L. occurred only in areas with the horse and were rarely noted in managed stands. Mountain ash occurred in great numbers, regardless of the presence or absence of the horse and the habitat quality. The shrub layer of alder trees occurred only in deciduous forests in the presence of the horse. Wounds created on trees as a result of bark damage, biting, or breaking can facilitate the penetration of pathogens or insects, resulting in the deterioration of wood quality or inhibition of growth [26,43,54]. In the presented research, no occurrence of any symptoms of infectious diseases was found.

The areas with Polish primitive horse were influenced by the foraging pattern of other ungulates, e.g., the red deer, which significantly increased the degree to which the tree stand was affected. The main food base for the horse is meadow, vegetation in gaps, while the diet of the red deer typically consists of about 64% of young tree and bush shoots [12,18,55]. The Polish primitive horses also use shoots and bark of trees and shrubs as a food supplement, but only in winter [18,53]. They prefer deciduous trees and shrubs and willingly bite plant shoots of the *Quercus* and *Corylus* genera [56,57]. This is indirectly proven by the results of this research, since the height of the shrub and understory layers in areas with the horse was up to 30% lower than in the areas where the horse was absent. In winter, Polish primitive horses also nibble plants in the herb layer of the forest, mostly the blueberry, the reed grass, or rush vegetation, i.e., plants that are of no interest to other animals [18,58]. The results presented in the study show that reed grass (*Calamagrostis arundinacea* L. Roth.) occurred only in poor habitats in the presence of the horse and was rarely noted in managed stands. The European blueberry (*Vaccinium myrtillus* L.) occurred in great numbers regardless of the habitat and the presence of the horse, while the lingonberry (*Vaccinium vitis-idaea* L.) occurred both in the presence and the absence of the horse in coniferous forests, but only in the presence of the horse in deciduous forests.

The lack of differences between the values of the Shannon-Wiener index for the herb and undergrowth (below 0.5 m) layer between the tree stands with the presence or absence of the Polish primitive horse observed in this study corresponds to the results of other authors. This suggests that forest vegetation, both in Popielno RS and in Maskulińskie FD, was also consumed to a similar degree by cervids. Cosyns et al. [18] and Dynowski [53] reported that in the full vegetation period, meadow and pasture plants are available for the horse diet and more willingly visited than the forest. Dynowski [personal communication] provides that the pellet of the Polish primitive horse includes 20 species of plants, none of which occurred in the evaluated forest areas. It should be concluded that the absence of a significant effect of the Polish primitive horse on the forest undergrowth and understory is a natural phenomenon. It results from the food preferences of this mammal, oriented towards meadow rather than forest species. A higher plant diversity evaluated on the basis of the Shannon-Wiener index was found for the shrub and understory layer in the areas inhabited by the Polish primitive horse.

The value of the Shannon-Wiener index obtained for the undergrowth higher than 0.5 m and understory layer—both in the control areas and in the areas with the Polish primitive horse—were

rather low when compared to Spanish *Pinus radiata* forests, where the grazing of horses took place [59]. According to Magurran [60], the so-called "good" level of the Shannon index ranges from about 3 to 4. In the presented research, for the areas with the absence of the horse, the value of the Shannon-Wiener index was 0.441 ± 0.034 and for the areas with the horse it was 0.517 ± 0.036. Stefańska-Krzaczek [61] provides at the same time that the value of the Shannon-Wiener index decreases with the age of the tree stand.

5. Conclusions

The impact of the Polish primitive horses on the studied forest environment was generally positive. In similar habitats it did not affect the biodiversity of the herbs and undergrowth below 0.5 m when compared with the managed forests. However, in the undergrowth higher than 0.5 m and the understory layer a significant effect of the habitat quality on species diversity was found. The presence of the Polish primitive horse significantly increased the species diversity index for the undergrowth higher than 0.5 m, and the understory layer, but the average height of these layers was 30% shorter in the forest stands with the presence of the horse. The average height of herb and undergrowth lower than 0.5 m was 20% higher on coniferous forests and did not depend on the presence of the Polish horse.

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