agronomy

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Wood-Ash Fertiliser and Distance from Drainage Ditch Affect the Succession and Biodiversity of Vascular Plant Species in Tree Plantings on Marginal Organic Soil

Austra Zuševica [1,*], Santa Celma [1], Santa Neimane [2], Moritz von Cossel [3] and Dagnija Lazdina [1]

1 Latvian State Forest Research Institute SILAVA, Riga St. 111, LV-2169 Salaspils, Latvia; santa.celma@silava.lv (S.C.); dagnija.lazdina@silava.lv (D.L.)
2 Faculty of Biological and Environmental Sciences, University of Helsinki, 00014 Helsinki, Finland; santa.neimane@helsinki.fi
3 Biobased Resources in the Bioeconomy (340b), Institute of Crop Science, University of Hohenheim, 70599 Stuttgart, Germany; mvcossel@gmx.de
* Correspondence: austra.zusevica@silava.lv; Tel.: +371-28145267

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Citation: Zuševica, A.; Celma, S.; Neimane, S.; von Cossel, M.; Lazdina, D. Wood-Ash Fertiliser and Distance from Drainage Ditch Affect the Succession and Biodiversity of Vascular Plant Species in Tree Plantings on Marginal Organic Soil. *Agronomy* **2022**, *12*, 421. https://doi.org/10.3390/agronomy12020421

Academic Editor: Nikos Tzortzakis

Received: 20 December 2021
Accepted: 5 February 2022
Published: 8 February 2022

Abstract: Cutaway peatland is a marginal land, which without further management is an unfavourable environment for plant growth due to low bearing capacity, high acidity and unbalanced nutrient composition of the soil. After wood-ash application, the soil becomes enriched with P and K, creating better conditions for tree growth. In addition to being economically viable, tree plantations ensure long-term carbon storage and promote habitat restoration. In a three-year term, we studied how distance from a drainage ditch and three different doses of wood-ash—5, 10, and 15 tons per hectare—affect the diversity of vascular plants in a tree plantation on a cutaway peatland. Plant species richness, vegetation cover and composition were positively affected by the distance from the drainage ditch and application with fertiliser, but in most cases, fertiliser dose had no significant effect. Both cover and species diversity were not affected by the planted tree species. In a tree plantation, herbaceous plants provide soil fertility by decay and recycling, and reduce mineral leaching in the long term. Since vascular plants play an important role in both the development of habitats and tree growth, it is important to know how multiple factors influence the development of vegetation in tree plantations.

Keywords: cutaway peatlands; ecosystem services; peat; plant growth forms; reforestation; restoration; vegetation

1. Introduction

It is estimated that peatlands occupy 2.84 percent [1] of the land area globally. These areas provide long-term carbon storage because the existing environmental conditions prevent plant material from decaying, causing accumulation in the ecosystem of a large amount of vegetation debris relative to the proportion of primary production [2]. During peat extraction, biomass accumulated as peat is removed from storage and used for either horticulture or energy production purposes [3]. In recent years, peat has been extracted in Latvia only for horticulture purposes [4]. After peat extraction, the previous mire ecosystem is completely changed and, without further management, the potential for habitat recovery is very low [5]. Without vegetation in cutaway peatland, no further carbon accumulation occurs, while oxidation reactions occur in the peat [6]. In Latvia there are 18,000 ha of abandoned milled peatlands, and the licenses for extraction of peat in peatland requires that the area must be restored or reclaimed after cessation of extraction [7]. Marginal land management also helps to mitigate greenhouse gases and later it is possible to gain financial income from land with low agricultural value [8]. Suitable uses of cutaway peatland include afforestation, rewetting, and use for the cultivation of crops or fodder plants [9]. In areas where ecological restoration is not possible because the water table cannot be raised, tree stands after soil improvement can be grown [10–12]. This process can be carried out in two ways: either by establishing a financially valuable tree plantation that has already shown a significant increase in growth and survival after wood-ash application, or by letting the area to restore naturally after soil improvement [13,14].

Although peat has large nitrogen reserves, which are beneficial for biomass production, vegetation naturally develops in cutaway peatland very slowly due to the following factors: fluctuating water level, lack of a viable seed bank in the ecosystem and unfavourable soil chemical properties, such as low pH values, and low levels of phosphorus and potassium, which adversely affect the fertility of the soil [6,15]. Drainage ditch systems in peatlands lower the water table, but the water table is not even in all drained areas, depending on the distance to the drainage ditch [16,17]. In mechanically managed peat fields, vegetation is usually sparse, but the natural occurrence of vascular species can be supported by the application of phosphorus fertilisers or wood-ash fertilisers that increase phosphorus and potassium uptake by plants [13,18]. The application of wood-ash fertiliser in cutaway peatland firstly increases biological activity, thereby increasing CO_2 emissions, but with a successful recovery of vegetation, a significant amount of carbon is accumulated in plants, thereby compensating for the emissions [19,20].

Many studies have shown that herbaceous plants are a key part of conservation of species diversity and maintaining the forest ecosystem [21–23]. In forest stands, understorey vegetation, together with tree litter, is the most important source of nutrients, which is particularly important during early ecosystem succession when there is a lack of nutrients in the soil and risk of soil erosion [24,25]. Herbaceous plants also play a key role in preventing nutrient leaching in tree stands after fertilisation [26]. In addition, perennial herbaceous plants have the highest mineral storage capacity in the spring period, which coincides with the time when mineral leaching from the soil is the highest [27]. It is important to add that plant composition mainly depends on soil properties, but forest soil properties are determined by the dominant tree species [28]. Understorey plant species' richness and biomass productivity are also influenced by overstorey tree species [29]. In comparison to deciduous tree stands, the litter in the coniferous forests has lower pH and the top layer of soil has limited plant-available nutrient content, but the pH of deeper layers of the soil does not differ significantly between stands [30].

In the case of secondary succession, vegetation plays an important role, both at the very beginning of succession, to store nutrients and reduce their leaching, and in the further stages, as one of the main sources of nutrients. In the case of cutaway peatland, it is important to clarify how combinations of factors such as the dose of wood-ash fertiliser and the distance from a drainage ditch, change the composition of natural plant communities, as this information is needed to determine the best management in terms of financial income and afforestation quality. This study addresses the following research questions: (1) Does application of wood-ash fertiliser in cutaway peatland affect the abundance and richness of naturally colonising vascular plant species and does increasing the amount of the dose of fertiliser increase plant diversity? (2) Does the distance from a drainage ditch affect the number and composition of species? (3) Does the planted tree species affect the composition of ground vegetation within the same wood-ash fertiliser group? Based on previous studies, it was assumed that increasing the amount of wood-ash fertiliser applied per hectare would increase the richness of vascular plants. As the drainage ditch is associated with higher soil moisture, which is one of the limiting factors in cutaway peatland, we hypothesised that the highest plant species number and abundance will be closer to the ditch. It is known that, in forests, the chemical composition of tree litter affects the chemical properties of soil, and thus the composition of understorey plant communities should be related to tree species.

2. Materials and Methods

Study Site and Design

The study site is located in central Latvia (N 56°43′41.35″ E 23°34′39.61″) in a cutaway peatland where active peat extraction is still ongoing in other parts of the area. Peat extraction was for horticulture. The residual peat layer consisted of acidic raised bog, fen, and transitional mire peat with variable depth of at least 50 cm. The upper part of the peat was acidic, moderately decomposed, raised bog peat [14].

The research field was established within the "Sustainable and responsible management and re-use of degraded peatlands in Latvia" (LIFE14 CCM/LV/001103) project [31]. At the beginning of the vegetation season in 2016, the study site was prepared for tree planting by sequentially performing milling, cleaning of drainage ditches, and wood-ash application [31]. Milling was performed to remove all vegetation, which mainly consisted of sparse *Phragmites australis*. The forest stand adjacent to one side of the study site and large remnants of wood exposed after the removal of the upper peat layer suggest that the study site had been a forest ecosystem at some time. The applied wood-ash was unprocessed and had a small particle size. To prevent the effect of wind on the spread of ash, water was added before application. The wood-ash consisted of K 24.7, Mg 18.2, Ca 120.4 and P 6.6 $g \cdot kg^{-1}$ [14]. The study site was fertilised in sectors with three different doses (5, 10, and 15 tons per hectare), and one control sector left without fertilisation (control). After the application, soil pH value changed from 3.5 in the control group to 5.9 in sectors with 15 tons per hectare [14]. All sectors were established in three replicates with size of 236 × 20 m. Drainage ditches separated each sector along the two longest sides. Peat extraction for horticulture in this site was carried out by vacuum harvesting, which requires an extensive network of shallow drainage ditches. After cleaning, the ditch dimensions were 50 cm wide and 100 cm deep; Figure 1. The total study site area was 8 ha. Each sector was divided into five parts with size of 900 m^2, where in four randomly selected parts, four economically significant tree species (*Pinus sylvestris*, *Alnus glutinosa*, Poplar clone *Vesten* (Biopoplar s.r.l., Cavallermaggiore, Italy) (*Populus* v. *Vesten*), and *Betula pendula*) were planted. In one part, no trees were planted, but natural reforestation from 2016 was observed. In each part, 95 trees were planted (equal to 1055 trees per hectare). In each part, three 2.5 × 3.5 m sampling plots were established—0.5 to 4 m, 4 to 7.5 m and 7.5 to 11 m from the drainage ditch. The total number of sampling plots was 180; Figure 2.

(**a**) (**b**)

Figure 1. Drainage ditch in the study site: (**a**) drainage ditch before cleaning; (**b**) drainage ditch after cleaning.

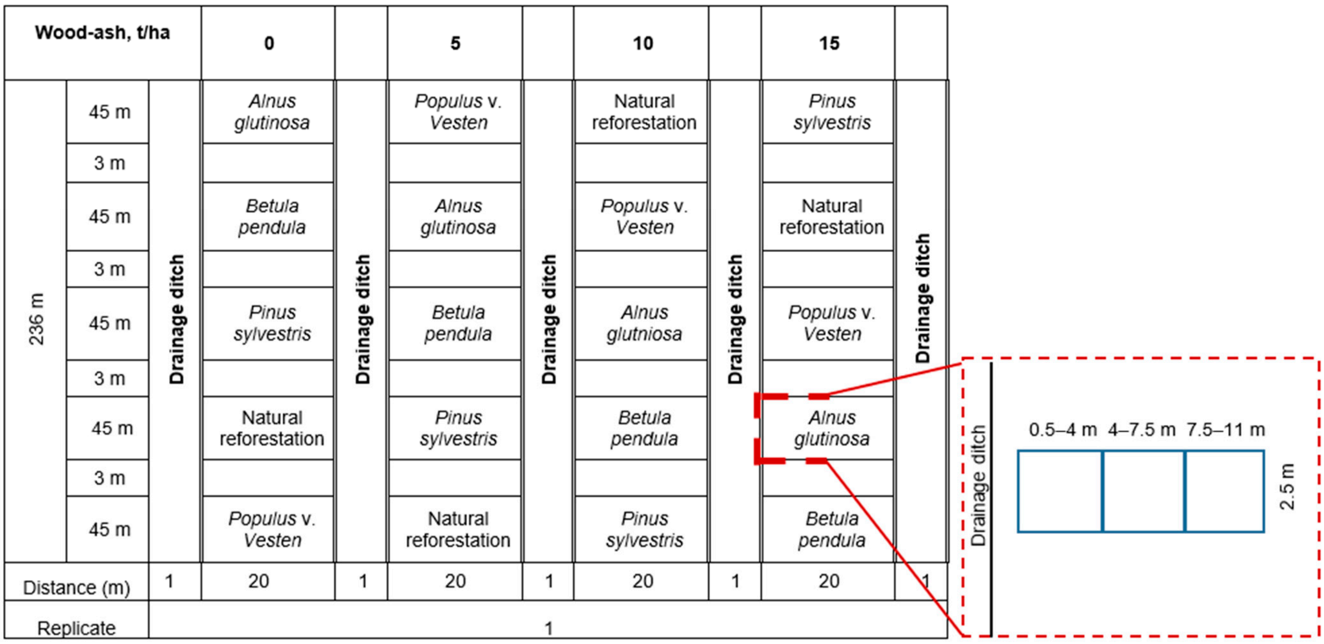


Figure 2. Plan of one repetition in research area.

The vegetation was surveyed three times over a period of three years, identifying all species in the sampling plots once annually in the middle of the growing season. No vegetation management was implemented before and after the vegetation survey. The understorey species canopy cover (%) was recorded to the nearest 5% once during the vegetation season in July. We used Ellenberg's indicator values [32] for the Czech Republic to determine plant functional traits such as light, temperature, moisture, reaction, nutrients, and salinity [33]. Experimental studies have found that Ellenberg's indicator values for nutrients (N), moisture (M), and soil reaction (R) are well correlated with real field data, including for areas outside the Central Europe region [34], and therefore could be applied in this study. The LEDA Traitbase: A database of life-history traits of Northwest European flora was used to determine plant functional traits [35] for each species. Cover-weighted average Ellenberg's indicator values F_m were calculated by summing each species i indicator value F_i and weight W_i, calculated for species based on its percentage cover C_i : $W_i = f(C_i)$, for all species n in each sampling plot:

$$F_m = \sum_{i=1,n} F_i W_i / \sum_{i=1,n} W_i$$

The species were divided into groups based on plant life form [36]: hemicryptophyte, therophyte, phanerophyte, geophyte; and Universal Adaptive Strategy Theory (UAST) [37]: competitor, stress-tolerant, and ruderal. The mean percentage cover for plant life forms and USAT classes was calculated for each sampling plot.

The computer package R Statistics 4.0.5 for Windows was used for two-way analysis of variance (ANOVA), Principal Component Analysis (PCA) and Tukey HSD analyses [38,39]. The independent two-sample Student's t-test was used to determine significant differences in plant functional traits between years. The effects of fertiliser dose, distance from the drainage ditch, and planted tree species on species richness were tested using ANOVA. Before preforming ANOVA, the Shapiro–Wilk test showed that the data did not differ significantly from a normal distribution. The Tukey HSD test was used to determine significant differences in variables between treatments. Each variable of plant functional trait data (plant growth form, ecological strategies) was analysed individually using ANOVA and the Tukey HSD test and visualised with PCA.

PCA was used to determine plant functional parameters that were significantly affected by fertiliser or ditch effect. All sampling plots, including the control group, were included in PCA analyses. Before analyses, the Kaiser–Meyer–Olkin (KMO) test for sampling adequacy was used to determine if the data fit the assumptions of PCA. The KMO test output was 0.6. The analyses were performed using the rda function from the vegan package [40]. The decostand function with the Hellinger method was used to standardise the data, as the data were not linear. The scaling method was used to observe differences between plots. The cumulative value of the eigenvalues for the first two axes was 63 percent. The ordiellipse function was used to visualise groups of plots by drawing polygons from standard error of the (weighted) average of scores.

3. Results

Over the three-year period, 84 herbaceous and woody plant species were observed in the study area (see Table A1). The overall trend shows that in most sectors, number of species (richness) continued to increase over the three-year period; Figure 3. In all three years of the study, both the distance from the ditch (2nd year $p = 0.001$; 3rd year $p = 0.001$; 4th year $p = 0.001$) and the fertiliser dose (2nd year $p = 0.001$; 3rd year $p = 0.001$; 4th year $p = 0.001$) had significant effects, but the planted tree species did not significantly affect species richness. The only exception was in the second year after the application of wood-ash, a higher number of species occurred in plots where *Alnus glutinosa* was planted compared to plots with *Betula pendula* ($p = 0.02$). During all three years, species richness was higher in the fertilised plots compared with the control group (2nd year $p = 0.001$, 3rd year $p = 0.001$, 4th $p = 0.001$), while it did not differ between fertiliser doses. In the third and fourth year of the study, species richness was significantly higher in the plots 0.5–4 m from the ditch than that at 4–7.5 and 7.5–11 m (0.5–4 and 7.5–11 m from the ditch 2nd $p = 0.001$, 3rd $p = 0.001$, 4th $p = 0.001$; 0.5–4 and 4–7.5 m from the ditch 2nd $p = 0.001$, 3rd $p = 0.003$, 4th $p = 0.001$), but no significant difference was observed between the sampling plots 4–7.5 and 7.5–11 m from the ditch.

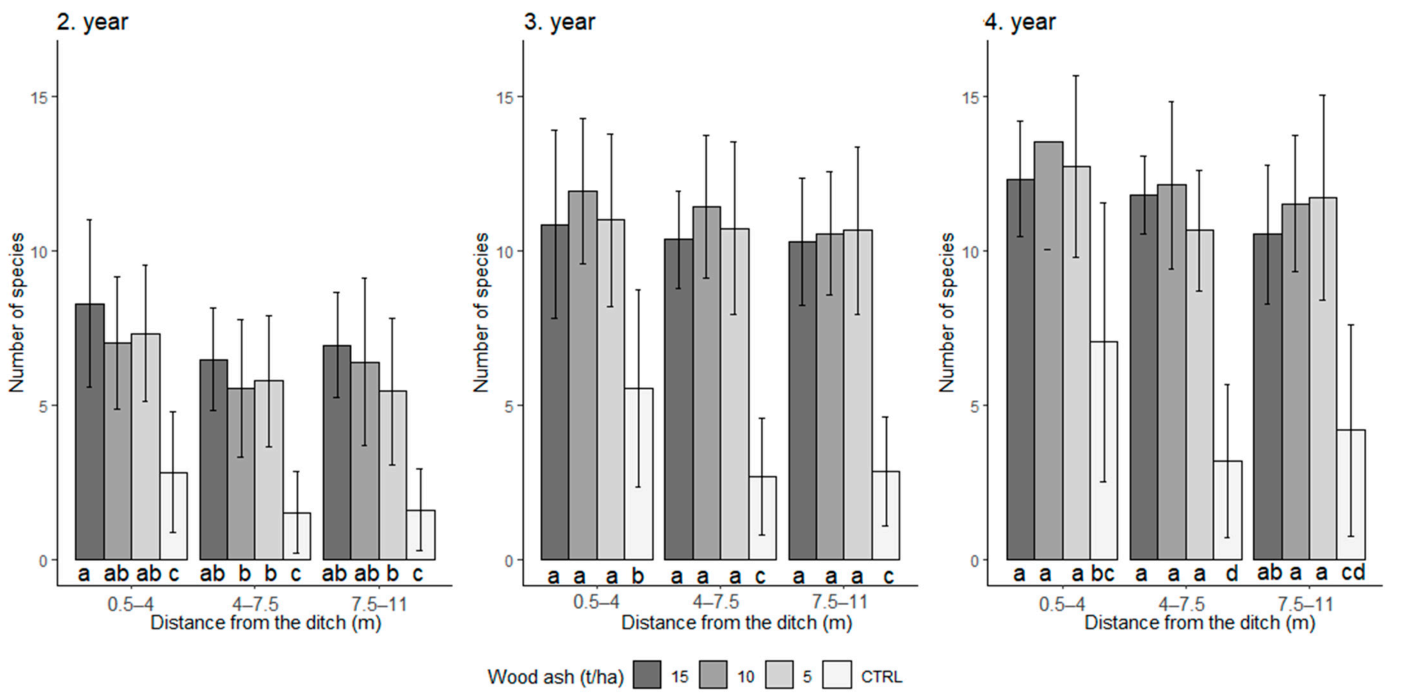


Figure 3. Species richness depending on the distance from the drainage ditch and wood-ash fertiliser dose during second to fourth vegetation season following the application of fertiliser. Different letters (a, b, c, d) indicate significant differences between groups, $p < 0.05$ according to the Tukey HSD test. Error bars represent standard deviation.

The total vegetation cover continued to increase over the three-year period and, similar to the number of species, developed more quickly in fertilised groups, regardless of wood-ash fertiliser dose Figure 4. In the fourth year after fertilisation, vegetation cover was significantly higher in plots 0.5–4 m from the ditch compared to 4–7.5 and 7.5–11 m from the ditch (p = 0.001)—Figure 4c.

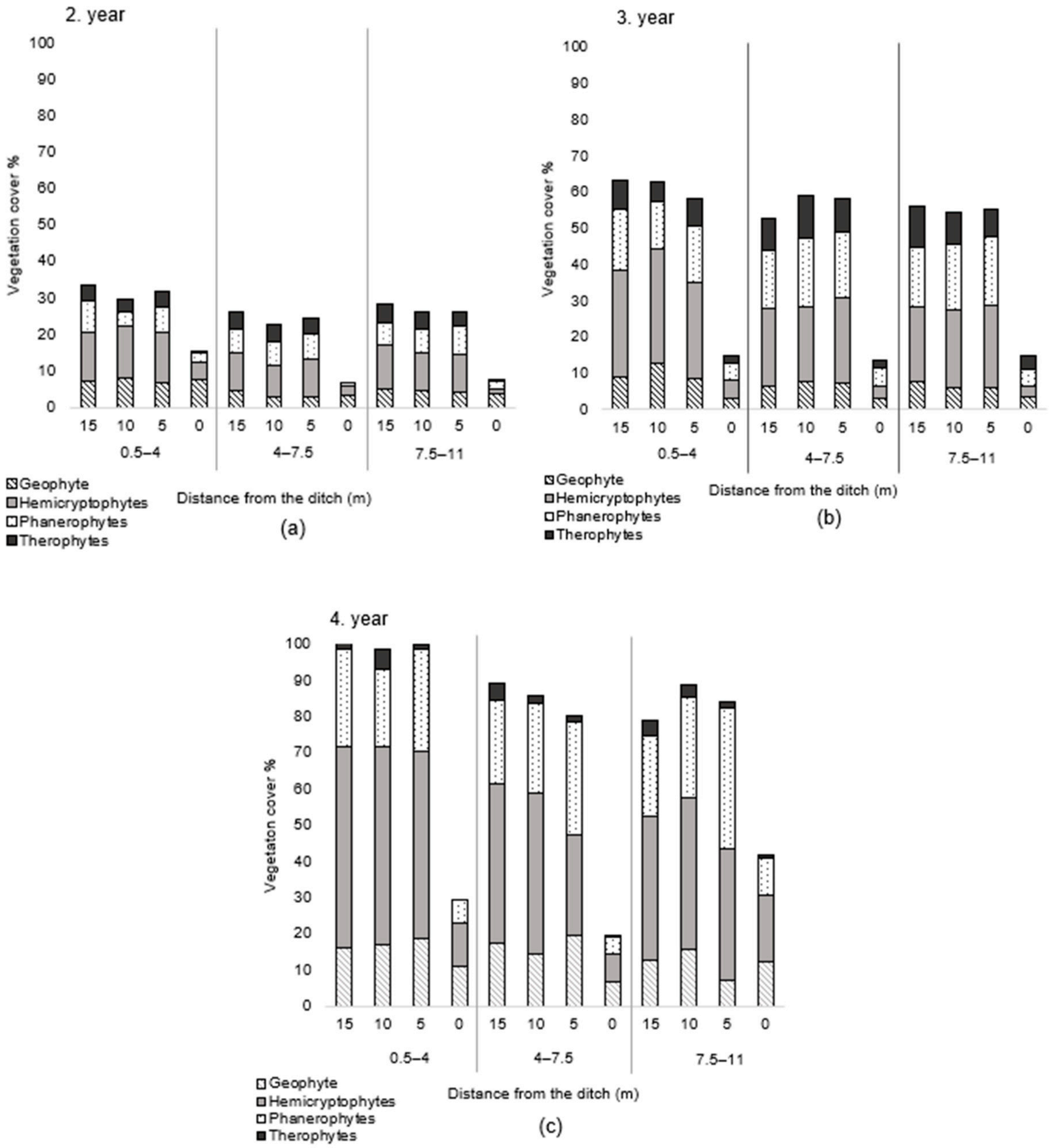


Figure 4. Plant growth form proportion from total vegetation cover depending on different doses of wood-ash fertiliser and distance from the drainage ditch: (**a**) second year after fertilisation; (**b**) third year after fertilisation; (**c**) fourth year after fertilisation.

Moreover, the structure of vegetation according to plant functional trait classes changed over the three-year ecological succession and was affected both by fertilisation and distance from the drainage ditch but was not affected by tree species; Figures A1–A11. During the three-year period, the cover of ruderal species in the plant community decreased, and the cover of competitor species and species with no specific plant adaptive strategy (CSR) increased; Tables 1 and 2. Higher cover of plants with the CSR strategy in the second year was found 0.5–4 m from the ditch, but during the three-year study, these strategies' plant cover significantly increased in plots 4–7.5 and 7.5–11 m from the ditch; Table 2. There was a tendency for geophyte cover to be lower under the highest fertiliser dose, independent of location; Figure A1. Although no significant changes occurred, the mean hemicryptophyte cover was higher in the plots 0.5–4 m from the ditch.

Table 1. Relative cover (proportion of total cover) of plants by strategy (UAST) and growth form and community weighted mean values for Ellenberg's indicator values in plots depending on the dose of wood-ash fertiliser during the observation period. Underlined text indicates significant differences in 3rd and 4th year of research with previous season and bold text indicates significant differences between 2nd and 4th year of research (Student's *t*-test ($p < 0.05$)).

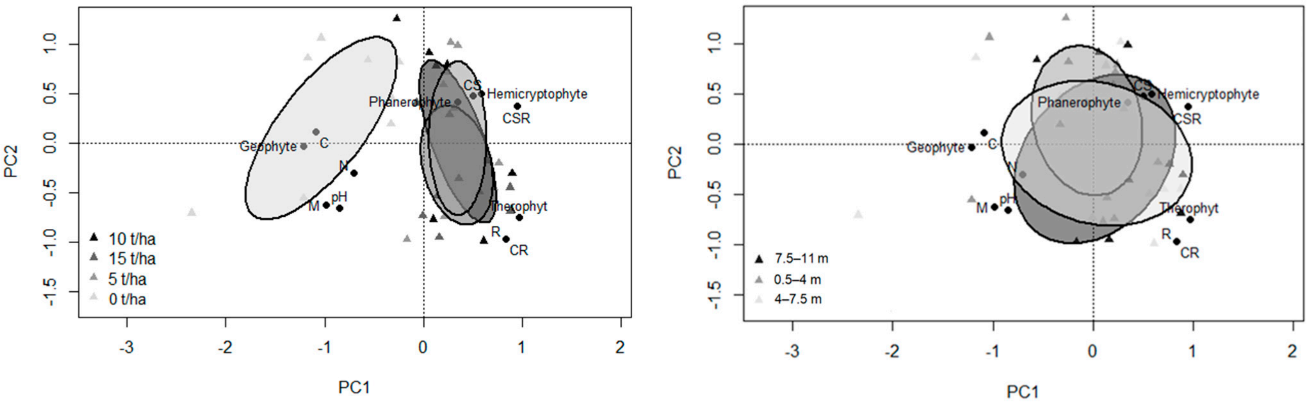
	Plant Functional Traits	Wood-Ash Dose (t/ha)											
		0	5	10	15	0	5	10	15	0	5	10	15
		2. Year				3. Year				4. Year			
UAST (%)	Competitors	50.4	53.8	47.1	44.9	27.8	34.6	35.9	26.7	51.7	53.0	45.5	46.4
	Ruderals	5.5	9.2	8.2	12.3	7	6.4	3.5	12.4	0	1	1.7	1.4
	Competitors/Ruderals Ruderals	5.3	7.6	5.3	9.1	7.3	6.8	7.3	6.4	10.2	9.7	8.8	11.1
	Competitors/Stress tolerant Stress tolerant	6.2	11.6	11.7	10.4	13.5	17.4	16.9	17.9	14.6	13.2	16.6	13.5
	Competitors/Stress tolerant/Ruderals	17.9	15.7	19.9	22.6	39.6	31.3	32.0	32.0	22.6	20.6	27.3	27.5
Growth form (%)	Geophyte	23.7	26.7	24.6	13.2	15.5	16.2	18.6	12.5	19.2	23.8	22.9	17.5
	Therophyte	8.3	13.7	9.7	18.1	10.0	9.2	4.6	16.4	0.6	0.4	0.8	0.6
	Hemicryptophyte	30.5	35.7	40.9	40.3	33.7	42.6	42.2	38.6	43.3	46.1	51.3	47.0
	Phanerophyte	22.7	22.1	17.5	28.2	39.7	30.5	32.1	31.3	36.9	27.3	25.0	34.9
Ellenberg's value	Moisture	6.6	6.9	6.5	6.2	6.5	6.5	6.2	6.6	6.9	6.8	6.9	7.0
	Nitrogen	5.0	5.3	5.1	5.3	5.4	5.4	5.3	5.4	5.9	5.5	5.6	5.8

Table 2. Relative cover (proportion of total cover) of plants by strategy (UAST) and growth form and community weighted mean values for Ellenberg's indicator values in plots depending on the distance from the drainage ditch during the observation period. Underlined text indicates significant differences in 3rd and 4th year of study with the previous season and bold text indicates significant differences between 2nd and 4th Year (Student's t-test ($p < 0.05$)).

	Plant Functional Traits	Distance from Drainage Ditch (m)								
		0.5–4	4–7.5	7.5–11	0.5–4	4–7.5	7.5–11	0.5–4	4–7.5	7.5–11
		2. Year			3. Year			4. Year		
UAST (%)	Competitors	52.6	45.3	48.8	37.6	28.4	27.9	49.6	49	48.8
	Ruderals	9.1	10.2	8	3.1	9.7	9.2	**1.9**	**1.1**	**0.8**
	Competitors/Ruderals	4.6	8.5	7.8	8.5	6	6.5	**8.5**	10.8	10.7
	Competitors/Stress tolerant	11.6	10.3	9	20	15.1	14.7	**15.6**	13.7	**14.1**
	Competitors/Stress tolerant/Ruderals	19.4	20.2	17.9	28.1	36.1	36.8	25.5	**25.4**	**23.8**
Growth form (%)	Geophyte	27.9	16.4	21.3	17.7	14.74	14.6	22.7	21.8	18
	Therophyte	11	15	12.5	4.3	13.2	12.8	**0.5**	**0.5**	**0.7**
	Hemicryptophyte	40.6	37.6	34.1	48.2	34.8	43.9	**51**	44.7	**45.1**
	Phanerophyte	19.2	25.2	23.6	27.6	35.6	36.9	**25.8**	32	**34.4**
Ellenberg's value	Moisture	7	6.1	6.5	6.2	6.6	6.6	6.8	**7**	**7**
	Nitrogen	5.4	5	5.2	5.3	5.5	5.4	5.5	**5.9**	**5.8**

Between the second and fourth research years, community weighted mean Ellenberg's moisture values increased in all study areas, but significantly only in highest fertiliser doses. In the second year, the moisture value was higher in plots 0.5–4 m from the ditch, but in the fourth year of research, it increased significantly in plots 4–7.5 and 7.5–11 from the ditch and was similar in all locations. The community weighted mean nitrogen indicator value was lower in the control group in the second year, but in the fourth year of the research it increased significantly in both control and fertilised groups, except for 5 t/ha. Nitrogen value was higher in plots 0.5–4 m from the ditch in the second year, but significantly increased in plots 4–7.5 and 7.5–11 m from the ditch, and did not differ between locations in the fourth year of research. Overall, the relative cover of therophytes and plants with ruderal strategy decreased over time, whereas phanerophyte and hemicryptophyte cover and community weighed mean Ellenberg's indicator moisture and nitrogen value increased.

In the control group, the changes in plant functional properties over time were less evident than in the fertilised plots. In general, vegetation in the control plots clearly differed from all fertilised plots; Figures 5a and A12. Although here were some differences in plant functional traits between years and less frequently between fertiliser doses, the overall trend in the development of vegetation was similar in all fertilised plots. Greater relative cover of geophytes, plant species with high Ellenberg's moisture indicator value, and relative cover of plants with a competitor strategy were found in the control plots. Distance from the drainage ditch was not as important in the formation of vegetation structure as the effect of fertiliser; Figure 5b.



(a) (b)

Figure 5. Principal Component Analysis of plant functional trait values that differ significantly: (**a**) between fertilised and non-fertilised plots; (**b**) depending on distance from the drainage ditch. Plant functional traits: Geophyte; Hemicryptophyte; Phanerophytes; Therophyte; C—competitors; S—stress tolerant; R—ruderal. Ellenberg's indicator values: N—Nitrogen, M—Moisture. Cumulative % variance for PC1 and PC2 explain 90.4%.

4. Discussion

It was found that both the wood-ash treatment and distance from the drainage ditch had a significant effect on plant species richness. In all years, there were significant differences in species richness between non-treated sampling plots and treated sampling plots, which shows that wood-ash fertiliser had a significant positive effect on recolonising species richness, even when used at a low dose. During the three-year period, species richness was higher in plots 0.5–4 m from the ditch, which is most likely due the higher soil moisture closer to the ditch, as water accessibility is one of the limiting factors for natural revegetation in cutaway peatland [6]. In meliorated peat soils in wet conditions, the soil moisture increases with distance to the ditch, but decreases in drier conditions [41]. As this area had been afforested, the hydrology of study area represented drier conditions. An abundant network of shallow drainage ditches, which were made during peat vacuum harvesting, may have a beneficial effect on revegetation in a tree stand because the water table depth is not as variable as in sites with a sparse ditch network. The effect of the dose of wood-ash fertiliser was greater than the effect of the distance from the ditch, as the effect of the latter was not very noticeable when fertilisation was applied. Natural revegetation can mitigate the negative effect of the melioration system, since plant root systems can decrease hydraulic conductivity and increase soil moisture [42,43]. The number of observed species also increased during the three-year period, which indicates that the vegetation structure is still changing from one ecosystem, a cutaway peatland, to a planted forest. To obtain a full picture of the revegetation under the influence of fertilisation and the distance from the ditch, it is necessary to observe vegetation over an even longer period, but with a wider interval of time between the surveys, since the changes will not be so noticeable within one growing season, but rather between several seasons.

Similar to the results for species richness, there were also major successional changes of plant functional traits in the treated plots, which were less evident in non-treated plots. Again, this confirms that wood-ash treatment accelerates the succession process in the cutaway peatland [18]. During all study times, phanerophyte cover was higher in the control plots, compared to the treated plots. In fertilised plots with higher dose (10 and 15 t/ha), plants with the CSR strategy, which are usually late successional species, had higher cover during all three years. In the control group and 5 t/ha, vegetation cover was sparser; therefore, in these plots, plants are exposed to a number of factors that may adversely affect revegetation—the erosion of the soil top layer, increased risk of the soil moisture level fluctuation, especially the top layers, and minerals leaching [6,26,44]. Wood-ash acts as a liming agent in acidic soils, therefore enhancing nutrient availability to plants. Wood-ash fertiliser may contribute understorey vegetation growth, which is more demanding for nutrients than phanerophytes and, after the first years, competes less with planted trees than naturally regrowing phanerophytes; Figure 6. In the control group, where vegetation was also sparse during the fourth season, geophytes such as *Phragmites australis*, *Tussilago farfara*, and *Taraxacum officinale* were more abundant than under higher fertiliser doses; Figure A1. These species indicate that, after four years, unfertilised cutaway peatland does not have optimal growth conditions because geophytes form underground organs for storage of water or nutrient reserves, thereby maintaining the availability of these stores under adverse environmental conditions [45]. This tendency was mostly significant in plots 0.5–4 m from the ditch because a large number of geophytes found in the study area grow not only under poor nutrient growing conditions, but also on sites where water is not a limiting factor, as in plots closer to a ditch [46,47].

(**a**) (**b**) (**c**)

Figure 6. Vegetation cover four years after treatment with wood-ash fertiliser in different doses: (**a**) control group; (**b**) 10 tons per hectare; (**c**) 15 tons per hectare.

The community weighted mean Ellenberg's indicator values showed significant differences between treated groups and the control group in moisture and nitrogen values, which both have a major role in natural vegetation formation in cutaway peatlands [6]. A higher Ellenberg's moisture value was observed in the non-fertilised plots in the second and third study year, but in the last study year it was higher in plots fertilised with 10 and 15 t/ha. In the first years in control plots, there tended to be a few ruderal species with a high Ellenberg's indicator value, such as *Phragmites australis* and *Tussilago farfara*, explaining the high moisture value in these plots. In fertilised plots with higher species richness, these values may be more reliable. As discussed before, vegetation cover development can raise soil moisture by decreasing water infiltration and soil conductivity. In fertilised plots, during the three-year period, species richness, total vegetation cover, and Ellenberg's moisture value increased. In the second year, the nitrogen indicator value was higher in fertilised plots, but in the fourth year it significantly increased both in fertilised and control groups. The distance from the drainage ditch has a greater influence on Ellenberg's nitrogen value than fertiliser. An experimental study showed that the Ellenberg's nitrogen value had a fairly poor correlation with soil N content, but represented overall productivity [48]. In the study area, vegetation cover and species richness were higher in plots 0.5–4 m from the ditch; Figure 4. It is possible that the Ellenberg's nitrogen values did not represent the amount of nitrogen in the soil, but the total productivity, which was higher in plots 0.5–4 m from the ditch.

Wood-ash fertiliser and distance from the drainage ditch have a more significant impact on the species richness and vegetation cover, but ecological successions have a stronger impact on species composition. In all the treated groups, during the first vegetation survey season, the dominated functional traits were typical of the early stages of primary successions—a large number of therophytes (annual plant species), in addition to plants with ruderal and stress-tolerant strategies. Such vegetation structure is usually combined with barren vegetation, which explains the lower CSR plant cover. During the four-year succession, in many parts, a large number of the therophytes were replaced by hemicryptophytes. As the vegetation structure stabilised, more plants that have no special strategy (CSR), thus indicating a later stage of habitat succession, were more common. During the time between the 2nd and 4th years after application of wood-ash, in fertilised plots the Ellenberg's moisture value increased due to the increase in the vegetation cover.

5. Conclusions

This study showed that both wood-ash fertiliser and distance from the drainage ditch, in addition to time after treatment application, have an impact on plant species richness, cover, and vegetation composition. Wood-ash fertiliser positively affects vascular plant species richness, but during the first growing years, there are no significant differences between treatment doses. Species richness is higher closer to the drainage ditch, most likely due to a higher water level, which is one of the limiting factors in a cutaway peatland. Consequently, it can be concluded that appropriate management of cutaway peatland provides the area with the nutrients it needs, thereby allowing colonisation of vegetation. In the first growing seasons, planted tree species have no significant effect on vegetation composition, richness, and distribution. Planted and naturally regrown trees on marginal land contribute to the overall development of the habitat by increasing the biodiversity due to interaction with other species. This restoration practice also increases the financial value of otherwise agronomically low-value land. Vascular plant diversity and cover is essential as it reduces nutrient leaching, thus improving growth conditions for planted trees. Along with the herbaceous species, tree species such as *Betula pendula*, *Betula pubescens*, and *Salix* spp. also naturally regrow in the area therefore the area has the potential to become a silvopastoral agroforestry system or naturally reforested site. Further research is needed to determine how different doses of fertiliser affect the development of vegetation over time and when planted tree species begin to affect the plant communities.

Author Contributions: Conceptualisation, D.L., S.N., A.Z.; methodology, D.L., S.N. and A.Z.; software, A.Z.; validation, D.L.; formal analysis, A.Z.; investigation, S.C., S.N., A.Z.; data curation, A.Z.; writing—original draft preparation, A.Z.; writing—review and editing, S.C., S.N., D.L., M.v.C.; visualisation, A.Z.; supervision, D.L., M.v.C.; project coordination, D.L.; funding acquisition, D.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 727698, the project "Sustainable and responsible management and re-use of degraded peatlands in Latvia" (LIFE14 CCM/LV/001103) and the European Regional Development Fund project Elaboration of innovative White Willow - perennial grass agroforestry systems on marginal mineral soils improved by wood ash and less demanded peat fractions amendments (1.1.1.1/19/A/112). The article processing charge was funded by the European Regional Development Fund project Elaboration of innovative White Willow - perennial grass agroforestry systems on marginal mineral soils improved by wood ash and less demanded peat fractions amendments (1.1.1.1/19/A/112).

Data Availability Statement: Data generated from this study is available upon request to the corresponding author.

Acknowledgments: We thank "Laflora" Ltd. for the chance to study the possibilities of improving the properties of peat soil with wood-ash.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

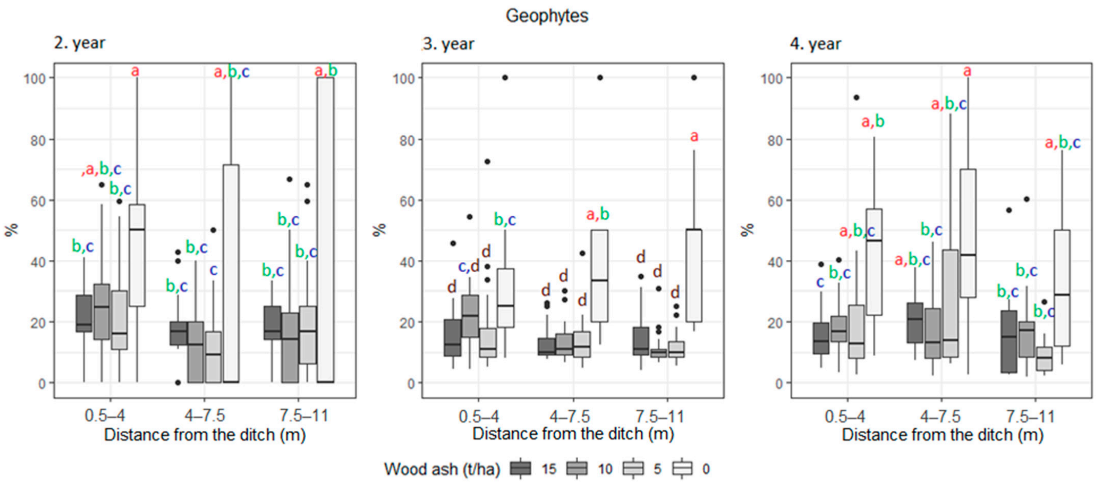


Figure A1. Relative cover of plants with geophyte growth form of the total vegetation cover, depending on the distance from the drainage ditch and the dose of wood-ash fertiliser. Different letters (a, b, c, d) indicate significant differences between groups, $p < 0.05$ according to the Tukey HSD test.

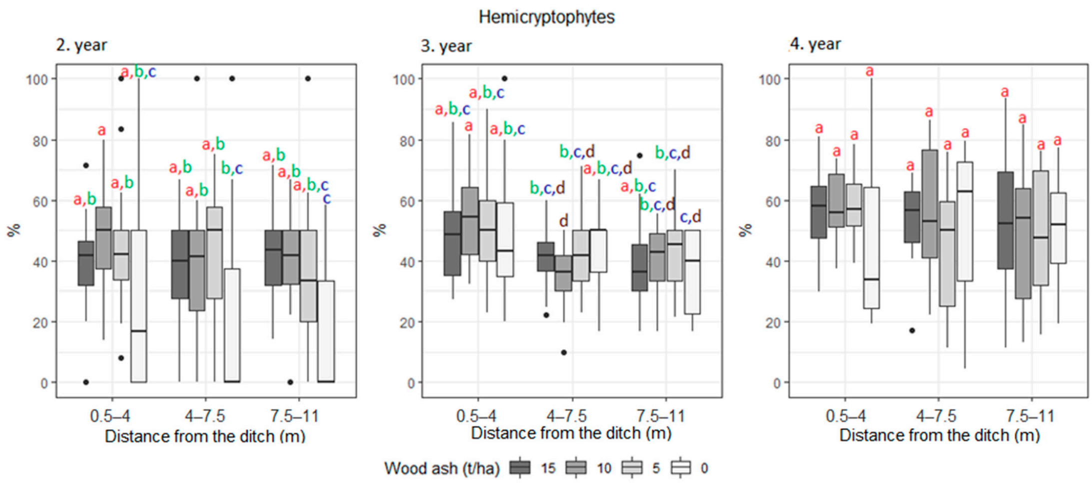


Figure A2. Relative cover of plants with hemicryptophyte growth form from the total vegetation cover, depending on the distance from the drainage ditch and the dose of wood-ash fertiliser. Different letters (a, b, c, d) indicate significant differences between groups, $p < 0.05$ according to the Tukey HSD test.

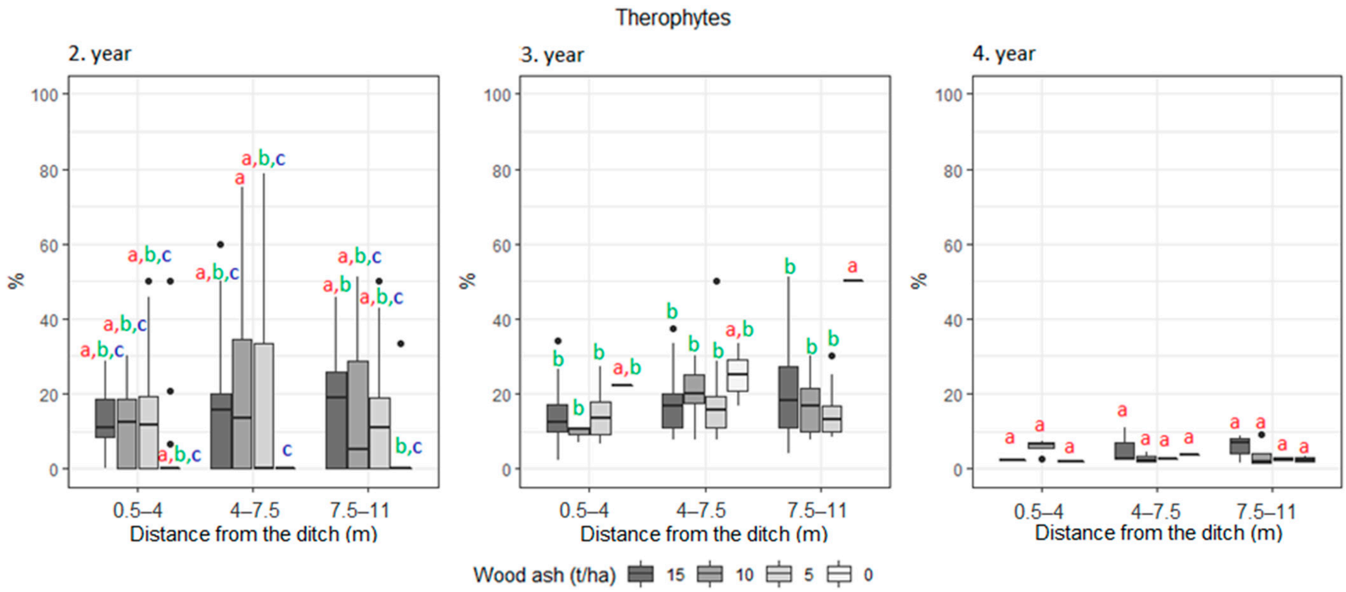


Figure A3. Relative cover of plants with therophyte growth form from the total vegetation cover, depending on the distance from the drainage ditch and the dose of wood-ash fertiliser. Different letters (a, b, c) indicate significant differences between groups, $p < 0.05$ according to the Tukey HSD test.

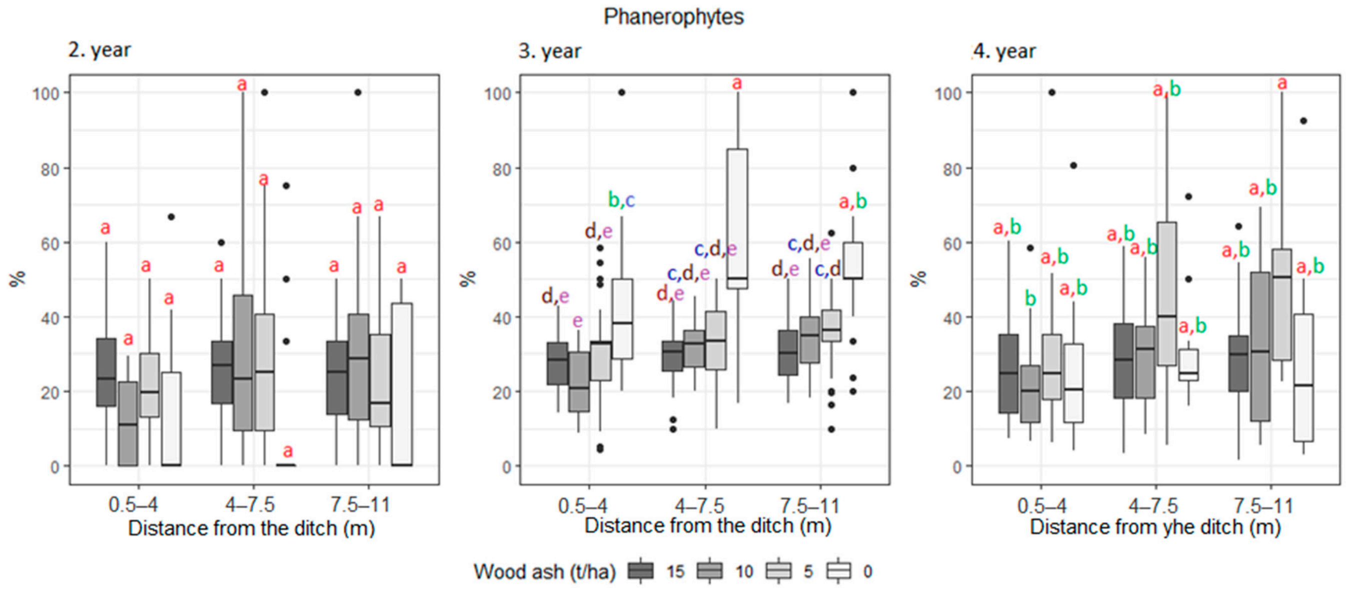


Figure A4. Percentage of plants with phanerophyte growth form from the total vegetation cover, depending on the distance from the drainage ditch and the dose of wood-ash fertiliser. Different letters (a, b, c, d, e) indicate significant differences between groups, $p < 0.05$ according to the Tukey HSD test.

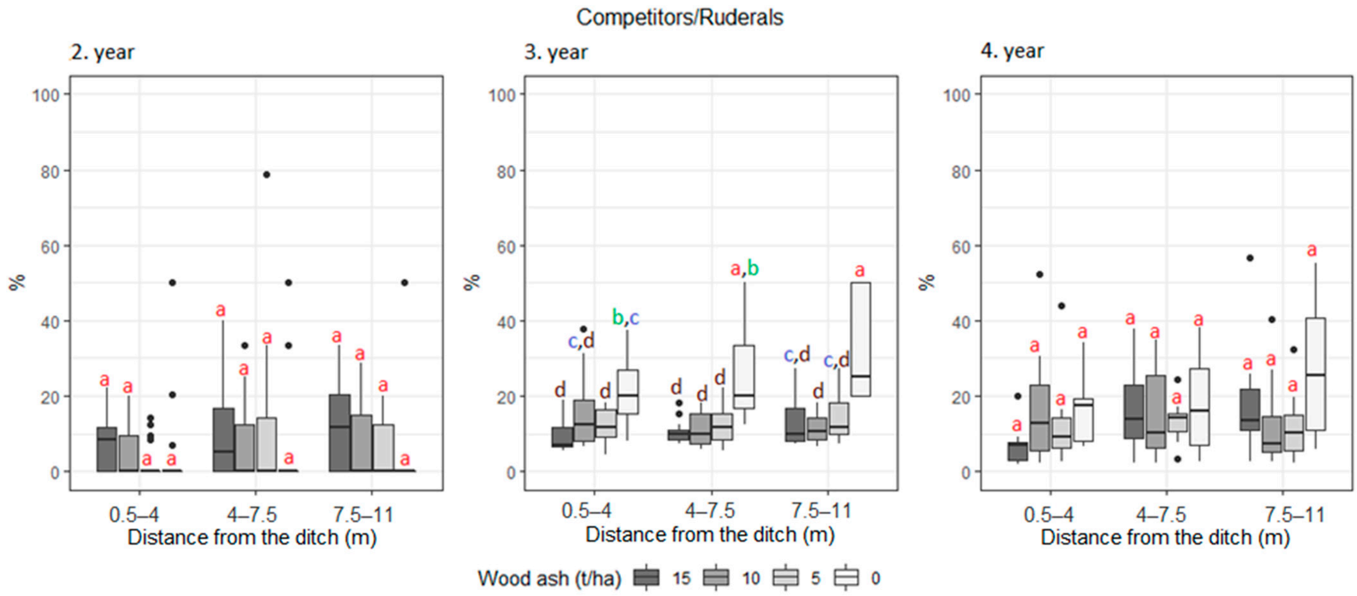


Figure A5. Relative cover of plants with competitor/ruderal universal adaptive strategy from the total vegetation cover, depending on the distance from the drainage ditch and the dose of wood-ash fertiliser. Different letters (a, b, c, d) indicate significant differences between groups, $p < 0.05$ according to the Tukey HSD test.

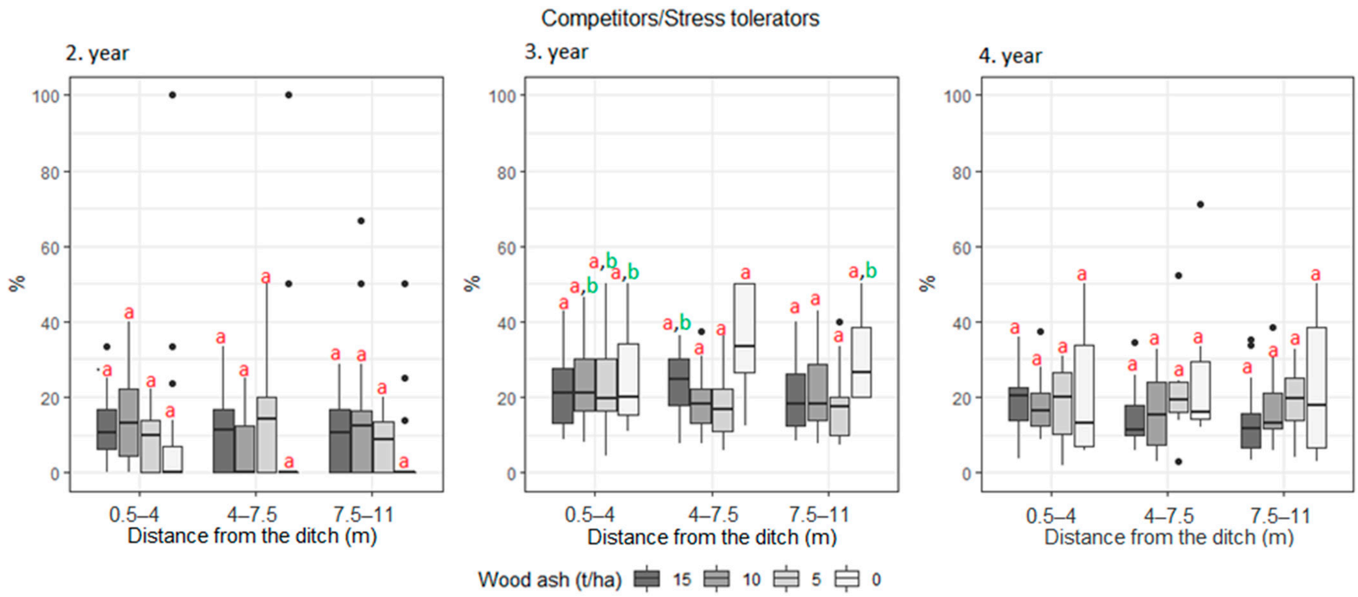


Figure A6. Relative cover of plants with competitor/stress tolerant universal adaptive strategy from the total vegetation cover, depending on the distance from the drainage ditch and the dose of wood-ash fertiliser. Different letters (a, b) indicate significant differences between groups, $p < 0.05$ according to the Tukey HSD test.

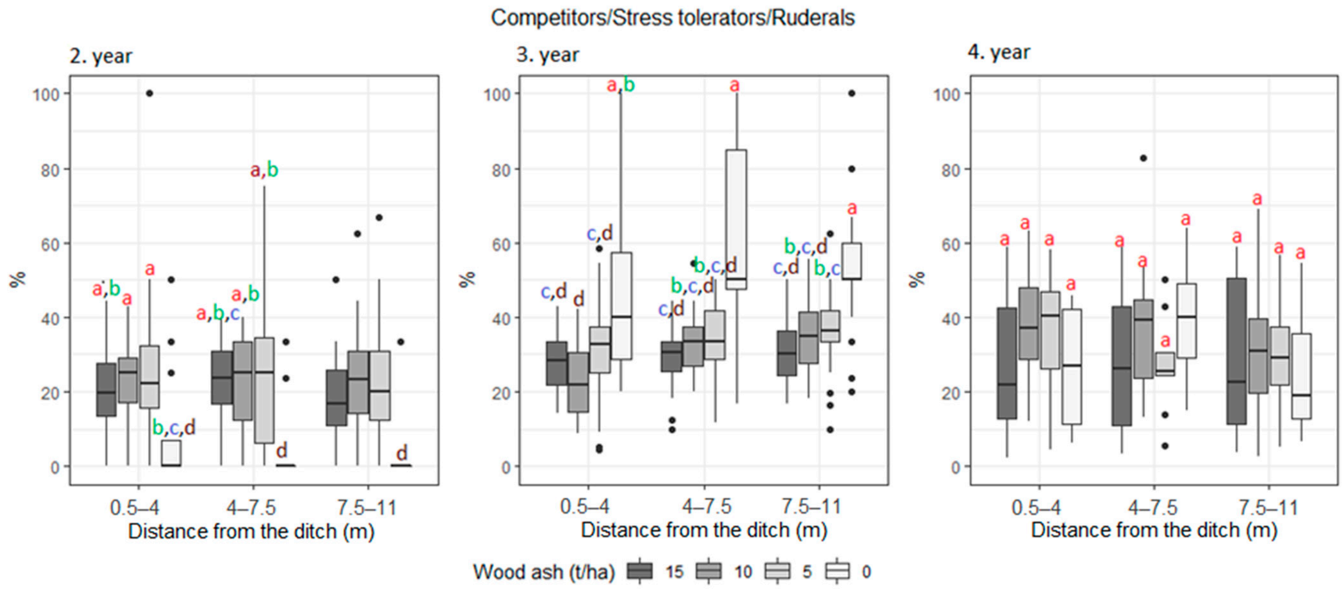


Figure A7. Relative cover of plants with competitor/stress tolerant/ruderal (no-specific strategy) universal adaptive strategy from the total vegetation cover, depending on the distance from the drainage ditch and the dose of wood-ash fertiliser. Different letters (a, b, c, d) indicate significant differences between groups, $p < 0.05$ according to the Tukey HSD test.

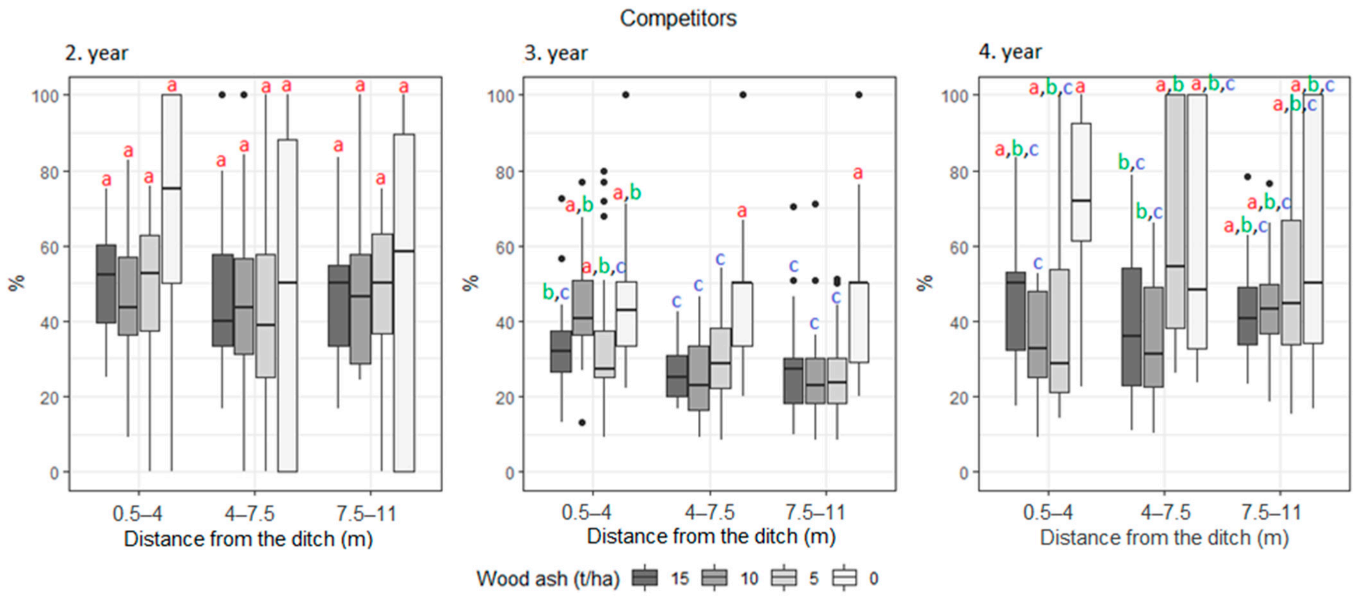


Figure A8. Relative of plants with competitor universal adaptive strategy from the total vegetation cover, depending on the distance from the drainage ditch and the dose of wood-ash fertiliser. Different letters (a, b, c) indicate significant differences between groups, $p < 0.05$ according to the Tukey HSD test.

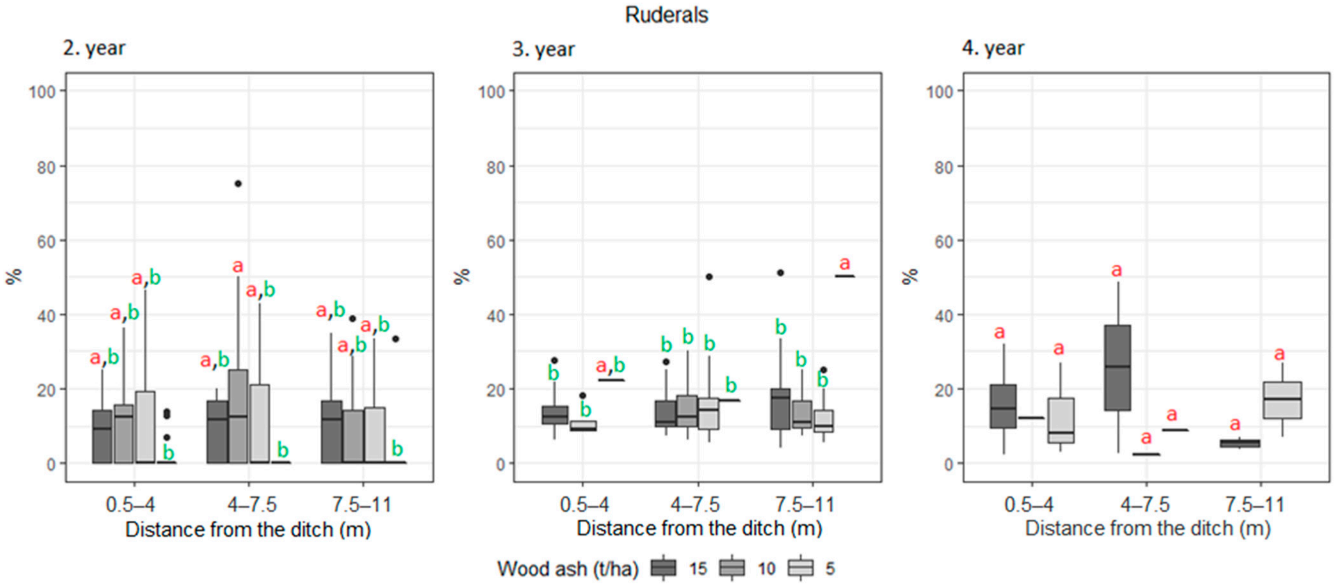


Figure A9. Relative of plants with ruderal universal adaptive strategy from the total vegetation cover, depending on the distance from the drainage ditch and the dose of wood-ash fertiliser. Different letters (a, b) indicate significant differences between groups, $p < 0.05$ according to the Tukey HSD test.

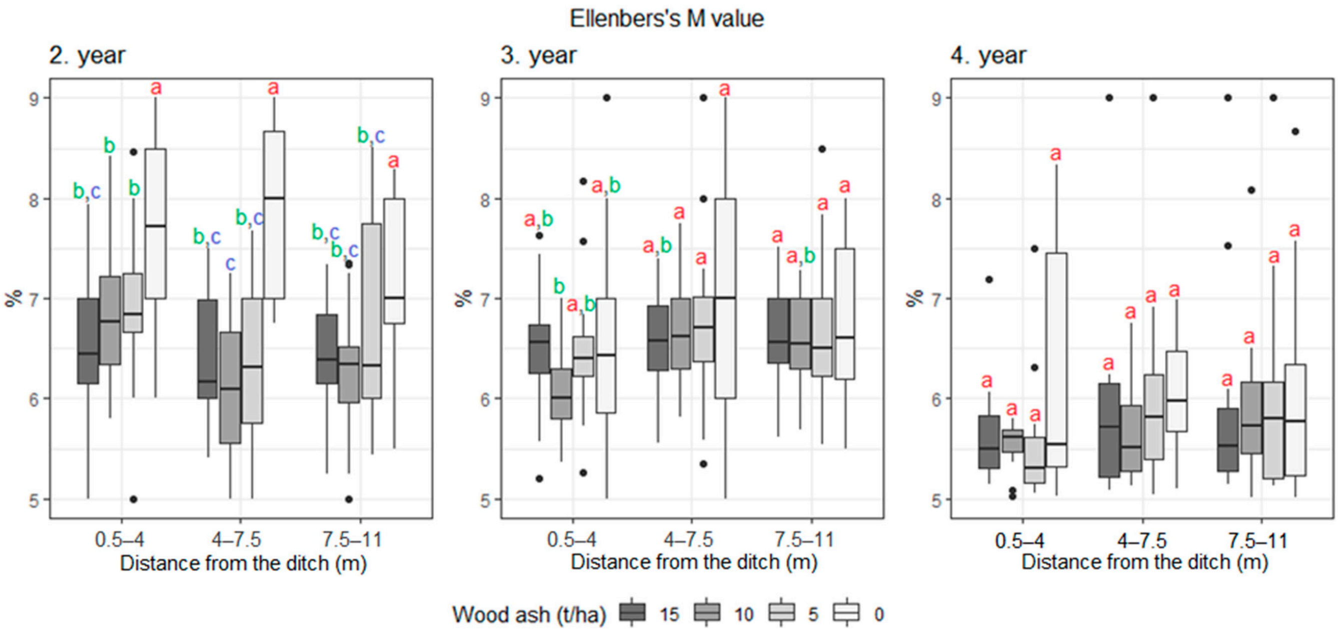


Figure A10. Community weighted mean Ellenberg's indicator Moisture value depending on the distance from the drainage ditch and the dose of wood-ash fertiliser. Different letters (a, b, c) indicate significant differences between groups, $p < 0.05$ according to the Tukey HSD test.

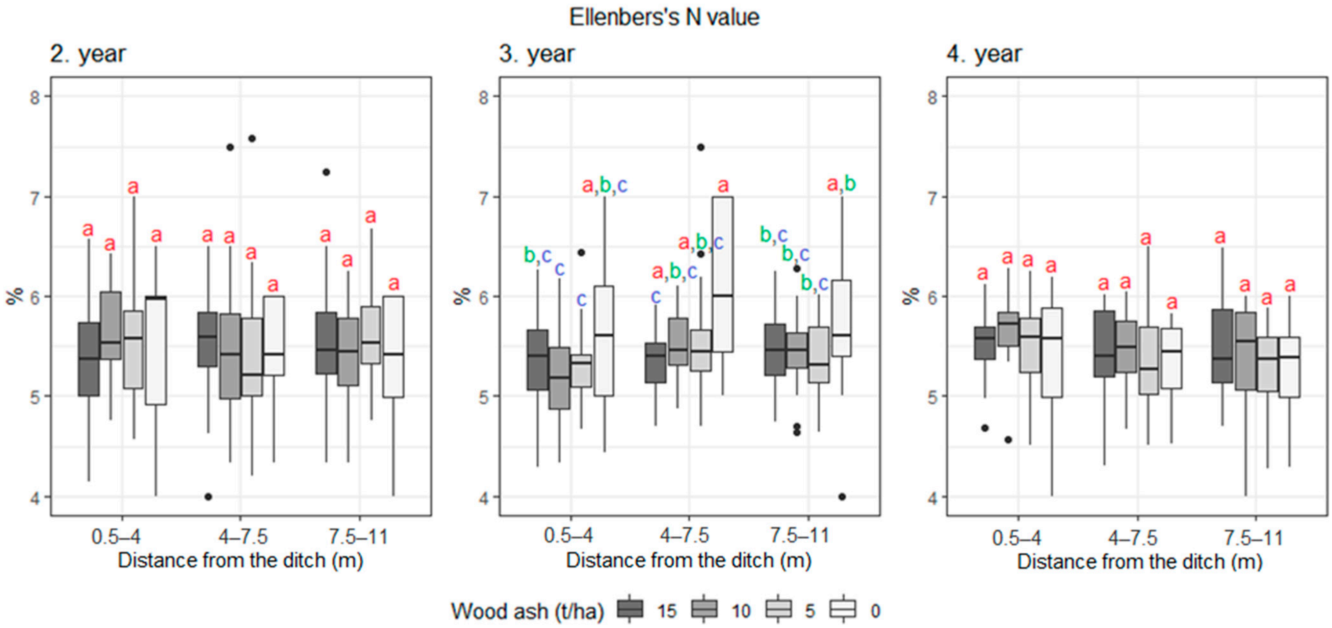


Figure A11. Community weighted mean Ellenberg's indicator Nitrogen value depending on the distance from the drainage ditch and the dose of wood-ash fertiliser. Different letters (a, b, c) indicate significant differences between groups, $p < 0.05$ according to the Tukey HSD test.

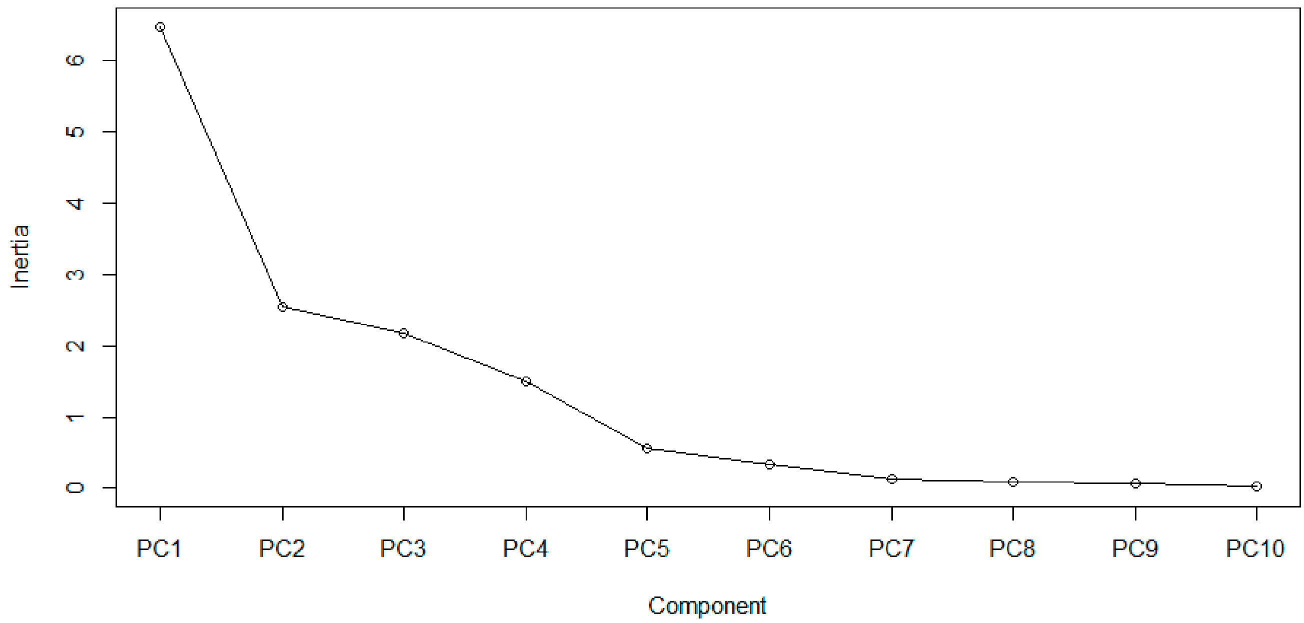


Figure A12. Scree plot from PCA analyses.

Table A1. Observed species in study area during the three-year study.

No.	Species	2019	2018	2017	No.	Species	2019	2018	2017
1.	*Agrostis capillaris*	x	x	x	43.	*Luzula pilosa*		x	
2.	*Arabidopsis thaliana*		x	x	44.	*Lycopus europaeus*	x	x	x
3.	*Arctium lappa*		x	x	45.	*Matricaria perforata*		x	x

Table A1. *Cont.*

No.	Species	2019	2018	2017	No.	Species	2019	2018	2017
4.	*Arctium tomentosum*		x		46.	*Mycelis muralis*			x
5.	*Barbara stricta*	x			47.	*Persicaria maculosa*	x		
6.	*Betula pendula*	x	x	x	48.	*Petasites hybridus*	x		
7.	*Betula pubescens*	x	x	x	49.	*Phragmites australis*	x	x	x
8.	*Bidens tripartita*	x	x	x	50.	*Picea abies*	x	x	x
9.	*Brassica campestris*		x	x	51.	*Picris hieracioides*	x	x	x
10.	*Calamagrostis canescens*	x	x	x	52.	*Pinus sylvestris*	x	x	x
11.	*Calluna vulgaris*		x	x	53.	*Plantago lanceolata*		x	
12.	*Carex cespitosa*	x	x	x	54.	*Plantago major*		x	x
13.	*Carex hirta*	x			55.	*Poa palustris*	x	x	x
14.	*carex pseudocyperus*	x			56.	*Polygonum* sp.			x
15.	*Carex vesicaria*	x			57.	*Polytrihum* sp.		x	x
16.	*Cerastium holosteoides*	x		x	58.	*Populus tremula*	x	x	x
17.	*Chamerion angustifolium*	x	x	x	59.	*Rubus idaeus*	x	x	x
18.	*Chenopodium album*	x		x	60.	*Rumex acetosa*	x	x	
19.	*Cirsium arvense*	x	x	x	61.	*Rumex acetosella*	x	x	x
20.	*Cirsium aucale*	x			62.	*Rumex longifolius*	x		
21.	*Cirsium oleraceum*	x		x	63.	*sagina nodosa*		x	
22.	*Cirsium palustre*			x	64.	*Salix alba*	x		
23.	*Crepis biennis*		x	x	65.	*Salix caprea*	x	x	x
24.	*Echinochloa crusgalli*		x	x	66.	*Salix myrsinifolia*	x		
25.	*Eirophorum polystachion*	x			67.	*Salix rosmarinifolia*	x		
26.	*Epilobium parviflorum*	x	x	x	68.	*Salix* sp.		x	x
27.	*Equisetum arvense*			x	69.	*Salix starkeana*	x		
28.	*Equisetum fluviatile*	x			70.	*Salix triandra*	x		
29.	*Equisetum sylvaticum*		x		71.	*Salix viminalis*	x		
30.	*Erigon canadesis*	x	x	x	72.	*Scirpus sylvaticus*			x
31.	*Eriophorum vaginatum*	x	x	x	73.	*Senecio sylvaticus*	x	x	
32.	*Eupatorium cannabinum*	x	x	x	74.	*Silene vulgaris*			x
33.	*Festuca rubra*	x			75.	*Solidago cannadensis*	x	x	x
34.	*Fragaria vesca*	x	x	x	76.	*Sonchus asper*		x	x
35.	*Frangula alnus*	x	x		77.	*Stellaria media*		x	x
36.	*Gnaphalium uliginosum*		x		78.	*Taraxacum officinale*	x	x	x
37.	*Hieracium pilosella*	x	x	x	79.	*Trifolium repens*			x
38.	*Juncus articulatus*	x	x	x	80.	*Tripleurospermum inodorum*	x		
39.	*Juncus effusus*	x	x	x	81.	*Tussilafgo farfara*	x	x	x
40.	*Juncus tenuis*	x	x	x	82.	*Typha latifolia*	x	x	x
41.	*Lamium album*		x	x	83.	*Utrica dioica*		x	
42.	*Linaria vulgaris*	x	x		84.	*Valeriana officinalis*		x	

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