Influence of Ditches on Plant Species Diversity in the Managed Forests of Central Poland

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Abstract

Anthropogenic structures introduced into the forest by silvicultural practices may lead to increased floristic diversity of the forest complex. Among artificial structures, ditches play a special role because they cause differences not only in lighting but also in moisture conditions. Species from contrasting habitats can exist together in a relatively small area because of the different conditions found on the bottom and slopes of the ditch. We studied the effect of the presence of three types of ditches (i.e. drainage ditches, road ditches, and war trenches) on the floristic diversity of forest phytocenoses in central Poland. These were managed forests on sites of *Vaccinio-Piceetea* and *Querco-Fagetea* phytosociological classes. In addition to measuring species richness, we analyzed the dominance structure, species rarity and ecological indicator values of plants. We have determined that species richness was higher in ditches than in the surrounding forest phytocenoses. Most species in ditches occurred at low frequencies. Based on Shannon's formula, ditches usually had greater diversity; species evenness, however, was variable in ditches when compared with the forest. Plants that occur in the ditches differed from these found in forests in terms of their trophic, humidity and light requirements. It has also become apparent that there are differences between the three types of ditches. Roadside ditches had the highest influence on floristic diversity, and war trenches the lowest.

Key words: floristic diversity, habitat heterogeneity, drainage ditches, roadside ditches, war trenches, managed forests

Introduction

Several theories have been developed by ecologists to explain patterns of plant diversity observed in natural ecosystems (Hubbell 2001, Huston 1979, Ricklefs 1977, Ricklefs 2006, Waide et. al. 1999). One of the factors affecting local plant diversity is resource heterogeneity, which may play an important role, especially in disturbed forests (Bartels and Chen 2010). Timber-oriented forest management may result in both an increase and decrease in the diversity. On the one hand, it can threaten the survival of many species that depend on natural forest habitats (Bengtsson et al. 2000). On the other hand, these silvicultural practices introduce anthropogenic structures, such as roads and ditches, which may increase floristic diversity in the forest complex (Buckley et al. 2003, Baltzinger et al. 2011, Hansen et al. 1991, Peterken and Francis 1999, Skov and Lawesson 2000, Suárez-Esteban et al. 2013).

Drainage ditches are one of the most common anthropogenic linear structures in forests. Drainage is applied to a forest to improve the productive capacity of soils through regulation of water and air conditions (Hillman 1992, Roy et al. 2000). Ditches, by enriching the morphology of the terrain, diversify woodland habitats. At the same time, as they are linear structures, they can facilitate the spread of alien species into the forest. Ditches provide habitats for plants of extremely varied requirements, especially in terms of humidity and light (Zielińska 2007). This is the result of different site conditions on the slopes and on the bottom of the ditches (Karim and Mallik 2008). The role of ditches in agricultural landscapes has been extensively investigated (Blomqvist et al. 2006, Dajdok and Wuczyński 2005, Goulder 2007, Herzon and Helenius 2008, Manhoudt et al. 2007, Milsom et al. 2004, Williams et al. 2003). These studies indicate particularly the role of ditches in increasing biodiversity. In agricultural landscapes, ditches play important roles as ecological corridors and as refugia for species preferring wet conditions. There are a number of publications concerning the problem of drainage of wet forests, and especially peatland among these (for example Korpela 1999, 2004, Kurowski 2007). However, in many parts of Poland, the ground water level is now lower than in the 19th and early 20th centuries (Lipiński 2006), and there are quite many ditches which remain dry through most and sometimes the entire year. This is quite common in central Poland, where such ditches no longer function as part of drainage system. The research of the role of such structures in forest complexes, from the point of view of their contribution to differentiation of forest habitats, rather than their intended use is scarce (Baltzinger et al. 2011, Karim and Mallik 2008, Peterken and Francis 1999).

Drainage ditches may directly pass through a forest or be related to road infrastructure. There are many studies on the role of forest roads. According to Avon et al. (2010), the road verge can be considered an early-successional habitat that favours fast-growing, nutrient- and light-demanding species, and offers a suitable habitat for non-forest herbs. Invasions of alien species occur more frequently along roads than in the interior of forest stands (Flory and Clay 2006, 2009, Parendes and Jones 2000, Pauchard and Alaback 2006, Watkins et al. 2003). A study of the flora of one of the large forests of central Poland showed that floristic diversity is greatest around these roads, along which ditches are located (Zielińska 2007). Ditches enrich road verges, especially in wet habitats.

In this study, we investigated the effect of ditches on vascular plant diversity in managed lowland forests and tested whether different types of ditches differ in their effect. We distinguished three types of ditches: drainage ditches, roadside ditches, and war trenches. These three types of anthropogenic linear structures have different characteristics and may affect plant diversity in different ways. In present-day central Poland, we can observe the presence of water in drainage ditches during snow melt or heavy rainfall. Roadside ditches are similar in this respect but they may, to a much greater extent, serve as plant migration routes resulting from roads being used for transport by forest services (Zielińska 2007). The third type of linear structures we studied were war trenches. Dug during World War II and located on the slopes of sandy hills, these were not created to facilitate water drainage. War trenches change the morphology of the terrain but have no significant effect on soil moisture. We hypothesized that floristic diversity would be significantly different in the presence of ditches, and that this change is dependent on ditch type, with the different types having different effects on habitat heterogeneity. We hypothesized that the greatest diversification would be introduced by roadside ditches, the smallest by war trenches.

There are several methods of species diversity assessment (Gotelli and Colwell 2001, Paillet et al. 2010, Peet 1974, van der Maarel 1988, Whittaker 1972). By using different kinds of indexes we were able to achieve a more accurate description of plant diversity. In addition to species richness, we used indicators that consider the dominance structure (Shannon's and Pielou's evenness indexes) and local rarity (floristic value and uniqueness indexes) of species. We also analyzed recorded species in terms of their ecological requirements.

In our study we addressed the following questions:

(i) Is the floristic diversity of ditches higher than that of surrounding forest?

(ii) Do the different types of ditches differ in their floristic diversity?

Materials and Methods

Study site

The study was conducted in several forest complexes located in an area of approximately 14,000 km^2 in the Polish Lowlands, central Poland (Figure 1). In

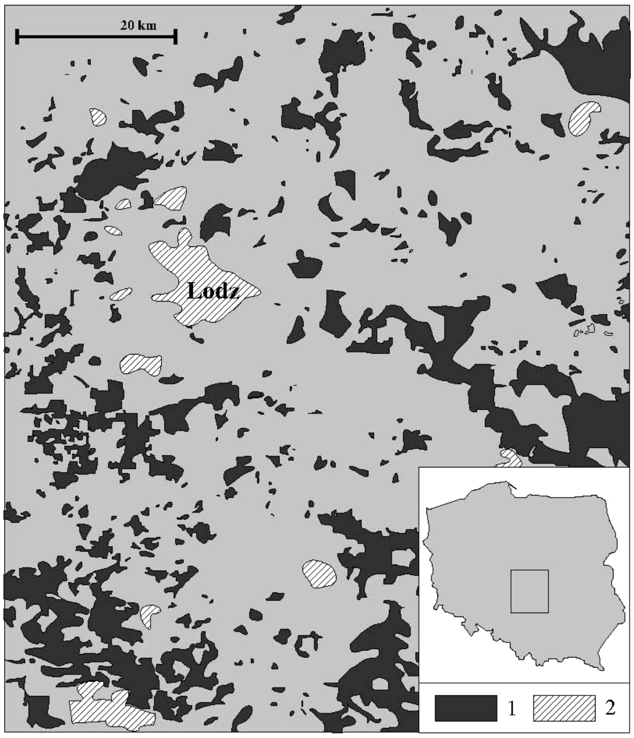

Figure 1. The study area including (1) forests and (2) urban areas in central Poland

the study area, forest fragments were located among agricultural and urban landscapes. Forests constituted about 20% of the area and were most used for producing timber. In each forest stand, the predominant tree species was pine or, in some cases, pine and oak. Much less frequent, there were stands composed of deciduous trees such as oaks, birch, and hornbeam. Because in such managed forests it is difficult to clearly define the community in phytosociological sense, we divided them into three categories as coniferous, mixed and deciduous. The number of research points in the abovementioned categories reflected the frequency of their occurrence in central Poland. There were 39 points with coniferous, 17 with mixed and 11 with deciduous stands.

Data collection

We surveyed all of the largest forest complexes of central Poland, and analyzed all ditches. We encountered that were at least 1m wide running through uniform phytocenoses, i.e., a stand type and age was identical on both sides of the ditch. In this way, we examined 40 study points along drainage ditches, 20 points along road ditches, and 7 points along war trenches. To exclude the influence of other open spaces, plots were located at least a dozen meters from features such as clearings, forest edges, and roads (except in the case of roadside ditches). One sampling point was generally established per ditch with the exception of some long ditches that were sampled at more than one point. Only a few war trenches were sampled because of their rarity on the area and these were found in the coniferous forests only.

Two plots were set up at each sampling point. One plot was located in the ditch. It was five metres long, and the width was equal to the width of the ditch. Ditches were differentiated in their width from 1 to 5 metres; their mean depth was 0.8m. The width and depth of each ditch was measured. In addition, the percentage of tree and shrub cover above the ditch was assessed. For each plot in the ditch, a corresponding plot of the same size was established in the surrounding forest phytocenosis. The forest plot was located in parallel to and about 10 m away from the ditch. In preliminary studies, this distance was sufficient to avoid the influence of the ditch on the floristic composition.

A list of understory vascular plant species was compiled for each plot. Species cover was assessed for each species using a decimal scale with particular regard to small values (Londo 1976). In our calculations, we assumed that individual small plant specimens occupied 0.5% of the plot, next we noted species that covered 5%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100% of the plot area.

Data analysis

To describe species diversity within the ditches and forest plots, we calculated species richness (*N*), Shannon's diversity index (*H*), Pielou's evenness index (*E*) (Ulrich 2001), and indexes of floristic value (*FV*) and floristic uniqueness (*FU*) developed by Géhu (1979).

The index of floristic value (*FV*) is the sum of rarity indexes of species found in a plot. The rarity index for each species was calculated using the formula $Ir = (S-s)/S$, where *S* is the total number of plots and *s* is the number of plots in which the species appears. The greater the number of species or the rarer the species, the higher the floristic value index for a given research plot.

The floristic uniqueness index (*FU*) is given by $FU = FV/N$, where *N* is the number of species found in a plot. This index takes the mean value of the rarity of species into consideration.

We used Spearman's rank correlation coefficients to examine whether the ditch width and depth and the percentage of tree and shrub cover above the ditch had a significant impact on biodiversity indexes. To detect differences in species diversity between ditches and the surrounding forests, taking into account the three ditch types and three types of forest, variation in *N*, *H*, *E*, *FV*, and *FU* was tested using the General Linear Models - GLM (two-way ANOVA design with repeated measures and missing cells). Multiple comparisons were performed using Tukey's method for unequal sample sizes.

Normality was tested using Shapiro-Wilk's test. Homogeneity of variances was tested with Levene's test. A few outliers were removed from analysis. Results were considered significant for $P < 0.05$.

Ditch and forest flora were also compared in terms of plant ecological requirements. The ecological indicator values of vascular plants of Poland were used (Zarzycki et al. 2002). These values range from 1 to 5 and express the intensity of particular factor from the smallest to biggest. For example, for light value, the number 1 means a deep shade and number 5 means a full light. The following environment variables based on the Zarzycki et al. (2002) were taken into account: light, temperature, continentality, soil moisture, soil trophy, soil acidity, soil granulometric and soil organic matter content values. The Redundancy Analysis of multivariate ecological ordination methods (RDA) was performed to determine the relationships between the environmental conditions and different types of plots.

All calculations were performed using STATISTICA PL version 10.0 (StatSoft, Inc. 2011) and the R 3.0.1 Statistical Software (Oksanen et al. 2013, R Core Team 2013).

Results

Out of 136 recorded species, 63 were observed only in ditches and 4 only in forests. Ditch characteristics had no effect on species diversity: there was no relationship between biodiversity indexes, ditch width and depth, and the percentage of tree and shrub cover (Spearman's rank correlation). This allowed us to collectively compare all plots located in ditches with those located in forests (Figure 2). Detailed calculations are given in Table 1.

When the indicators used to describe diversity were compared (Table 1, Figure 2a), significant differences were detected between ditches and forests. Ditches had considerably higher species richness. The average number of species in ditches was 15.0 ± 6.0

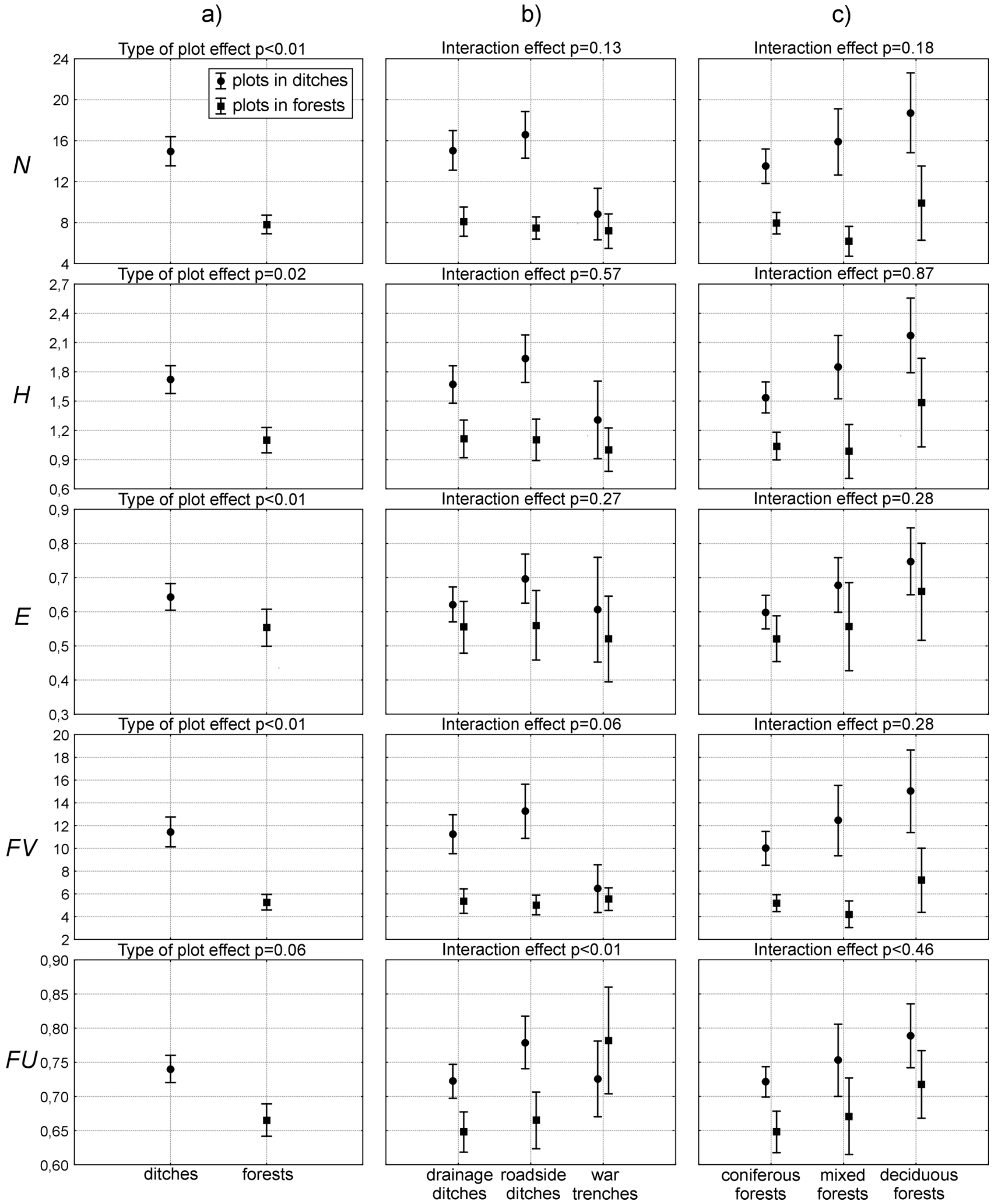

Figure 2. Differences in species richness (*N*), diversity (*H*), evenness (*E*), floristic value (*FV*), and floristic uniqueness (*FU*) analyzed with GLM (two-way ANOVA design with repeated measures and missing cells; mean ± 95% confidence intervals); (a) Type of plot effect, (b) type of plot*type of ditch interaction effect and (c) type of plot*type of forest interaction effect with statistically significant differences (multiple comparisons with Tukey's method for unequal sample sizes, $P < 0.05$)

Table 1. Basic descriptive statistics of indicator values: (*N*) species richness, (*H*) Shannon's diversity index, (*E*) Pielou's evenness index, (*FV*) index of floristic value, and (*FU*) index of floristic uniqueness

Variable	Factor	Factor level		Mean	SD	Min	Max	Median	Q25	Q75
N	type of plot	plots in ditches		14.97	5.83	4	26	14	11	19
		plots in forests		7.82	3.72	0	22	7	6	10
	interaction type of plot * type of ditch	drainage ditches		15.05	6.06	4	26	14.5	11	19.5
		corresponding plots in forests		8.10	4.47	0	22	7.5	5	11
		roadisde ditches		16.57	5.01	8	26	16	13	20
		forests		7.48	2.38	3	12	7	6	9
		war trenches		8.83	2.40	6	11	9	7	11
		forests		7.17	1.60	5	10	7	7	7
	interaction type of forest * type of plot	coniferous	ditches	13.51	5.18	4.00	26.00	12.00	11.00	17.00
			forests	7.95	3.24	0.00	15.00	7.00	6.00	10.00
		mixed	ditches	15.88	6.28	4.00	26.00	16.00	13.00	20.00
			forests	6.18	2.83	2.00	12.00	6.00	5.00	8.00
		deciduous	ditches	18.73	5.80	10.00	25.00	18.00	13.00	25.00
			forests	9.91	5.39	5.00	22.00	8.00	6.00	14.00
H	type of plot	plots in ditches		1.72	0.58	0.16	3.00	1.67	1.36	2.12
		plots in forests		1.10	0.53	0.07	2.81	1.09	0.69	1.48
	interaction type of plot * type of ditch	drainage ditches		1.67	0.60	0.16	2.94	1.61	1.36	2.05
		forests		1.11	0.60	0.07	2.81	1.10	0.61	1.50
		roadisde ditches		1.94	0.54	1.02	3.00	1.87	1.52	2.24
		forests		1.10	0.47	0.33	1.87	1.17	0.81	1.37
		war trenches		1.31	0.38	0.66	1.78	1.35	1.17	1.54
		forests		1.00	0.21	0.77	1.38	0.97	0.85	1.07
	interaction type of forest * type of plot	coniferous	ditches	1.54	0.49	0.16	2.44	1.52	1.32	1.90
			forests	1.04	0.43	0.26	2.02	1.07	0.69	1.31
		mixed	ditches	1.85	0.63	0.67	3.00	1.92	1.50	2.17
			forests	0.98	0.54	0.07	1.87	0.98	0.60	1.36
		deciduous	ditches	2.17	0.57	1.27	2.94	2.18	1.79	2.69
			forests	1.48	0.68	0.43	2.81	1.49	0.93	1.79
E	type of plot	plots in ditches		0.64	0.16	0.12	1.00	0.65	0.55	0.77
		plots in forests		0.55	0.22	0.06	1.00	0.56	0.43	0.69
	interaction type of plot * type of ditch	drainage ditches		0.62	0.16	0.12	0.91	0.63	0.56	0.73
		forests		0.55	0.23	0.06	1.00	0.56	0.42	0.71
		roadisde ditches		0.70	0.16	0.40	1.00	0.76	0.58	0.79
		forests		0.56	0.22	0.20	1.00	0.60	0.44	0.66
		war trenches		0.61	0.15	0.34	0.74	0.65	0.55	0.71
		forests		0.52	0.12	0.34	0.71	0.52	0.48	0.55
	interaction type of forest * type of plot	coniferous	ditches	0.60	0.15	0.12	0.87	0.62	0.53	0.71
			forests	0.52	0.20	0.12	1.00	0.54	0.42	0.64
		mixed	ditches	0.68	0.16	0.39	1.00	0.65	0.60	0.77
			forests	0.56	0.25	0.06	1.00	0.56	0.43	0.74
		deciduous	ditches	0.75	0.15	0.47	0.91	0.81	0.58	0.85
			forests	0.66	0.21	0.27	1.00	0.66	0.52	0.77
FV	type of plot	plots in ditches		11.44	5.37	2.12	23.51	10.68	7.27	14.98
		plots in forests		5.27	2.81	0	17.11	4.62	3.71	6.38
	interaction type of plot * type of ditch	drainage ditches		11.24	5.36	2.12	21.29	10.68	7.22	15.18
		forests		5.36	3.36	0.00	17.11	4.58	2.93	7.46
		roadisde ditches		13.26	5.22	4.92	23.51	13.00	9.78	17.27
		forests		5.02	1.90	1.68	9.24	4.20	3.90	5.80
		war trenches		6.46	2.00	4.30	8.94	6.53	4.55	7.89
		forests		5.53	0.95	4.48	7.20	5.32	4.96	5.93
	interaction type of forest * type of plot	coniferous		10.00	4.58	2.38	21.29	8.76	7.21	12.76
				5.19	2.29	0.00	10.33	4.96	3.91	6.08
		mixed	ditches	12.44	6.01	2.12	23.51	12.73	9.38	17.27
			forests	4.21	2.27	1.49	9.24	3.74	2.62	5.57
		deciduous	ditches	15.02	5.40	6.34	22.30	14.28	10.48	19.88
			forests	7.20	4.20	3.39	17.11	6.38	3.95	9.73
FU	type of plot	plots in ditches		0.74	0.08	0.53	0.93	0.75	0.68	0.79
		plots in forests		0.67	0.10	0.49	0.92	0.65	0.60	0.72
	interaction type of plot * type of ditch	drainage ditches		0.72	0.08	0.53	0.83	0.75	0.66	0.79
		forests		0.65	0.09	0.49	0.82	0.62	0.58	0.71
		roadisde ditches		0.78	0.08	0.61	0.93	0.77	0.74	0.84
		forests		0.66	0.09	0.52	0.92	0.64	0.60	0.71
		war trenches		0.73	0.05	0.65	0.81	0.72	0.71	0.74
		forests		0.78	0.07	0.71	0.90	0.76	0.72	0.85
	interaction type of forest * type of plot	coniferous	ditches	0.72	0.07	0.59	0.84	0.72	0.66	0.77
			forests	0.65	0.09	0.49	0.90	0.63	0.59	0.71
		mixed	ditches	0.75	0.10	0.53	0.92	0.76	0.71	0.79
			forests	0.67	0.11	0.52	0.92	0.65	0.59	0.74
		deciduous	ditches	0.79	0.07	0.63	0.93	0.79	0.77	0.81
			forests	0.72	0.07	0.57	0.82	0.71	0.70	0.78

(mean ± *SD*) compared with 8.0 ± 4.0 in forest areas. There was high variation, however, in the number of species among ditches. All other indicators of biodiversity were also significantly higher in ditches (in case of *FU* with significance for $P < 0.10$ only). In the case of Shannon's index, the values were 1.7 ± 0.6 for ditches and 1.1 ± 0.5 for forests. In the case of the evenness index, the difference between ditches and forests was small, with the values almost identical: 0.6 ± 0.2. These small differences are a consequence of the fact that the evenness index values for many ditch plots were lower than for their corresponding forest plots. The largest observed difference was in the floristic value index; in ditches it was about two times higher than in the forest (11.4 ± 5.4 for ditches and 5.3 ± 2.8 for forests). In the case of floristic uniqueness, values were approximately 0.7 ± 0.1, with small differences in mean values between ditches and forests.

When compared among themselves, no statistically significant differences were found among the three ditch types (Figure 2b); however, drainage ditches and roadside ditches differed significantly from surrounding forests with respect to floristic uniqueness. This is due to the fact that war trenches had less diversified flora in respect to its local rarity than the corresponding plots in forests whereas drainage and roadside ditches differed significantly ($p<0.01$) in comparison with forest plots (Figure 2b). No statistically significant differences were revealed between the three types of forest - for each of them the effect of the ditch presence was similar, for war trenches, however, it was the smallest (Figure 2c).

The ecological values of plants gave us indirect information about the differences in site conditions (Figure 3) and direct information about differences in the ecological variability of plants between ditches and forests. RDA-ordination method revealed that the diversification of plots is significantly ($p<0.05$) affected by the trophy (Tr), moisture (M) of soils and the

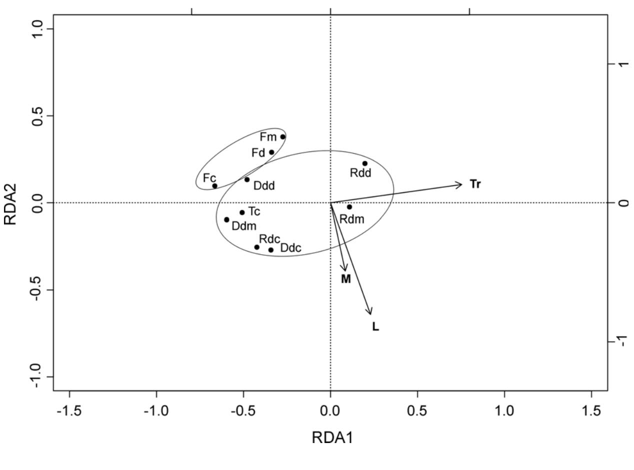

Figure 3 RDA biplot showing the two first axes of a canonical ordination (the eigenvalue of the first axis was 0.25 and of the second axis 0.06; for both p=0.005). Points corresponding to particular species were omitted. Designation of environmental vectors: L – light, Tr – trophy, M – moisture; designation of site categories: F – forest plot, Dd – drainage ditch, Rd – roadside ditch, T – war trench, c – coniferous forest, m – mixed forest, d – deciduous forest

lighting conditions (L). Plant occurrence in ditches indicates more trophic, wet soils and more lighted sites. This is the case for each type of forest, coniferous, mixed and deciduous.

Discussion and conclusions

Compared with the forest, more diverse flora was on the plots established in ditches. For example, species richness was higher in ditches. The average number of species was almost two-times higher than in forests, and about 46% of identified species were found only in ditches. This is consistent with Baltzinger et al. (2011), who compared plots located in drainage ditches with forest control plots and discovered that the former were responsible for about 52% of the reported floristic species richness. Corney et al. (2006) and Smith et al. (2007) also found that forest drainage ditches tend to enhance floristic richness.

As the number of species increased, a corresponding increase in the value of the Shannon index took place. The analysis of evenness indexes revealed that its value may sometimes be higher or lower in comparison with corresponding forest plots. Hence changes in species richness were of greater importance than alterations in dominance structure for characterizing the influence of ditches.

Large differences between ditch and forest plots were observed with respect to floristic value index. This index takes into account the number of species and the frequency of their occurrence. Many of the species that contributed to the increase in species richness were locally rare, i.e., those that were listed only once or a few times during the study. This result was corroborated by the statistically significantly higher floristic uniqueness values observed for drainage and roadside ditch plots. None of the locally rare species occurring in ditches, for which ditches could serve as refugia, were endangered. The most valuable species was *Lycopodium clavatum*, but this can be found in other forest areas of central Poland besides ditches. Peterken and Francis (1999), who studied the vascular flora of forest openings, also found that many enumerated species occurred at low frequency. Because of the presence of forest openings, shade-intolerant species were an important component of the flora; however, open spaces acted not as efficient refugia for the vulnerable flora of grasslands, wetlands, heathlands, and similar areas, but instead mainly provided habitats for common widespread species. Furthermore, in a study conducted by Baltzinger et al. (2011), species found in forest artifacts, e.g., tractor ruts, drainage ditches, roads, paths, and fire pits, were not endangered. More than half of the species supported by different forest artifacts were common generalists. Our results confirm that ditches have little conservation value for endangered species.

In our study, ditches did not act as migration pathways for alien species as the number of such species occurring in ditches did not exceed that of the forests. During this study, we identified five alien species, two of which were restricted to forests. Only two alien species—*Aesculus hippocastanum* and *Oxalis stricta* — were present in ditches but absent in forests, and each was noted only once during the study. The same finding that drainage ditch flora comprises mostly indigenous species, was found by Baltzinger et al. (2011) and Banach (2009).

The results of our study indicate that ditches have a significant effect on diversity in terms of ecological characteristics of species. The ecological indicator values of plants occurring in the ditches confirm that ditches provide different conditions than forest interior sites in comparison with those in surrounding forest. Hansen et al. (1991), examining managed forests, asserted that structures creating light and soil conditions different from those found in typical phytocenoses may increase forest-wide plant diversity. Our findings confirm this statement.

Drainage and roadside ditches provided habitat for species characteristic of moist soils, such as *Carex acutiformis*, *Filipendula ulmaria*, *Galium palustre*, *Iris pseudacorus*, *Lycopus europaeus*, *Peucedanum palustre*, *Stellaria palustris*, and *Thelypteris palustris*. There was wide variability of moisture indicator values, however; species of dry places, such as *Rumex acetosella* and *Viola canina*, also grew in the ditches. Furthermore, ditches provided suitable conditions for plants of both open and shaded sites. In contrast to the forest interior, they allowed for the presence of more light-demanding plants as *Tussilago farfara*, *Sieglingia decumbens* and *Tanacetum vulgare*. Species of shaded sites, e.g., *Equisetum sylvaticum*, were present as well. Our findings are consistent with those of Baltzinger et al. (2011) who demonstrated that the mean Ellenberg light index of plots varied significantly depending on whether or not the plot was located in a drainage ditch. The mean Ellenberg light index was also higher in ditches than in forest plots; nevertheless, they found six shade-tolerant species to be more frequent in ditches.

Ditches also provided habitats for species characteristic for more trophic soils in comparison with forest interior. It can be explained by the fact that ditches can be seen as small-scale edges in the forests. Many authors draw attention to the fact that nitrophilic herb species benefit from the edge effects (for example Hamberg 2009, Korpela and Reinikainen 1996).

The flora found in different types of ditches in our study varied but there were no statistically important differences between them. This can be attributed to the high variability of results obtained among individual ditches of a given type. We tested whether this variability was the result of differences in size or degree of shading of the examined ditches but did not find any significant relationships. Nevertheless, roadside ditches were associated with the highest values obtained for most analyzed biodiversity indicators. This result is consistent with that of other studies (for example, Baltzinger et al. 2011, Buckley et al. 2003, Smith et al. 2007). According to the work conducted in managed hardwood stands by Watkins et al. (2003), however, the road vicinity was associated, on the one hand, with a decrease in native species richness and Shannon index values and, on the other hand, an increase in exotic species richness. The total species richness did not change near the road. This implies that change in species composition, rather than number of species, may sometimes be the primary effect of road presence. In our study, the change brought by ditch presence was both qualitative and quantitative. The question of whether ditches along forest roads help or hinder invasion of alien species in comparison with flat roadsides, requires further study. This is a question of the great importance because many studies have found that exotic species can penetrate into the forests along roadsides (for example, Flory and Clay 2009, Forman et al. 2003, Jakubowska-Gabara and Zielińska 2005, Johnston and Johnston 2004, Parendes and Jones 2000). Ditches certainly provide more different habitats for non-forest species than flat roadsides (Smith et al. 2007, Zielińska 2007).

War trenches most differed from the others of all three analyzed types of ditches. Flora in the trenches was very similar to this of the forest, probably because trench hydrological conditions were identical to the surrounding forest. War trenches were located on the slopes of wooded dunes in relatively dry pine forests on very permeable soils; conversely, drainage ditches were built to drain the land in more humid forests.

Conclusions

Our data indicated higher species richness and greater number of species that are locally rare (i.e., not typical in the analyzed forest phytocenoses) in ditches. The ditches, however, were not effective as refugia for endangered species. Despite the presence of alien species in analyzed forest complexes, ditches did not seem particularly important for their migration. Nevertheless, a greater diversity of flora with different ecological requirements was possible due to the variety of lighting, trophy and moisture conditions in ditches.

Ditch presence had a much greater effect on floristic diversity level than did its size or degree of shading. The effect of its presence was pronounced regardless of the type of forest. Roadside and drainage ditches had greater impact on plant species diversity than the war trenches.

References

Avon, C., Bergès, L., Dumas, Y. and Dupouey, J-L. 2010. Does the effect of forest roads extend a few meters or more into the adjacent forest? A study on understory plant diversity in managed oak stands. *Forest Ecology and Management* 259: 1546-1555.

Banach, B. 2009. Vascular flora of drainage ditches in forest area of the Polesie National Park. *Acta Agrobotanica* 62(1): 117-126.

Bartels, S.F. and Chen, H.Y.H. 2010. Is understory plant species diversity driven by resource quantity or resource heterogeneity? *Ecology* 91(7): 1931-1938.

Baltzinger, M., Archaux, F., Gosselin, M. and Chevalier, R. 2011. Contribution of forest management artefacts to plant diversity at a forest scale. *Annals of Forest Science* 68: 395-406.

Bengtsson, J., Nilsson, S.G., Franc, A. and Menozzi, P. 2000. Biodiversity, disturbances, ecosystem function and management of European forests. *Forest Ecology and Management* 132: 39-50.

Blomqvist, M.M., Tamis, W.L.M., Bakker, J.P. and van der Meijden, E. 2006. Seed and (micro)site limitation in ditch banks: germination, establishment and survival under different management regimes. *Journal for Nature Conservation* 14: 16-33.

Buckley, D.S., Crow, T.R., Nauertz, E.A. and Schulz, K.E. 2003. Influence of skid trails and haul roads on understory plant richness and composition in managed forest landscapes in Upper Michigan, USA. *Forest Ecology and Management* 175: 509-520.

Corney, P.M., Le Duc, M.G., Smart, S.M., Kirkby, K.J., Bunce, R.G.H. and Marrs, R.H. 2006. Relationships between the species composition of forest field-layer vegetation and environmental drivers, assessed using a national scale survey. *Journal of Ecology* 94: 383-401.

Dajdok, Z. and Wuczyński, A. 2005. Biocenotic differentiation, functions and protection problems of the small mid-field ditches. In: L. Tomialojć and A. Drabiński (Editors) Środowiskowe aspekty gospodarki wodnej, p. 227-252, (in Polish with English abstract).

Flory, S.L. and Clay, K. 2006. Invasive shrub distribution varies with distance to roads and stand age in eastern deciduous forests in Indiana, USA. *Plant Ecology* 184: 131-141.

Flory, S.L., Clay, K. 2009. Effects of roads and forest successional age on experimental plant invasions. *Biological Conservation* 142: 2531-2537.

Forman, R.T.T., Sperling, D., Bissonette, J.A., Clevenger, A.P., Cutshall, C.D., Dale, V.H., Fahrig, L., France, R., Goldman, C.R., Heanue, K., Jones, J.A., Swanson, F.J., Turrentine, T. and Winter, T.C. 2003. Road ecology: science and solutions. Island Press, Washington, D.C.

Gotelli, N.J. and Colwell, R.K. 2001. Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. *Ecology Letters* 4: 379-391.

Géhu, J.M. (ed) 1979. Étude phytocoenotique analytique et globale de l'ensemble des vases et prés salés et saumãtres de la facade atlantique francaise. Faculté de Farmacie, Univ. De Lille II et Station de Phytosociologie, Bailleul, 514 pp.

Goulder, A.R. 2007. Conservation of aquatic plants in artificial watercourses: are main drains a substitute for vulnerable navigation canals? *Aquatic Conservation: Marine and Freshwater Ecosystems* 28: 163-174.

Hamberg, L. 2009. The effects of habitat edges and trampling intensity on vegetation in urban forests. http://urn.fi/URN:ISBN:978-952-10-5377-1.

Hansen, A.J., Spies, T.A., Swanson, F.J. and Ohmann, J.L. 1991. Conserving biodiversity in managed forests: lessons from natural forests. *Bioscience* 41: 382-392.

Herzon, I. and Helenius, J. 2008. Agricultural drainage ditches, their biological importance and functioning. *Biological Conservation* 141: 1171-1183.

Hillman, G.R. 1992. Some hydrological effects of peatland drainage in Alberta's boreal forest. *Canadian Journal of Forest Research* 22: 1588-1596.

Hubbell, S.P. 2001. The unified neutral theory of biodiversity and biogeography. Princeton University Press, Princeton, New Jersey.

Huston, M. 1979. A general hypothesis of species diversity. *The American Naturalist* 113: 81-100.

Jakubowska-Gabara, J. and Zielińska, K. 2005. Influence of the human activity on forest plant diversity. *Thaiszia – Journal of Botany* 15: 53-62.

Johnston, F.M. and Johnston, S.W. 2004. Impacts of road disturbance on soil properties and on exotic plant occurrence in subalpine areas of the Australian Alps. *Arctic Antarctic and Alpine Research* 36(2): 201-207.

Karim, M.N. and Mallik, A.U. 2008. Roadside revegetation by native plants. I. Roadside micorohabitats, floristic zonation and species traits. *Ecological Engineering* 32: 222-237.

Korpela, L. 1999. Diversity of vegetation in pristine and drained forested mire margin communities in Finland. *International Peat Journal* 9:94-117.

Korpela, L. 2004. The importance of forested mire margin plant communities for the diversity of managed boreal forests in Finland. Finnish Forest Research Institute, Vantaa Research Centre, Vantaa, Finland, 60 pp. http://urn.fi/URN:ISBN:952-10-2218-3

Korpela, L. and Reinikainen, A. 1996. A numerical-analysis of mire margin forest vegetation in south and central Finland. *Annales botanici Fennici* 33(3): 183-197.

Kurowski, J.K. 2007. Xerophytisation of marsh forests in the vicinity of an open pit brown coal mine in Central Poland. *Ekologia* (Bratislava) 26 (3): 282-294.

Lipiński, J. 2006. Zarys rozwoju oraz produkcyjne i środowiskowe znaczenie melioracji w świetle badań [An outline of land amelioration development and its productive and environmental significance in view of studies]. *Acta Scientarum Polonarum Formatio Circumiectus* 5 (1): 3–15 (in Polish).

Londo, G. 1976. A decimal scale for relevés of permanent quadrats. *Vegetatio* 33: 61-64.

Manhoudt, A.G.E., Visser, A.J. and de Snoo, G.R. 2007. Management regimes and farming practices enhancing plant species richness on ditch banks. *Agriculture, Ecosystems & Environment* 119: 353-358.

Milsom, T.P., Sherwood, A.J., Rose, S.C., Town, S.J. and Runham, S.R. 2004. Dynamics and management of plant communities in ditches bordering arable fenland in eastern England. *Agriculture, Ecosystems & Environment* 103: 85-99.

Oksanen, J., Blanchet, F.G., Kindt, R., Legendre, P., Minchin, P.R., O'Hara, R.B., Simpson, G.L, Solymos, P., Stevens, M.H.H. and Wagner, H. 2013. vegan: Community Ecology Package. R package version 2.0-8. URL http://vegan.r-forge.r-project.org/.

Paillet, Y., Bergčs, L., Hjältén, J., Ódor, P., Avon, C., Bernhardt-Römermann, M., Bijlsma, R-J., De Bruyn, L., Fuhr, M., Grandin, U., Kanka, R., Lundin, L., Luque, S., Magura, T., Matesanz, S., Mészáros, I., Sebastià, M-T., Schmidt, W., Standovár, T., Tóthmérész, B., Uotila, A., Valladares, F., Vellak, K. and Virtanen, R. 2010. Biodiversity Differences between Managed and Unmanaged Forests: Meta-Analysis of Species Richness in Europe. *Conservation Biology* 24,1: 101-112.

Parendes, L.A. and Jones, J.A. 2000. Role of light availability and dispersal in exotic plant invasion along roads and streams in the H.J. Andrews Experimental Forest, Oregon. *Conservation Biology* 14: 64-75.

Pauchard, A. and Alaback, P.B. 2006. Edge type defines alien plant species invasions along Pinus contorta burned, highway and clearcut forest edges. *Forest Ecology and Management* 223: 327-335.

Peet, R.K. 1974. The measurement of species diversity. *Annual Review of Ecology and Systematics* 5: 285-307.

Peterken, G.F. and Francis, J.L. 1999. Open spaces as habitats for vascular ground flora species in the woods of central Lincolnshire, UK. *Biological Conservation* 91: 55-72.

Ricklefs, R.E. 1977. Environmental heterogeneity and plant species diversity: a hypothesis. *The American Naturalist* 111: 376-381.

Ricklefs, R.E. 2006. Evolutionary diversification and the origin of the diversity-environment relationship. *Ecology* 87(7) Supplement: S3-S13.

Roy, V., Plamondon, A.P. and Bernier, P. 2000. Draining forested wetland cutovers to improve seedling root zone conditions. *Scandinavian Journal of Forest Research* 15: 58-67.

R Core Team. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Skov, F. and Lawesson, J.E. 2000. Estimation of plant species richness from systematically placed plots in a managed forest ecosystem. *Nordic Journal of Botany* 20: 477-483.

Smith, G.F., Iremonger, S., Kelly, D.L., O'Donoghue, S. and Mitchell, F.J.G. 2007. Enhancing vegetation diversity in glades, rides and roads in plantation forests, *Biological Conservation* 136: 283-294.

StatSoft, Inc. 2011. STATISTICA (data analysis software system), version 10. URL www.statsoft.com.

Suárez-Esteban, A., Delibes, M. and Fedriani, J.M. 2013. Barriers or corridors? The overlooked role of unpaved roads in endozoochorous seed dispersal. *Journal of Applied Ecology* Doi: 10.1111/1365-2664.12080.

Ulrich, W. 2001. Models of relative abundance distributions II: diversity and evenness statistics. *Polish Journal of Ecology* 49(2): 159-175.

van der Maarel, E. 1988: Species diversity in plant communities in relation to structure and dynamics. In: H.J. During, M.J.A. Werger and H.J. Willems (Editors), Diversity and pattern in plant communities. SPB Academic Publishing. The Hague.14 pp.

Waide, R.B., Willig, M.R., Steiner, C.F., Mittelbach, G., Gough, L., Dodson, S.I., Juday, G.P. and Parmenter, R. 1999. The relationship between productivity and species richness. *Annual Review of Ecology, Evolution, and Systematics* 30: 257-300.

Watkins, R.Z., Chen, J.Q., Pickens, J. and Brosofske, K.D. 2003. Effects of forest roads on understory plants in a managed hardwood landscape. *Conservation Biology* 17: 411-419.

Williams, P., Whitfield, M., Biggs, J., Bray, S., Fox, G., Nicolet, P. and Sear, D. 2003. Comparative biodiversity of rivers, streams, ditches and ponds in an agricultural landscape in Southern England. *Biological Conservation* 115: 329-341.

Whittaker, R.H. 1972. Evolution and measurement of species diversity. *Taxon* 21(2/3): 213-251.

Zielińska, K. 2007. The influence of roads on the species diversity of forest vascular flora in Central Poland. *Biodiversity: Research and Conservation* 5-8: 71-80.

Zarzycki, K., Trzcińska-Tacik, H., Różański, W., Szeląg, Z., Wołek, J. and Korzeniak U. 2002. Ecological indicato values of vascular plants of Poland. In: Z. Mirek (editor), Biodiversity of Poland. W. Szafer Institute of Botany, Polish Academy of Sciences, Kracow, 183 pp.

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ВЛИЯНИЕ КАНАВ НА ФЛОРИСТИЧЕСКОЕ РАЗНООБРАЗИЕ В ЛЕСАХ ЦЕНТРАЛЬНОЙ ПОЛЬШИ

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Резюме

Структуры антропогенного происхождения, которые внедряются в хозяйственно используемых лесах, могут приводить к повышению флористического разнообразия. Среди таких структур особую роль выполняют канавы, так как их наличие является причиной повышения дифференциации мест обитания лесных комплексов не только по условиям освещения, но и влажности. Благодаря им, на небольщой площади одновременно могут обитать видоспецифически контрастные виды, так как условия на дне и на склонах канав заметно отличаются. В статье проводится анализ влияния наличия трёх типов канав: мелиоративных, придорожных, а также траншей (военных земных укрытий) на флористическое разнообразие лесных фитоценозов центральной Польши. Кроме видового богатства учитывалась структура доминирования, а также коэффицент редкости видов как экологический индикатор значимости растений.

Указывается, что видовое богатство было значительно больше в канавах по сравнению с окружающими их лесными фитоценозами. Среднее количество наблюдаемых в них видов было почти вдвое больше. Кроме того, около 46% всех отмеченных таксонов наблюдалось исключительно в канавах. Однако с природной точки зрения, исключительного значения не наблюдалось, так как отмеченные виды не числились как редкие или ценные на государственном уровне. В них также не наблюдалось значительно большего количества чуждых видов по сравнению с окружающими лесами. Канавы обычно имели большее разнообразие, выраженное коэффициентом видового разнообразия Шеннона (*Shannon*), однако показания индекса выравненности видового состава сообщества значительно различались по сравнению с лесами: в одних случаях результаты для канав были больше, в других - меньше. Большинство видов в канавах имели низкую встречаемость. Авторы определили, что, по сравнению с окружающими лесами, канавы обеспечивают существование многих видов, типичных для более влажных, солнечных и плодотворных ареалов. Наблюдалась дифференциация трёх типов придорожных канав. Наибольшее влияние на флористическое разнообраазие оказывали придорожные канавы. Большое влияние на разнообразие видов в анализируемых лесных комплексах имели мелиоративные канавы. Флора траншей существенно не отличалась от флоры окружающих лесов.

Ключевое слова: флористическое разнообразие, дифференциация местообитаний, мелиоративные канавы, придорожные канавы, траншеи, хозяйственно используемые леса