Estimating the impact of ditches' presence on the diversity of forest flora

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Abstract

In managed forest complexes the natural variety of habitats disappear while anthropogenic structures, for instance roads and ditches, appear more often. This study analyzes an impact of drainage ditches, roadside ditches and old war trenches on increasing flora's diversity. We propose a simple method of data comparison between the flora of forest area including a ditch with the flora from forest area without such structure. We estimated that on average the presence of drainage ditches in the surveyed areas of forest phytocenoses in central Poland had increased values of such indexes as species richness of about 37%, Shannon's 23%, evenness 6%, floristic value 41%, floristic uniqueness 10%. For roadside ditches these values were also increased respectively: 45%, 37%, 19%, 51%, 12%; as well as for war trenches: 13%, 6%, 1%, 14%, 2%.

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

1. Introduction

Habitat diversity characteristic of natural forests in managed forests has been replaced by a habitat diversification caused by man. Occurrence of such natural differentiation as for example gaps in canopy and hollows in ground caused by dying trees remained only in the areas of reserve protection. In exchange structures related to the requirements of economical management of forest ecosystems appear. Anthropogenic habitats in forests are often linear, these are for example roads, rail tracks, high-voltage lines.

With the big ratio of length to width these structures can act as a kind of ecological corridors along which other vegetation than in the whole forest complex develops (Forman et al., 2003, Lugo & Gucinski, 2000). Such corridors can be a way of migration for one species, a refugium for others and a barrier for yet another (Liro & Szacki 1993). Such narrow belts in the forests may have features characteristic of forest edges or ecotones also. Many environmentalists underline the fact of increasing species richness in such structures so that their presence may affect the biodiversity of forests complexes treated as a whole (Baltzinger et al., 2011; Hansen et al., 1991; Peterken & Francis, 1999; Zielińska, 2007).

In this study, among different types of linear anthropogenic habitats, ditches were selected. They are very interesting because they allow the presence of a large diversity of species characteristic of various habitats. The bottom of the ditch can provide moist habitats and the slopes the drier ones, also depending on the tree canopy over the ditch the site can be more sunlighted than the interior forest. This prompted us to accept the hypothesis that the ditches enriching managed forests into new habitats should be the cause of increasing the diversity of species.

An understanding of human disturbances and management practices impact on diversity is crucial to preserve and manage biodiversity and ecosystem functions in the present European forests (Nilsson & Ericson, 1997). Strongly transformed managed forests seem to be at a greater risk of damage because of unforeseen variations in environmental conditions, e.g. because of climate change. Very important advantage of retaining diverse ecosystems is the `insurance hypothesis', which suggests that high diversity leads to more reliable ecosystem functions over time when environmental conditions vary (Folke et al., 1996, Naeem, 1998). Because of the loss of natural diversity in managed forests these resulting from anthropogenic habitat diversification may become very important. Nature reserves alone are not sufficient to preserve the biodiversity of European forests so it is necessary to manage most forest complexes for both production and biodiversity (Bengtsson et al., 2000, Niemelä, 1997). At the same time we must not forget that diversity should not be treated as the sum of the species, it is important what species make up this diversity (Bengtsson et al., 2000).

There is a need for development of tools useful to assess the importance of various structures (both anthropogenic and natural) that by increasing the number of habitats contribute to increase of biodiversity. There are many methods for estimating species diversity. The concept is broad and in addition to the species richness it may include analysis of structure of domination or analysis of variety of chosen features which can be attributed to the species. We assumed that ditches not only allow the presence of a larger number of species, but also that there will be among them locally rare species, so occurring in forest complexes in the low frequencies. Therefore, in addition to species richness and diversity expressed by the Shannon with the evenness indexes (Ulrich, 2001) we used floristic value and floristic uniqueness indices developed by Géhu (1979) in this analysis.

The above-mentioned numerical indicators are easy to use and good for comparisons between different areas, but they have many limitations. The article proposes a simple method of analysis that makes it possible not only to assess the impact of structures such as ditches on the diversity of forest flora, but also to compare the results obtained with the help of various indicators.

During the field research in central Poland we found ditches running directly through the forest complex, ditches associated with the system of forest roads and the remnants of the old war trenches. We assumed that the impact of different types of ditches could be different.

This article aims to answer the question whether the ditches have a significant influence on the floristic diversity of forests and if the impact of various types of ditches differs.

2. Materials and methods

2.1. Field research

The study conducted in 2006-2007 covered forests located in the Central Poland. The area occupies a large part of Polish Lowlands (approximately 14,000 km^2) and was originally covered by primarily forest communities. Today, though largely deforested, occupied by agricultural and urban landscape, it still contains forest complexes of different size. Forests constitute about 1/5 of the Central Poland area and in most they are used for timber production.

For purpose of the research fragments of managed forests with ditches were chosen. In each study point the plot located within the ditch (*d*) with length of 5 meters and width depending on the width of the ditch (usually 2.5-3.5 m) was established (Fig. 1). 67 such plots were laid out within the area of different forest complexes of Central Poland. For each of them in the surrounding phytocoenosis three forest plots (f_1, f_2, f_3) of the same size as the corresponding plot in the ditch were designated. It was verified in field research that information collected from forest plots represented almost the whole diversity of forest flora of analyzed phytocoenoses. The scheme of collection of field data responded transect method. The field research consisted of creating lists of understory vascular plant species with the classes of cover according to the Londo scale (1976) on the research plots.

Three types of ditches were taken into account. We distinguished drainage ditches, roadside ditches, and war trenches. In many parts of Poland ground water level is now lower than in the 19th and early 20th centuries when intensification of drainage was performed (Lipiński 2006). Nowadays, in forest ditches – those directly running through the forest (we called them drainage ditches) and those along forest roads (roadside ditches) - we can observe the presence of water only during snow melt or heavy rainfall. The third type of ditches we studied were war trenches. The latter were dug during World War II and located on the slopes of sandy hills, their presence changes the morphology of the terrain but has no significant effect on soil moisture. There were 40 plots located in the drainage ditches, 21 in the roadside ditches and 6 in the war trenches. A small number of the latter is due to the fact that this type constitutes only small percentage of ditches found in the forests of the Central Poland, and all the tested plots were very similar.

2.2. Data analyses

To show whether there are differences between the plots located within the ditches in comparison to the plots located in the surrounding forest phytocoenoses we analyzed species richness (*N*), diversity expressed by the Shannon's formula (*H*), Pielou's evenness index (*E*) (Ulrich, 2001) and indexes of floristic value (*FV*) and floristic uniqueness (*FU*) developed by Géhu (1979).

To calculate the floristic value index we have to count the rarity index for each species by the formula: $Ir = (S-s)/S$, where: *S* – the total number of plots, *s*- the number of plots where the species appears. Index of floristic value (*FV*) is the sum of indexes of rarity of species found in the plot. The greater the number of species is or the rarer the species are in the research plot, the greater the floristic value index is. The floristic uniqueness index (*FU*) is given by: $FU = FV/N$, where *N* is the number of species found in the plot, so this index takes the mean value of the rarity of species into consideration.

To evaluate how much the presence of the ditch changes the values of the mentioned indicators we used a simple index, which we called the index of habitat heterogeneity impact on the species richness (HI_N), on the diversity (HI_H), on the evenness (HI_E), on the floristic value (HI_{FV}) and on the floristic uniqueness (HI_{FU}). The idea of this indicator is a comparison of how much richer is the area containing some additional item such as a ditch from the area of the same size without that element. For example, for species diversity expressed by the Shannon's formula the index of habitat heterogeneity impact is expressed by formula:

$$HI_H = \frac{H_{df} - H_f}{\max\{H_{df}, H_f\}}$$

where: H_{df} – Shannon diversity index computed for the aggregate results of the plots located in ditch and in forest $d+f_{1+2+3}$; H_f – Shannon diversity index computed for the forest plots plus an area equal to a plot designated in the ditch in order to maintain the same total area $f_{1+2+3+4}$ (Fig 1). For practical reasons in this article for calculation of H_f previously demarcated forest area was not enlarged but amplified by the data collected from randomly selected forest plot. Obviously, $-1 \le HI_H \le 1$; also: $HI_H > 0$, when the presence of ditch results in an increase of diversity (1 is achieved when in the forest there is no species, and in the plot d there is at least one species); $HI_H < 0$, when the presence of ditch results in a decrease of diversity (-1 is achieved when on the plots $d+f_{1+2+3}$ there is no species, and on the plot f_4 there is at least one species); $HI_H = 0$, when the presence of the ditch did not affect the diversity expressed in Shannon's formula.

To compare the different types of ditches on account of the index of habitat heterogeneity impact on the species richness (HI_N), on the diversity (HI_H), on the evenness (HI_E), on the floristic value (HI_{FV}) and on the floristic uniqueness (HI_{FU}) one-way ANOVA or the Kruskal – Wallis test was performed (depending on the results of the Shapiro – Wilk's test for normality). Box – and – whiskers plots were presented to show the results. Results were considered significant for $p < 0.05$. The statistical calculations were performed using STATISTICA PL version 10.0 software (StatSoft, Inc. 2011).

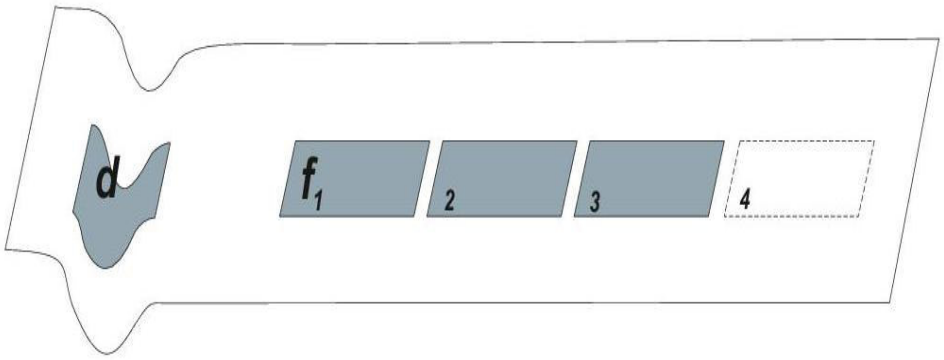

Fig.1. Simplified sampling scheme right to the application of the calculations using habitat heterogeneity impact index in forest complex through which the drainage ditch passes; d – plot in the ditch, f – reference plots in the forest of equal size as plot in the ditch

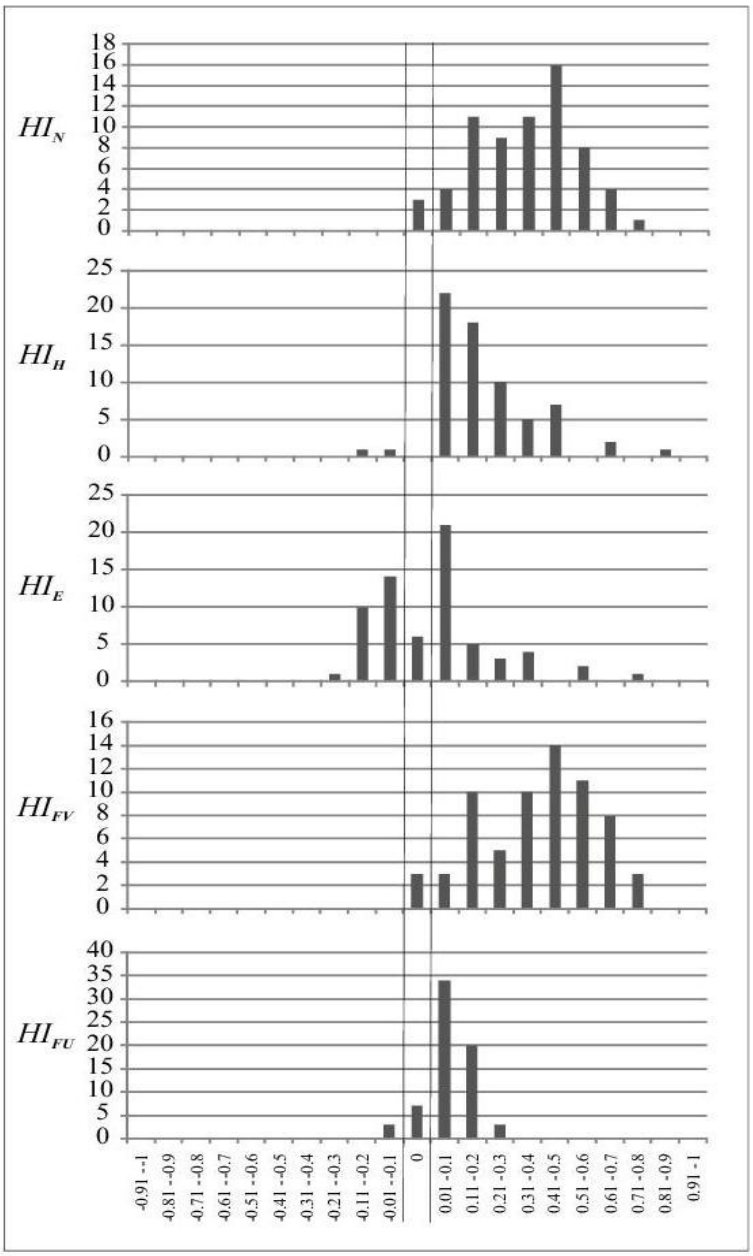

Fig. 2. Diagram of values of *HI* index counted for species richness (HI_N), Shannon's (HI_H), evenness (HI_E), floristic value (HI_{FV}), floristic uniqueness (HI_{FU}); the horizontal axis shows the class intervals for values, the vertical - the number of plots

3. Results and Discussion

3.1. Impact of ditches on forest flora

Totally on the research plots 138 species were recorded, 63 of them were observed only on plots located in the ditches, and 6 only in the forests.

The presence of ditches usually results in an increase of species richness (Fig. 2, Tab. 1). There were only three cases where the presence of this structure did not increase the number of species. The diagram made for the HI_N values shows that the impact of ditches is varied. There are ditches, which only

slightly change values of *N* and such that have a very significant impact on the richness of forest phytocenoses. The values have normal distribution.

Differently distributed are values of habitat heterogeneity impact index for Shannon diversity index (Fig. 2, Tab. 1). Most of the ditches only slightly increase diversity of forest complexes. The reason is that the index *H* depends not only on the number of species. It reaches the greater values the more the dominance structure of species is aligned. In addition, with the increase of the number of species each additional cause a smaller increase in the value of this index. The diagram of the HI_E clearly demonstrates that the ditches do not have a clear impact on the evenness and that for the most cases this effect is small. Increased species richness in the ditches indicates that more species grow at a relatively small space. So the structure of species dominance may be more or less uniform than in the forest plots, depending on the quantitative relationship between the forest species growing in a ditch and the species typical for the ditches. So for the values of floristic diversity expressed by *H* index mainly the bigger number of species does matter.

Values of index HI_{FV} are very much like it was with the HI_N (Fig. 2, Tab. 1). On the values of this index besides richness the local rarity of species affects. As we can see on the diagram of the values of HI_{FU} the presence of ditch changes the local rarity in plus, this is a minor change, but present in most cases. So presence of the ditches in forest complexes first of all increases species richness, and the new species are more rare than the other forest species.

Obtained results indicate important role of ditches for the variety of forest flora. This is consistent with the results obtained by other authors. Baltzinger et al. (2011) who compared the plots located in drainage ditches with the forest control plots showed that these first contribute to about 52% of the species richness of flora. Also Corney et al. (2006) and Smith et al. (2007) found that forest drainage ditches tended to enhance floristic richness. Importance of ditches is like of the other forest artefacts which create light and soil conditions different from those found in surrounding forest fitocenoses. According to Hansen et al. (1991) such structures may increase plant diversity at the whole forest complex scale. Peterken & Francis (1999) by studying vascular flora species in the forests of central Lincolnshire (UK) found that plants characteristic of occurring in this forests open spaces formed a substantial majority of the total flora. Species requiring open spaces formed over 50% of the total vascular flora. Also the research conducted by Skov & Lawesson (2000) confirms that intra-forest open spaces generated by forest management significantly increase the floristic richness. In our studies about 46% of identified species were found only in the ditches and not on the forest plots. This is why the number of species is the most important difference between the flora of ditches and forests. It is noteworthy that the study showed large variations between the influence of individual ditches on the forest flora (Fig. 2).

Greater floristic uniqueness indicates the presence of many locally rare species, namely the ones that were listed only once or several times during the study. Among these species, however, there were not endangered ones. Peterken & Francis (1999) by studying vascular flora of open spaces in the forests also found that many of these species occurred at low frequency. Due to the presence of open spaces the shade-intolerant species occurred in forest complexes but they were mainly common, wide-spread species. Also none of the species found on forest artefacts in the research conducted by Baltzinger et al. (2011) were endangered. More than the half of the species supported by different forest artefacts were generalist or non-forest species. So such artefacts had little conservation value in forest.

In our study we found only two alien species that were present on the single plots in the ditches and absent in forests. These species are *Aesculus hippocastanum* and *Oxalis stricta*. Similarly, research of drainage ditches in forest areas of the Polesie National Park in Poland conducted by Banach (2009) showed that the ditches which significantly enrich local biodiversity were colonized by native flora, characteristic of

the study area. Baltzinger et al. (2011) also recorded only indigenous species. So ditches are not a pathway of migration of alien plants.

The study suggests that the habitat diversification occurring due to the presence of ditches play a positive role. In the natural forests non-forest species i.e. not found in dense forest stand have always been present. Even such small changes in forest topography like these connected with treefalls can be a source of fine-scale variability in soil properties and hence spatial distribution of herbs and woody seedlings (Beatty 1984). In the case of forest bred for timber production there is a loss of some natural habitats, which are replaced by a much larger open spaces created by man. We proved that ditches increase floristic diversity of managed forest complexes.

Tab. 1. Descriptive statistics for values of *HI* index counted for species richness (HI_N), Shannons (HI_H), evenness (HI_E), floristic value (HI_{FV}), floristic uniqueness (HI_{FU})

Indexes	Mean	Median	Min	Max	Q25	Q75	SD
drainage ditches							
HI_N	0,334	0,343	0,000	0,737	0,194	0,473	0,173
HI_H	0,185	0,129	-0,084	0,818	0,062	0,230	0,186
HI_E	0,049	0,010	-0,258	0,735	-0,046	0,088	0,199
HI_{FV}	0,381	0,397	0,000	0,767	0,227	0,520	0,190
HI_{FU}	0,083	0,086	-0,006	0,258	0,037	0,116	0,060
roadside ditches							
HI_N	0,449	0,500	0,071	0,700	0,357	0,542	0,149
HI_H	0,269	0,271	0,008	0,676	0,145	0,340	0,172
HI_E	0,085	0,050	-0,167	0,585	-0,019	0,145	0,180
HI_{FV}	0,506	0,542	0,105	0,752	0,399	0,611	0,157
HI_{FU}	0,113	0,132	-0,014	0,221	0,076	0,163	0,066
war trenches							
HI_N	0,147	0,139	0,000	0,417	0,000	0,188	0,154
HI_H	0,052	0,074	-0,136	0,149	0,067	0,081	0,097
HI_E	-0,016	0,018	-0,156	0,088	-0,132	0,068	0,103
HI_{FV}	0,154	0,138	0,000	0,453	0,000	0,196	0,167
HI_{FU}	0,011	0,005	-0,021	0,062	0,000	0,017	0,028

3.2. Different types of ditches are varied in their impact

Roadside ditches have the highest average values of all indicators, war trenches have the lowest ones (Fig. 3, Tab.1). The type of ditch significantly affects the values of HI_N (p=0,0012), HI_H (p=0,0136), HI_{FV} (p=0,0012), HI_{FU} (p=0,0027). There is no such effect on HI_E (p=0,4584). For each of the four indicators for which the type of ditch influence is significant war trenches differ above all from roadside ditches (HI_N: p=0,0018; HI_H: p=0,0206; HI_{FV}: p=0,0014; HI_{FU}: p=0,0019). The differences are also significant between roadside and drainage ditches for the index HI_N (p=0,0379) and between the war trenches and the drainage ditches for HI_{FU} (p=0,0266). For the latter index at $p<0.10$ all types of ditch differ significantly (Fig. 3, Tab. 1).

Among the three analyzed types of ditches the most different from the others are war trenches (Fig. 3). Flora of these ones almost do not differ from the flora of the forest most likely due to the fact that they are not related to the change in hydrological conditions. War trenches are located on the slopes of the

wooded dunes. Drainage ditches and ditches connected with roads allow the presence of species associated with moist habitats for example: *Carex acutiformis*, *Filipendula ulmaria*, *Galium palustre*, *Iris pseudacorus*, *Lycopus europaeus*, *Peucedanum palustre*, *Stellaria palustris*, *Thelypteris palustris*. The result consistent with the research carried out by other authors is that the roadside ditches reach the highest values for most of the analyzed indicators (Fig. 3, 5). These ditches are part of the road infrastructure. Baltzinger et al. (2011) who are taking into consideration different types of forest artefacts showed that road verges are the most original forest artefact type (in their research they found about 82% of species only on the plots located on the road verges in comparison with the forest control plots).

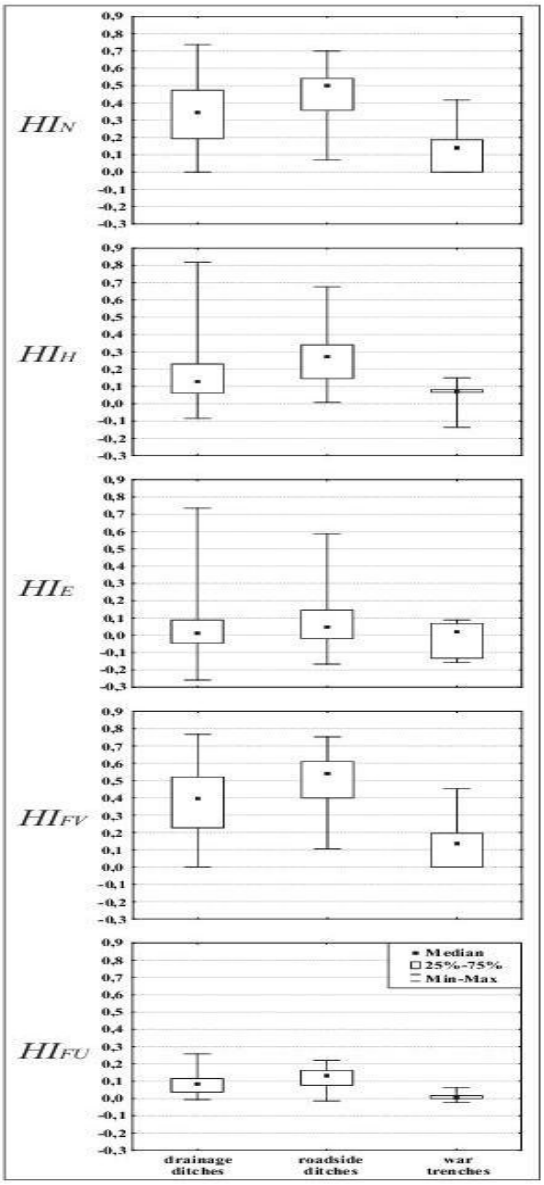

Fig. 3 Comparison of the different types of ditches on account of the index of habitat heterogeneity impact on the species richness (HI_N), on the diversity (HI_H), on the evenness (HI_E), on the floristic value (HI_{FV}) and on the floristic uniqueness (HI_{FU})

4. Conclusions

In case of necessity to assess the impact of concrete ditch or some other artefact on flora the usage of the habitat heterogeneity impact index can be valuable. The results obtained in this work showed that the presence of ditches most affects species richness and floristic value, and the least the evenness indexes. We estimated that on average the presence of drainage ditches in the surveyed areas of forest phytocenoses in central Poland had increased values of species richness of about 37%, Shannon's 23 %, evenness 6%, floristic value 41 %, floristic uniqueness 10 %. For roadside ditches these values were also increased respectively: 45%, 37%, 19%, 51%, 12%; as well as for war trenches: 13%, 6%, 1%, 14%, 2%. The calculation of habitat heterogeneity impact index showed significant differences between the individual ditches. Comparing the impact of different types of ditches on this index confirmed that roadside ditches have the biggest impact on the flora, and the war trenches the lowest.

The primary factor that differentiates the various ditches is the degree to which they create small-scale environmental heterogeneity. The smallest change is introduced by war trenches, which lay on the sand dunes in a fairly light pine forests and do not substantially alter the light or soil moisture conditions. While the drainage ditches which are wet in the spring and which are often only partially shaded by a canopy allow the existence of species preferring very different habitat conditions. The most important are roadside ditches, which always at least from the side of the road receive more light and are subjected to influx of propagules from outside the forest complex. Although the most important element that shapes the otherness of the ditch flora from the surrounding forest is the increased number of species and the fact that they are locally rare, the ditches are not found to be effective refugia for endangered species. Despite the presence of alien species in analyzed forest complexes ditches were not found to be particularly important for their migration also.

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