

# The influence of roads on the species diversity of forest vascular flora in Central Poland

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**Abstract:** The influence of the presence of roads on the diversity and degree of vascular flora synanthropization of *Quercus-Pinetum* phytocoenoses was the focus of the investigation. The role of road category was evaluated taking into account forest tracks, admitted only for forest administration, dirt roads admitted to traffic and tarmac roads. The research was carried out in the forests of Bolimów Landscape Park in the years 2000-2003. The linear transect method was applied. There were 105 transects, each comprised three research plots lying in various distances from the road. For each investigated plot a list of species together with their cover measure was made.

The significant influence of the presence of roads on the species diversity of the vascular flora of forest communities was proved. The increase in diversity of the areas located close to transport routes was an effect of greater richness, composed of locally rare species and to a lesser extent was the result of increase in variety of taxonomic and ecological features of species. The presence of roads was the cause of the simultaneous increase in the extent of synanthropization. It was observed that the road category is of significance to the degree of influence on the composition of forest flora. The most exploited roads contributed to the biggest changes in flora composition.

**Key words:** Central Poland, forests, roads, species diversity, synanthropization, vascular plants

## 1. Introduction

The change of environmental conditions may lead to either growth or reduction in the number of species and to changes in floral composition. Measurable assessment of species diversity involves the use of a range of numerical indexes including the most popular Shannon-Weaver index (Ulrich 2001). However, numerical indexes are not sufficient for the full description of species diversity. Particular species contribute to the diversity in a different way (Fabiszewski 1996). The species manifesting greater variation of their features form greater diversity. Ecological and morphological features and the taxonomic positions of the species should be taken into account. Regarding the description of species diversity at local scale, it is also useful to observe the local frequency of the species in the investigated area.

Sax & Gaines (2003) highlight the need for distinguishing between native and exotic diversity. Changes in diversity are occurring in two ways: changes in numbers of species, and the identity of those species

because of the loss of some species and the addition of the others (Thompson & Starzomski 2006). The concept of synanthropization of flora (Faliński 1972) taking into consideration the historical-geographical origin of species allows for the broad view of changes of flora diversity which are the result of human activity.

One of the factors relevant to synanthropization is transport, which involves the construction of road networks that enable the transportation of goods and people (Faliński 1972). Roads may lead to the fragmentation of forest complexes and enable plant migration (Kopecký 1978; Buckley *et al.* 2003), thus becoming one of the causes of the synanthropization of flora (Paszek & Załuski 2000; Jakubowska-Gabara & Zielińska 2003). Lugo & Gucinski (2000) treat roads as ecosystems and state that establishing a new road segment or road network in a landscape is equivalent to adding a new ecosystem to the existing one.

Nevertheless, the issue of the influence of roads on the diversity of forest flora has not been investigated thoroughly yet. The few publications on the subject are concerned first of all with the flora of phytocoenoses

on roadsides and forest roads (Faliński 1961; Hansen & Jensen 1972; Balcerkiewicz & Brzeg 1978, 1993; Brzeg 1981; Lausi & Nimis 1985; Herbich & Herbichowa 1987; Brandes 1988; Szwed & Sykora 1996; Paszek & Załuski 1998; Ulmann *et al.* 1990; Buckley *et al.* 2003), the phenomenon of trampling undergrowth (Faliński 1973; Guzikowa 1982) as well as with exotic plants invasions in roadside plant communities (Parendes & Jones 2000).

Increased humans' influence on the surrounding natural environment leads to rapid changes in the diversity of the native flora. It is necessary to intensify the research work on the diversity and synanthropization of flora and connections between them. The main goal of the present study is to assess the role of roads for the species diversity in forest landscapes of the Bolimów Forest in Central Poland. The focus of attention is vascular flora. Assuming that forest roads have an impact on floral compositions of forest phytocoenoses lying in the vicinity of roads and that the category of a road influences the intensity of changes, the following aims of the study were formulated: (i) evaluation of the floristic diversity of the examined areas; (ii) evaluation of the degree of synanthropization of the vascular flora of the examined areas; (iii) specification of the relationship between the type of a road and the diversity of the flora of forest phytocoenoses adjacent to the road.

## 2. Material and methods

### 2.1. The study area

The research work was conducted in the area of the Bolimów Forest in Central Poland (Fig. 1). The description of the Forest appears as early as in the 16<sup>th</sup>-century archives. The economic development of the area

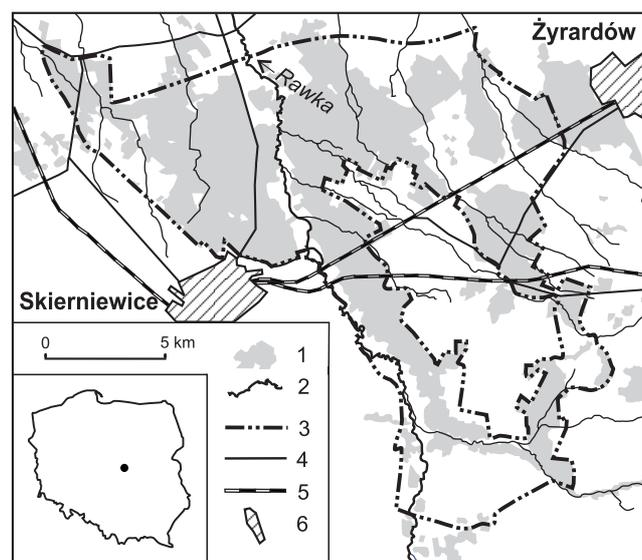


Fig. 1. The location of the study area

Explanations: 1 – forests, 2 – rivers, 3 – boundary of the Bolimów Landscape Park, 4 – main roads, 5 – railway, 6 – towns and larger villages

occurring at the expense of the loss of natural forest ecosystems was interrupted several times, especially by wars. However the forests were affected by different anthropogenic impacts (Olaczek 1999). In 1976 the Bolimów Forest became an area of protected landscape and in 1986 the Bolimów Landscape Park (BLP) was founded. Currently, after being expanded, the area of the Park covers 23130.11 ha. This form of protection led to the reduction of the unsustainable economic development. However transport routes, both railway and roads of different categories, go through the forest areas (Fig. 1). The majority of the roads form a regular network of forest tracks corresponding to the spatial division of the BLP into forest compartments.

The natural vegetation cover of the Mazowsze Region, where the Bolimów Landscape Park is located, is dominated by pine and mixed woods (Szafer 1977). In the area in question, fifteen forest associations and several subassociations were found (Olaczek 1972; Jakubowska-Gabara 1999). The present study concerns one of them which covers a relatively big area in BLP: *Quercus roboris-Pinetum*, the Mid-Polish pine-oak mixed wood.

The level of identification of the flora of the researched area is quite good. The floristic data concerning the area belonging to the BLP were collected among others by Jakubowska-Gabara *et al.* (2003). The flora of BLP is diverse, rich in rare, vanishing and endangered species and consists of 1049 taxa of vascular plants (Jakubowska-Gabara *et al.* 2003).

### 2.2. Methods

In the period of 2000-2003, 105 linear transects (Traczyk 1960; Faliński 2001) were delineated perpendicularly to the roads, each transect consisting

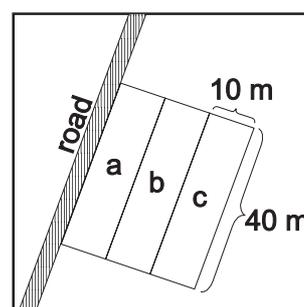


Fig. 2. The method of delineating a transect with reference to a model transport route

of three plots located at different distances from the road (Fig. 2). The plots of the transects were rectangles (10x40 m), labeled with the letters: a, b, c. The width of the plots was determined on the basis of preliminary field observations. The transects were delineated in the area of *Quercus-Pinetum* with the criteria of habitat

homogeneity and the age of tree stand over 60 years taken into account. They were located close to roads of different type: (i) forest tracks – dividing the forests into compartments and used only by forest administration, with the width of traffic surface 3-4 m (56 transects); (ii) dirt roads admitted to traffic and called forest roads in the present study with the width of 3-5 m (34 transects); (iii) tarmac roads with the width of approximately 6 m (15 transects).

A list of vascular plants with the degree of cover based on the 6-degree scale of Braun-Blanquet was compiled for each plot (Scamoni 1967).

The corrected Pearson coefficient  $C_{cor}$  was calculated in order to determine whether the species richness (number of species) in particular plots is correlated with the distance of the plot from the road and if there is a correlation between the richness and the category of a road.

For each species an average of the degrees of cover observed in all plots “a”, “b” and “c” within a given category of transects was calculated, for the class “+” in the scale of Braun-Blanquet the value of 0.5 was taken into consideration.

The diversity of flora of the plots was estimated with the use of numerical indexes: Schannon-Weaver index  $H'$  with evenness index  $E$  (Ulrich 2001). The taxonomical diversity index was calculated by assigning ranks to particular units of the taxonomical system:  $Z_s =$  the number of species + 5 × the number of genera + 25 × the number of families (Olaczek, personal communication).

Also the index of rarity  $W_r$  was estimated for each species:

$$W_r = \frac{N - n}{N},$$

where:  $N$  – the total number of plots,  $n$  – the number of plots where the species appears. The index was used for further calculations of floristic value ( $W_f$ ) and floristic uniqueness ( $O_f$ ) of the plot indexes:

$$W_f = \sum W_r ; W_f = \frac{W_r}{l},$$

where  $l$  is the number of species found in the plot (Géhu 1979 after Loster 1985). 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 takes the mean value of the rarity of species into consideration.

For more thorough research into species diversity, the analysis of the ecological features of species was carried out. The species were classified in terms of life forms in the sense of Raunkiaer (1934), ecological values proposed by Ellenberg *et al.* (1992) and Zarzycki *et al.* (2002) and on the basis of their position in the classes of syntaxonomic system of Matuszkiewicz (2001).

The statistical tests of significance for the differences between the mean values of the numerical indexes calculated for plots located close to roads and plots in the forest were conducted. The probability of 99% was adopted (Stanisz 2006).

In order to estimate the degree of synanthropization of flora, the classifications of species into geographical and historical groups was conducted. Spontaneophytes, i.e. native species characteristic of the forest flora, and synanthropic species were distinguished. Synanthropic species were divided into apophytes, i.e. native but non-forest species, occurring in the habitats transformed as a result of human activity, and anthropophytes, i.e. species of foreign origin which were brought or came in pre- and early-historic times (archaeophytes) or in modern times (kenophytes) and were cultivated (diaphytes). The classification of the identified species into geographical and historical groups was conducted following Jackowiak (1990), Kornaś (1968), Zając *et al.* (1998). The degree of flora synanthropization was calculated on the basis of the index of total synanthropization  $W_t$  (Jackowiak 1990):

$$W_t = \frac{Ap + An}{N} \cdot 100\%$$

where:  $Ap$  – the number of apophytes,  $An$  – the number of anthropophytes,  $N$  – total number of species.

### 3. Results

#### 3.1. The species diversity

The total number of the observed species is 309 and a large part of this number was found in plots “a”. The total species richness of plots “a” is 300 whereas only 123 and 109 species were found in plots “b” and “c”, respectively.

There is a strong correlation between the species richness and the distance of the plot from a road (Fig. 3). The corrected Pearson coefficient ( $C_{cor}$ ) calculated for the

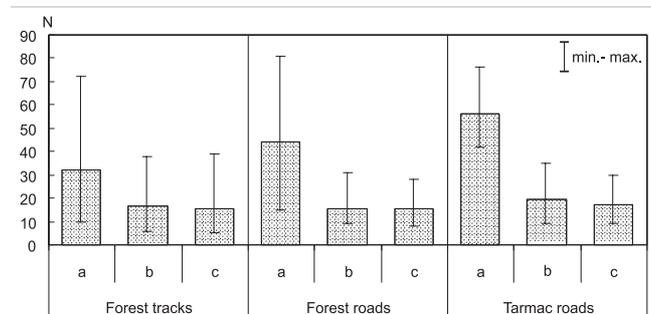


Fig. 3. Mean numbers of species found in the investigated plots

average number of species in plots “a” and “c” is 0.84. This correlation is strongest for the tarmac roads where the minimum number of species in plots lying close to a road is larger than the maximum number in plots “c”.

$C_{cor}$  equals 0.85 for the transects delineated near forest roads and 0.78 for forest tracks. As illustrated above, the road category has a large impact on the vascular plant richness. It is confirmed by the correlation coefficient calculated for the mean numbers of species found in plots „a” and the road category:  $C_{cor} = 0.52$ .

means that in the area under analysis the locally rare species dominate. A large part of these species (172) was found only in plots “a”, 88 of which were noted only once or twice. The mean floristic value of the plot index ( $W_j$ ) is statistically greater for the plots situated close to roads in comparison with the plots lying deeper

**Table 1.** Mean values of numerical indexes calculated for particular plots

Index	Forest tracks			Forest roads			Tarmac roads		
	a	b	c	a	b	c	a	b	c
H	2.45	1.97	1.94	2.65	1.90	1.85	3.19	2.02	1.86
E	0.72	0.72	0.72	0.73	0.72	0.71	0.79	0.69	0.66
Zs	637	392	378	783	371	370	939	425	406
Wf	20.91	7.52	6.96	31.67	6.77	6.44	42.93	9.92	7.92
Of	0.61	0.42	0.40	0.68	0.40	0.39	0.76	0.46	0.42

Regarding the mean values of the Shannon-Weaver index for plots “a”, “b” and “c”, the flora of the plots situated close to roads is statistically more diverse (Table 2). Plots “b” and “c” do not exhibit significant differences. The index of evenness ( $E$ ) for the majority of the investigated plots reaches fairly high values, which indicates an even structure of species dominance (Table 1). The mean values are statistically greater for the plots delineated close to tarmac roads only.

in the forest. Also, the mean floristic uniqueness index ( $O_j$ ) values are statistically greater in plots “a”. The mean values of the floristic value and floristic uniqueness indexes for plots “b” and “c” do not demonstrate significant differences (Table 1).

In plots “a” not only is there a bigger number of species locally rare but also 8 species precious in the scale of the country were found. These are species (strictly or partially) protected by the law according to

**Table 2.** The number (N) and participation (%) of species indicating different features of environment

Indicators	Forest tracks						Forest roads						Tarmac roads					
	a		b		c		a		b		c		a		b		c	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Strong irradiance intensity	48	23.5	13	13.5	11	12.4	47	21.2	7	11.3	6	10.0	44	22.9	11	14.7	4	7.1
Weak irradiance intensity	23	12.8	16	16.6	18	19.9	25	12.7	9	13.6	8	12.5	21	12.3	16	20.3	16	27.1
Warm climate	4	2.0	1	1.0	1	1.1	5	2.3	1	1.6	0	0	5	2.6	0	0	0	0
Cool climate	6	3.0	3	3.1	3	3.4	3	1.4	3	4.8	2	3.3	1	0.5	1	1.3	1	1.8
Continental climate	1	0.5	1	1.0	1	1.1	0	0	0	0	0	0	1	0.5	1	1.3	0	0
Oceanic climate	10	4.9	8	8.3	6	6.7	8	3.6	5	8.1	5	8.3	4	2.1	3	4.0	5	8.9
Moist soils	30	14.7	12	12.5	10	11.2	37	16.7	10	16.1	8	13.3	26	13.5	4	5.3	5	8.9
Dry soils	14	7.4	5	5.2	3	3.3	13	6.4	2	2.9	2	3.1	13	7.2	2	2.6	1	1.7
Acid soil	31	15.2	18	18.8	17	19.1	30	13.5	17	27.4	16	26.7	20	10.4	14	18.7	12	21.4
Neutral soil and alkaline soil	40	21.3	10	10.3	11	12.1	49	23.8	5	6.9	5	7.1	49	26.9	11	13.8	5	7.6
Soil with a large amount of nitrogen	33	16.2	6	6.3	6	6.7	47	21.2	3	4.8	3	5.0	40	20.8	8	10.7	7	12.5
Soil with a small amount of nitrogen	65	34.7	39	40.5	34	37.9	54	27.5	22	34.5	23	37.1	48	27.8	19	24.5	16	26.0

In terms of statistics the mean values of taxonomic diversity index ( $Z_j$ ) are vitally greater for the plots lying close to roads. The values do not differ significantly between plots “b” and “c”. There is a clear relationship between the taxonomic diversity and the road category. The mean value of  $Z_j$  calculated for plots “a” is greatest for tarmac roads (Table 1).

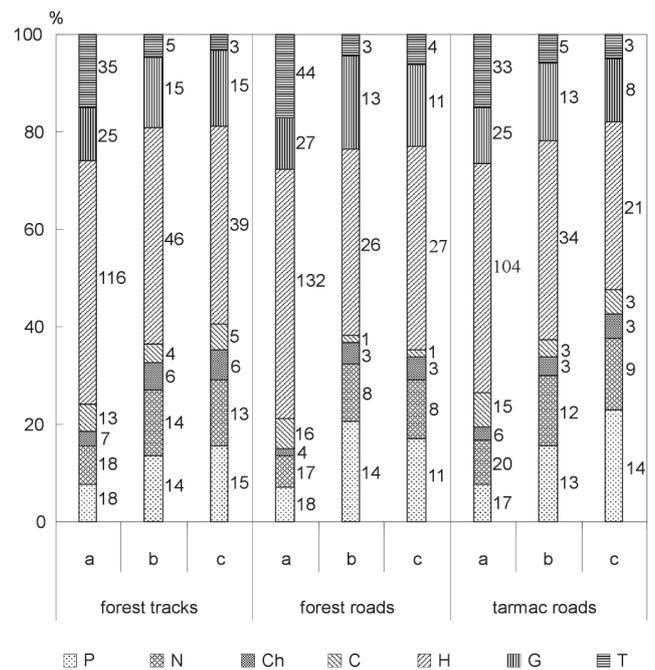
The great majority of species (257) is characterized by a very high rarity index:  $Wr$  from 0.9 to 0.99. This

the Regulation of the Minister of Environment of 09 July 2004 and the species from the ‘red list’ of endangered and rare species (Zarzycki *et al.* 2002). This group includes, among others, *Cnidium dubium* (Schkuhr) Thell., *Lycopodium annotinum* L., *Lycopodium clavatum* L., *Polypodium vulgare* L. In the plots “b” and “c” 5 such species were found.

Considering the life forms they are not more numerous on the plots located close to roads. The important thing

is that in plots “a” there is a different percentage share of particular life forms in comparison with plots “b” and “c” (Fig. 4). The presence of roads has a considerable impact on the number of plant species indicating different features of the environment. An interesting observation that has been made is that the largest number of species characteristic of the opposite features of the environment appears in plots “a” (Table 2). The species indicating strong irradiance intensity as well as those indicating weak irradiance intensity are represented by the greatest number of species. The same pattern can be observed in the case of plants characteristic of dry soils and those preferring moist soils as well as in the case of plants indicating neutral or alkaline soil and those indicating soil acidification. Considering the species typical of soils rich in available nitrogen and of poor soils, their number is larger near roads too. A larger number of indicator species in plots “a” does not always lead to their greater percentage share (Table 2).

To give a proper consideration to the ecological characteristics of the species we should take into account their interactions not only with abiotic factors but also with biotic components of the site. To some degree it is possible due to an analysis of positions of species in the syntaxonomical system. The flora of plots “a” is characterized by a very wide variety of syntaxonomical classes represented by particular species. In the plots close to roads, 18 different phytosociological units at



**Fig. 4.** The percentage and the number of species assigned to various life forms according to Raunkiaer  
 Explanations: P – phanerophytes, N – nanophanerophytes, Ch – arborescent chamaephytes, C – herbaceous chamaephytes, H – hemicryptophytes, G – geophytes, T – therophytes

the level of class representatives were found. In the forest there were 13 classes found (Table 3). There is a greater number of species characteristic of non-forest

**Table 3.** The number of species characteristic of the classes of plant communities

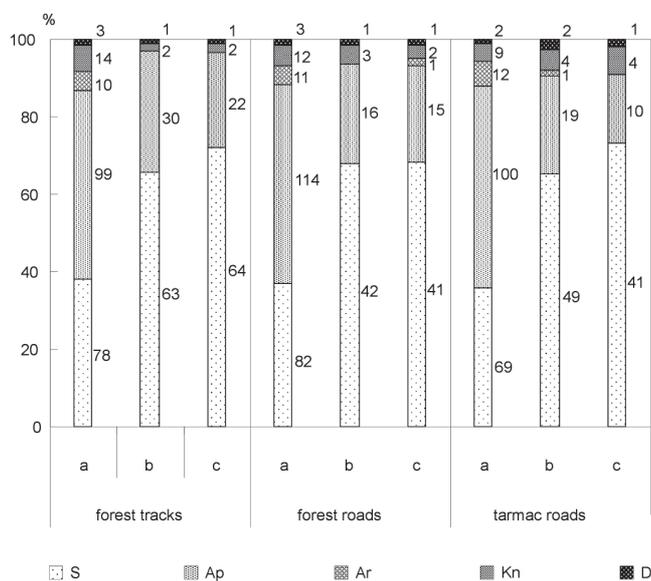
Classes of communities	Forest tracks			Forest roads			Tarmac roads		
	a	b	c	a	b	c	a	b	c
<i>Quercus-Fagetea</i>	18	15	17	19	6	6	19	14	11
<i>Vaccinio-Piceetea</i>	8	7	7	6	5	5	6	5	6
<i>Molinio-Arrhenatheretea</i>	35	6	8	39	5	3	35	6	2
<i>Nardo-Callunetea</i>	14	11	9	12	7	7	11	8	5
<i>Epilobietea angustifolii</i>	6	4	3	5	1	1	6	4	1
<i>Koelerio glaucae-Corynephoretea canescentis</i>	9	3	3	10	2	2	7	2	1
<i>Trifolio-Geranietea sanguinei</i>	6	3	2	5	2	3	7	3	2
<i>Rhamno-Prunetea</i>	4	2	2	4	0	0	5	1	1
<i>Quercetea robori-petreae</i>	3	1	2	2	1	1	1	1	2
<i>Artemisietea vulgaris</i>	12	0	0	25	0	0	17	2	1
<i>Stellarietea mediae</i>	13	1	0	15	0	1	13	2	0
<i>Alnetea glutinosae</i>	2	1	0	3	1	1	3	0	0
<i>Phragmitetea</i>	4	0	0	4	0	0	4	0	0
<i>Agropyretea intermedio-repentis</i>	4	1	0	3	0	0	4	0	0
<i>Scheuchzerio-Caricetea nigrae</i>	2	1	0	3	1	1	1	0	0
<i>Salicetea purpureae</i>	0	0	0	2	0	0	3	0	0
<i>Bidentetea tripartiti</i>	3	0	0	2	0	0	0	0	0
<i>Asplenieta rupestris</i>	1	0	1	1	0	0	0	0	0
<i>Isoeto-Nanojuncetea</i>	2	0	0	0	0	0	0	0	0
<i>Festuco-Brometea</i>	0	0	0	0	0	0	1	0	0
Others	58	40	35	62	31	29	49	27	24
Total:	140	56	53	157	31	31	142	48	32



classes, like *Artemisietea vulgaris*, *Molinio-Arrhenatheretea* and *Stellarietea mediae*, in plots situated in the immediate vicinity of roads. Nevertheless, there is a greater number of species characteristic of the forest classes. The category of a road has no great significance for the syntaxonomic diversity of flora.

### 3.2. Synanthropization of the flora

Spontaneophytes have the greatest share only in the plots lying deeper in the forest (Fig. 5). In the case of the plots situated in the vicinity of roads apophytes are a predominant group of plants. The percentage share of anthropophytes is larger in plots "a" in comparison with plots "b" and "c". Anthropophytes (archaeophytes, kenophytes, and diaphytes) constitute from 3 to 9% of species noted in plots "b" and "c" and from 12 to 13% in plots "a" (Fig. 5).



**Fig. 5.** The percentage and the number of species representing different geographical-historical groups in the plots "a", "b" and "c"  
 Explanations: S – spontaneophytes, Ap – apophytes, Ar – archaeophytes, Kn – kenophytes, D – diaphytes

The value of a total synanthropization index is greatest for tarmac roads, smaller for the plots lying in the vicinity of forest roads and smallest for forest tracks (Table 4).

**Table 4.** The values of the index of total synanthropization [%]

Road category	Plots		
	a	b	c
Forest tracks	61.8	34.4	28.1
Forest roads	63.1	32.3	31.7
Tarmac roads	64.1	34.7	26.8

## 4. Discussion

The diversity of vascular plant species is significantly greater on the plots lying close to roads in comparison with the plots lying deeper in the forest. The mean species richness is about two or three times as large there (Fig. 3). In the plots lying close to the roads the taxonomic diversity is greater too (Table 1). Moreover, the Shannon-Weaver index is significantly greater (Table 1). The index of evenness does not identify such great differences between plots "a", and plots "b" and "c" as the Shannon-Weaver index. It means that the reason for the higher species diversity in the "a" plots is significantly larger number of species, not the species evenness.

A very important aspect of the evaluation of diversity is estimation of the flora from the point of view of local rarity of species. A large share of 34 % of the species noted on the plots "a" was found only once or twice. The values of floristic value and the floristic uniqueness indexes are significantly greater for the areas close to roads (Table 1). It means that the "a" plots are characterised not only by a greater number of species, but also by greater local rarity of species.

The evaluation of species diversity from the point of view of their ecological features demonstrates the importance of the presence of roads as well. There is no greater number of life forms represented in the plots "a" (Fig. 4). However the number of plants indicating the extreme features of environment is greater for the areas close to the roads (Table 2). The larger ecological variety of noted plants is to a large extent proved by the analysis of their syntaxonomical features (Table 3).

The qualitative and quantitative analysis of flora shows the important role of roads for the vascular plant species diversity. The increase in diversity is, first of all, an effect of greater richness, composed of locally rare species. To a lesser extent it is an effect of increase in variety of taxonomic and ecological features of species.

The main factor stimulating the greatest diversity of flora along the roads is creation of new sites with new environmental conditions. Species indicating strong irradiance intensity, warm climate, moist soils, dry soils, neutral and alkaline soils and soils rich in available nitrogen have a greater share in the "a" plots than in "b" or "c" ones for each category of transects. The roadsides can provide a great variety of sites depending on their width and geomorphology. In particular, drainage ditches along roads can enable existence of plants characteristic of moist sites, on the bottom of a ditch, and those typical of dry sites on the banks. This is a reason for the occurrence of species representing a great variety of features in the small area of the roadside. Buckley *et al.* (2003) state that creation of skid trails and haul roads in managed forests in Upper Michigan

(USA) introduces novel combinations of microsite conditions unique to forest ecosystems. They also observed the greater plant species richness as the effect of the microsite diversity contributed by haul roads and skid trails.

The new sites are a factor facilitating the occurrence of anthropophytes and apophytes. In this study these plants constitute 88% of species noted only in the plots lying near the roads. Thus, the majority of the species contributing to a greater species richness of plots "a" involves the species connected with the activity of man. The greater diversity seems to be an effect of synanthropization of flora.

Roads as linear disarrangements in the forest landscape can be tracks for migration of foreign species. Radkowsch (2003), who analyses the migration of *Senecio inaequidens* and *Dittrichia graveolens*, invasive neophytic plants in Germany, observes the linear migration of these species along the roads and railways. She draws a conclusion that roadsides and central strips of the motorways represent a vast integrated system of biotops of immigration tracks (Radkowsch 2003). The present study demonstrates that the small forest roads can play a similar role. The results are in accordance with the findings of other researchers. Paszek & Załuski (2000) argue that forest roads cause synanthropization at the landscape, vegetation, flora and population level in the Górzno-Lidzbark Landscape Park situated in north-eastern Poland. In the analysis of habitat preferences of some alien plants, Tokarska-Guzik (2003) ascertains that roadsides are one of habitats frequently penetrated by kenophytes. Other authors also confirm that there is a relationship between the presence of roads and occurrence of synanthropic plants (Greenberg *et al.* 1997, Adamowski *et al.* 1998; Faliński 1998; Jakubowska-Gabara & Zielińska 2003; Kopała & Woźniak 2003; Załuski & Paszek 2003). The migration along roads can be the first step in the process of colonisation of forest communities by alien plants. This pattern was found for *Impatiens parviflora* in Białowieża Forest by Kujawa-Pawlaczyk (1991).

The possibility of a species to move along roads can result from the ecological similarity of habitats of roads and of their roadsides over a vast area. Roads as habitats have a lot in common despite differentiation depending on neighbouring associations of plants (Faliński 1961). This suggests that they can play the role of an ecological corridor. The linear system of vegetation can be a way of migration for one species, a refugium for the others and a barrier for yet another, depending on the requirements of a particular species (Liro & Szacki 1993). Roads can act as a kind of a selective filter that enables migration of one species and limits the spread of others (Forman 1995; Lugo & Gucinski 2000).

The present study does not demonstrate any negative effect of the presence of roads on the occurrence of spontaneophytes, protected, rare or endangered species.

The human activity causes merely an increase in the number of species, with no loss of native species. Peterken & Francis (1999) emphasise the importance of open space habitats, among others of rides, in the woods for the preservation of a number of valuable species. Intensive forest management can be the reason for uniformity of sites because of the damage of microhabitats like the holes after fallen trees, the small indentations etc. The roadsides are the source of habitat differentiation of the area. However Sax & Gaines (2003) state that increases in species diversity at local scales cannot be assumed to be beneficial to community or ecosystem functioning. Such increase could cause unknown and quite possibly detrimental effects. Diversity is one of the determinants of ecosystem structure and dynamics (Tilman 1999) and it is diversity composed of autochtonic elements of flora that should be protected, not diversity per se.

The analysis of results obtained for different categories of roads indicates that there is an important relationship between the degree of floral transformations and the type of the road. The greatest diversity and the greatest degree of synanthropization was observed near the tarmac roads; the smallest near forest tracks. The latter are seldom used roads, admitted only for forest administration. Forest roads are similar in width but more frequently used because the public traffic is allowed there. This is a sufficient factor for causing greater synanthropization of flora. Tarmac roads are the most frequently used and the widest of the analysed roads. The change of flora is the greatest close to these roads and reaches deeper into the forest. The analysis of ecological characteristics of species noted in the particular plots of transects in this category of roads produces different results for the plots "b" and "c". There are more light loving plants and more species indicating neutral and alkaline soils in the plots "b". The influence of different intensity and time of using the trail on species composition and richness and diversity of the vegetation on a road and roadsides was demonstrated also by Witkowska-Żuk & Andrzejewski (2002).

For the protection of plant diversity it is important to extend the knowledge about the process of synanthropization. The analysis of diversity should always be accompanied by an analysis of the degree of synanthropization of flora. It is of special importance to protect natural plant diversity of particularly valuable areas under legal protection, such as reserves, national and landscape parks. Olaczek (1998) argues that roads are one of the factors making such areas accessible for anthropophytes and apophytes. For the protection of forest diversity it is important to restrict establishment of new roads and restrict road traffic on those existing ones. Simultaneously, it is vital to avoid destruction of natural forest microhabitats.

## 5. Conclusions

1. The presence of roads lead to significant increase in the diversity of forest flora. The increase in diversity of the areas located close to transport routes is, first of all, an effect of greater richness, composed of locally rare species. To a lesser extent it is an effect of increase in variety of taxonomic and ecological features of species.
2. In the immediate vicinity of roads a significant increase of the degree of flora synanthropization can be observed.
3. The category of road plays an important role in the intensity of its influence on the composition of forest flora. The greatest changes in the floristic composition are caused by the presence of the most frequently used roads.
4. For the protection of forest flora diversity it is important to restrict establishment of new roads and restrict road traffic on those already existing with simultaneous protection of natural differentiation of forest habitats.

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