WPŁYW ZRÓŻNICOWANIA KRAJOBRAZU ROLNICZEGO NA ZGRUPOWANIE PSZCZÓŁ

THE EFFECT OF A DIFFERENTIATION OF AGRICULTURAL LANDSCAPE ON *APOIDEA* COMMUNITIES

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INTRODUCTION

Due to human economic activity most of the Earth's ecological systems were changed. Depletion of natural resources and degradation of environment enforce the necessity for planned management of the areas intensly used by people which would be based on knowledge of the ecological laws governing functioning of ecosystems on large area — landscapes (physiocenoses).

One of the pioneeros of landscape approach in ecological research and nature conservation was Professor Adam Wodziczko. He distinguished an overecosystem unit of biosphere organization — physiocenosis and defined it as a selfregulatory unit of the higher order whose all components are bonded by mutual relations and influences (Wodziczko 1946, 1948-49).

Today landscape ecology deals with investigating ecological phenomena and processes on the level of a landscape. This science defines the landscape as an ecological system hierarchitically higher than ecosystem, i.e. this is a fragment of the Earth's area composed of regularly repeating in space group of given ecosystems which influence each other (Forman, Godron 1986).

The theoretical concept behind landscape research is an asumption that landscape being a higher than ecosystem level of life organization determines the processes of energy and matter flow between ecosystems (Forman, Godron 1986, Andrzejewski 1983).

A significant branch of landscape investigations constitutes research into the landscapes strongly changed by human activity particularly concerning agricultural ones.

Recently the structure of agricultural landscape has been considered mostly as a system of patches, corridors and barriers constitute ecological network on the matrix of

arable fields (Forman, Godron 1986). The area, shape, distribution, age and level of disturbance of each environmental patch and ecological corridors have the basic importance for many animal groups of the agricultural landscape. Therefore zoological research in the landscape focuses on explanation of zoocenological phenomena related to the physiocenosis structure.

The earliest research of this kind was carried out on birds and mammals. At present the studies concentrate on functional analysis of the landscape elements which are refuge habitats for fauna (forests, shelterbelts, hedges). The effect of the size, age, plant composition, disturbance regime and isolation of each element on population is analysed (Gromadzki 1970, Forman et al. 1976, Hooper 1976, Stenseth 1977, Burgess, Sharpe 1981, Mader 1984, Opdam et al. 1985, Opdam 1987, Johnson, Beck 1988).

In the ecological studies of agricultural landscapes insects have an important position since due to their large biotic potential they can and usually do affect significantly the yield of crops. Recognition of the mechanisms and relations governing developement of species belonging to this group of animal in different landscape types and elements has not only cognitive meaning but, first of all, practical one. Hence there is rich literature analysing dependencies between various elements of agricultural landscape and selected groups or species of insects (Lewis 1969 a, 1969 b, Den Boer 1970, Tischler 1975, Brunels, Cancela da Fonseca 1979, Dąbrowska-Prot 1980, Stenseth 1981, Bowden, Dean 1977, Ranta, As 1982, Banaszak 1983, Dix, Leatherman 1988, Pasek 1988, Karg 1989).

The research on landscape level are also carried out on bees *(Apoidea)*. The meaning of this group cannot be overestimated, it would be enough to quote historical problems of New Zealand settlers with clover cultivation on the areas with no bumblebees, or spectacular successes of American farmers in production of alfalfa for seed based on bred Megachile rotundata (F.) (Bohart 1962).

The studies on *Apoidea* ecology in agricultural landscape started in the early 1980s by Banaszak proved that presence of refuge habitats in the agricultural landscape is significant for survival and developement of this group of insects. These habitats include permanent landscape elements — forests, xerotermic swards being enclaves of potential fauna and providing fauna to less permanent but also functioning as refuge shelterbelts and roadsides (Banaszak 1983). It was also found that mosaic structure of agricultural landscape compensates reducing effect of farming on the populations of wild *Apoidea* (Banaszak 1983, 1986, Pawlikowski 1989).

From the statement of significant role of forest, shelterbelts and roadsides in maintaining richness and variability of *Apoidea* in agricultural landscape results the following question: what features of these habitats and how decide about their importance as refuge and developement habitats for *Apoidea* communities? The goal of this work is an attempt at finding the answer to this question and determination on the example of two types of agricultural landscape of total natural resources of *Apoidea* in these kinds of physiocenoses.

TERRAIN

The research was carried out in typically agricultural landscape on two study areas 875 ha each near the villages Turew and Szołdry (about 40 km south of Poznań).

The terrain is located on the Kościan Plains being a part of the Leszno Lake District (Kondracki 1977). It consist of moraine upland cut by systems of lakeless glacial gullies. The changes in terrain level do not exceed 30 m. Hydrographic network is poor. Besides the greatest water—cours — the Wyskoć Gully there are melioration ditches and field water holes. The terrain soils were made of boulder formations of ground moraine. The parental rock were mostly light boulder clays with different degree of sand on the surface. Podzolic soils predominate with small areas of brown soils and only in depressions bog black earths and silt—peat soils can be found (Margowski 1972).

The area has one of the lowest rainfalls in Poland (below 500 mm/year). The vegetation season is about 225 days. Yearly amplitude does not exceed 20°C (July — 17.5°C, January — 2.4°C) (Woś 1970).

The potential natural vegetation on the area constitute forests growing on dry ground (Wojterski et al. 1981). Strong anthropogenic pression working here since 12th century is responsible for the fact that actual growth of vegetation consits mostly of synantropic—segetal and ruderal communities. The phitocenoses most resembling the natural ones can be alder grooves along the water—courses and water and bushes communities (Ratyńska 1990).

On the determined study areas farming was of similar character, rather intensive. The most of the cultivated area is under cereals (about 50 %), about 20 % occupy root crops. There is quite large proportion of fore— and aftercrops and alfalfa.

The percentage of arable fields, meadows and grasslands and other elements of landscape as well as their distribution clearly differentiated both areas (Table 1, Figure 1) and constituted the basis for discrimination of two types of agricultural landscape. In the first type — the landscape of complex structure (vicinity of Turew) — arable fields with the area up to 50 ha were separated by different refuge habitats of fauna with an average area of 4.85. These included roads with wide roadsides, fruit tree alleys, woodlots and shelterbelts and mid—field forests. These elements constituted 18 % of the studied area. The other landscape type — a more simplified one (vicinity of Szołdry) — was more homogenous. The refuge habitats with an average area of 1.08 ha constituted only 2.9 % of the landscape and were scattered among large arable fields not smaller than 60 ha.

The structural differences between these areas result besides natural conditions, from the work of D. Chłapowski who in the 19th century introduced numerous woodlots and shelterbelts near Turew to separate the fields (Chłapowski 1835).

Table 1. Characteristic of two investigated types of agricultural landscape. A — complex landsca (875 ha, Turew), B — simplified landscape (875 ha, Szołdry)

landscape element	total	area	(ha)		average area	(ha)	number of landscape elements	
	A	%	B	%	A	B	A	B
roadsides — width 0.5 m	—	—	0.12	0.01	—	0.12	—	1
roadsides — width 1 m	0.27	0.03	1.10	0.13	0.27	0.27	1	4
roadsides — width 3—4 m	2.46	0.28	5.49	0.63	0.75	0.91	2	6
roadsides — width 5—7 m	6.70	0.77	5.35	0.61	1.67	1.78	4	3
shelterbelts	5.10	0.58	0.92	0.11	5.10	0.46	1	2
woodlots	17.28	1.97	0.32	0.04	2.16	0.16	8	2
mid—field forests	26.74	3.06	—	—	13.37	—	2	0
parks	1.50	0.17	3.80	0.46	1.50	3.80	1	1
meadows	78.35	8.95	—	—	19.58	—	4	—
buildings and ruderal habitats	19.04	2.18	8.03	0.92	3.23	1.15	6	7
total	157.40	18.00	25.10	2.88	x = 4.8	x = 1.1	29	26

Figure 1. Terrain of investigation. A — complex landscape, B — simplified landscape

METHODS

In the both investigated landscapes 13 refuge habitats of bee fauna were selected from among the most typical (the most frequently encountered) ones. These included: roadsides (0.5 − 7 m wide, 7 stands), woodlots (2 stands), shelterbelts (2 stands) and mid−field forests (2 stands). Additionaly the studies were carried out on rapeseed and alfalfa crops in both landscape types. In the years 1987−1990 from April to September quantitative samples were taken at two−three weeks intervals. The quantitative samples were taken with the belt method according to Banaszak (1980). The method consists in counting and catching insects from 200 m long belt 1 m wide. The samples are collected in similar weather conditions on sunny, windless day at temperature over 20°C. From the sites a total of 936 samples was taken.

To evaluate *Apoidea* communities of the studied biotopes the following coefficients were used:

− density defined as a number of individuals of a species on 1 ha

− Shannon− Weaver's coefficient of species diversity (Shannon, Weaver 1963)

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

were p_i is a proportion between a mean number of individuals of the i−th species and a sum of a mean number of individuals of all species found in a community. The value of H' increases when the number of species in the community rises and their proportion becomes more even.

During sampling the plant species visited by bees were noted which facilitated determination of an average (mean number of species in a sample) and total number of species of food plants for *Apoidea* in this habitat.

Also the percentage of covering the plot by nectar plants was estimated using the Braun−Blanquet's method (1964).

Besides the total area of each studied environment, so called, feeding area was calculated which is the area of a given refuge habitat taken by communities of food plants.

In the studied refuge habitats the kind of anthropogenic disturbances was noted. The disturbances here are understood as considerable and usually sudden changes of ecological conditions caused by human farming activity. Outside the habitats the disturbances were also noted by means of checking once every month 10 km of roadsides in each landscape types − 8 sections 2.5 km each representing the roadsides 0.5 − 5 m wide and all shelterbelts and woodlots occuring in the landscape.

To determine the landscape structure a set aerial pictures 1: 10000 taken in April 1988 by Aerial Photo Centre was used. Basing on these pictures the following parametres were calculated:

— area of each landscape elements

— isolation of the studied refuge habitats (King 1968 after Forman, Godron 1986)

$$r_i = \frac{1}{n} \sum_{i=1}^{j=n} d_{ij}$$

where n is a number of neighbouring refuges for the i—th habitat, d_{ij} is a distance between the i—th refuge and a given neighbouring refuge j.

The problem of calculating the area of roadsides requires additional description. Analysing the effect of refuge area on *Apoidea* communities it would be unjustified to compare the roadside area calculated for stretch several kilometers long with the area of a point habitat. Hence a separate rule for calculating roadside area was assumed for zoocenological analyses. Basing on the assumption that most of *Apoidea* species do not fly more than 500 m and the character of roadside on this distance did not change the roadside lenght was determined to be extending the sampling site by 500 m in each direction.

To determine translocation of some bumblebee species among different landscape elements colour marking of individuals was applied. The method dealt with applying quicly drying lacquer (red, blue) on thorax of a bumblebee sitting on a flower. The marking stability was estimated to be 7 days (maximally 14 days).

The linear dimensions of landscape elements were read from the pictures with the accuracy of 1 m.

Computer program Statgrafics was used for all normall distribution tests, analyses of variances, and multiple regressions. Independent variables were combined in multiple regression analyses (stepwise variable selection) to determine which variables explained the most variation in animal densities and diversities.

RESULTS

Characteristics of *Apoidea* communities in the typical refuge habitats of agricultural landscape

Roadsides

The studies included 6 types of roadsides and railway embankment (Tab. 2). In the roadsides a total of 50 *Apoidea* species was found (Tab. 5) which constitute 74.6 % of the whole bee fauna observed in both landscape types. The density in each roadside ranged from 21.1 ind./ha to 812.9 ind./ha and was determined mostly by bumblebees and *Apis mellifera L.* These species accounted for from 51.5 % (road IV) to 98.1 % (road III) of the community. Such a dominance of several species (and often of only *Apis mellifera L.*) made the diversity coefficient H' rather low ranging from 0.21 to 1.94.

Table 2. Comparison of *Apoidea* density and diversity in the studied roadsides. (A — with *Apis mellifera L.*, B — only wild bess)

roadsides	width of roadsides (m)	number of food plant species	mean cover by food plants (%)	mean density of *Apoidea* (ind./ha)		H'		number of bee species
				A	B	A	B	
roadside of the track	7	26	40	812.9	702.5	1.94	1.80	34
dirt road I	6	18	55	312.3	240.1	1.55	1.64	17
dirt road II	5	29	30	691.7	287.1	1.57	1.46	15
cherry— —tree alley	4	10	15	330.8	168.3	1.39	1.52	11
highway	3.5	21	15	257.7	88.2	1.10	1.36	18
dirt road III	1	11	30	759.9	81.8	0.64	1.26	14
dirt road IV	0.5	7	5	21.1	10.0	0.21	0.21	3

The richest *Apoidea* community was found on the railway embankment with 34 species of bees and mean density of 812.9 ind./ha. This allows comparison between this habitat and open natural habitats in the Wielkopolski National Park (Banaszak 1983) or xerothermic swards of Toruń Valley (Pawlikowski 1985).

With narrowing the roadsides both diversity and density of wild bees decreased even to the value 10 ind./ha in case of the narrowest of the studied ones (0.5 m). These great differences in diversity and density resulted mostly from varied food basis on each roadside and considerable intensification of anthropogenic disturbances.

It was found that wide roadsides (4—7 m) had much richer phytocenoses thus creating richer and, what is more important, continous food source (Tab. 2). On narrow roadsides often no flowering plants attractive for *Apoidea* were found. The spectrum of flowering of the food plants from the roadsides with maximal and minimal width is given in Tables 3 and 4.

Table 3. Flowering spectrum of plants visited by bees on the roadside of the track. (Data from 1987–1990)

plant species	IV 1	IV 2	IV 3	V 1	V 2	V 3	VI 1	VI 2	VI 3	VII 1	VII 2	VII 3	VIII 1	VIII 2	VIII 3	IX 1	IX 2	IX 3
Taraxacum officinale Web.		+	+	+	+													
Capsella bursa-pastoris L.			+	+	+													
Cerastium arvense L.				+	+													
Ranunculus acer L.				+	+	+												
Veronica chamaedrys L.			+	+	+	+	+	+										
Anchusa officinalis L.			+	+	+	+	+	+	+	+	+	+	+	+				
Anthemis arvensis L.							+	+	+									
Sedum acre L.							+	+										
Coronilla varia L.							+	+	+	+	+	+						
Myosotis arvensis (L.) Hill.							+	+	+	+	+	+						
Papaver dubium L.							+	+	+	+	+	+						
Centaurea cyanus L.							+	+	+	+	+	+	+					
Convolvulus arvensis L.							+	+	+	+	+	+	+	+	+			
Rubus caesius L.							+	+	+	+	+	+	+	+	+			
Agrimonia eupatoria L.							+	+	+	+	+	+	+	+	+			
Lotus corniculatus L.								+	+									
Medicago falcata L.								+	+	+	+							
Hypericum perforatum L.								+	+	+	+	+	+					
Linaria vulgaris Mill.								+	+	+	+	+	+	+				
Knautia arvensis (L.) Coutt.								+	+	+	+	+	+	+				
Viccia cracca L.										+	+	+						
Rubus sp.										+	+	+						
Achillea millefolium L.										+	+	+	+	+	+	+		
Melandrium album (Mill.) Garcke													+	+				
Cirsium arvense (L.) Scop.													+	+	+			
Cichorium intybus L.													+	+	+	+		

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Table 4. Flowering spectrum of plants visited by bees in the roadside IV. (Data from 1988––1990)

plant species	IV			V			VI			VII			VIII			IX		
	ten day period																	
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Taraxacum officinale Web.	+	+	+															
Capsella bursa-pastoris (L.)	+	+	+															
Brasica napus L.				+														
Anthemis arvensis L.					+	+	+	+	+	+	+	+						
Centaurea cyanus L.								+	+									
Anchusa officinalis L.								+										
Lathyrus pratensis L.									+									

Since the investigated landscapes had small differentiation of soil the richness of plant communities from roadsides is mostly related to the stages of secondary succession which is dependent on frequency and intensity of disturbances resulting from farming activity. Hence the richness of *Apoidea* communities depends on the level of the disturbances. More detailed discussion of this issue is given on the chapter „Effect of anthropogenic disturbance..." (38).

Considering the area occupied by roadsides in the studied landscapes (Tab. 1) it is possible to state that they constitute one of more important and in case of the landscape with simplified structure the most important type of refuge habitats for *Apoidea* in the agricultural landscape (47.9 % of the area of all refuges).

For wild bees the most important are wide roadsides (over 3 m) on which rich communities of ruderal and segetal plants develop.

Table 5. Comparison of the occurence and density of *Apoidea* in studied habitats of the agricultural landscape; A — simplified landscape, B — simplified landscape, ★ — species noted only on plantations

species	roadsides A — roadside of the track (1)	roadsides A — cherry-tree alley (2)	roadsides A — dirt road II (3)	roadsides A — highway (4)	roadsides B — dirt road I (5)	roadsides B — dirt road III (6)	roadsides B — dirt road IV (7)	shelterbelts/woodlots A — shelter-belts I (8)	shelterbelts/woodlots A — woodlot I (9)	shelterbelts/woodlots B — shelter-belts II (10)	shelterbelts/woodlots B — woodlot II (11)	forests A — forest I (12)	forests A — forest II (13)
COLLETIDAE													
Colletes daviesanus Smith	0.5												
Colletes fodiens (Fourcroy)	4.3					2.1	6.7						
Hylaeus confusus Nylander	4.3											9.3	4.3
Hylaeus communis Nylander	4.3												
Hylaeus gracilicornis Morawitz													
ANDRENIDAE													
Andrena labiata Fabricius	2.9												
Andrena tibialis (Kirby)	4.3.		5.8										
Andrena subopaca Nylander				2.1	4.2.			1.2	5.6				
Andrena falsifica Perkins													
Andrena minutula (Kirby)	12.5			2.1	4.2								
Andrena haemorrhoa (Fabricius)	6.8	25.0	8.3							21.7			
Andrena gravida Imhoff	0.8	6.2	4.2										
Andrena nigroaenea (Kirby)	1.6				5.6	1.6		1.2	16.7	0.7	62.5	6.2	
Andrena carantonica (Perkins)													
Andrena denticulata (Kirby)						1.0							
Andrena fucata Smith		6.2								6.9			
Andrena fulva (Schrank)				2.1					1.7	6.0	1.0	4.2	
Andrena helvola (Kirby)						16.7							
HALICTIDAE													
Halictus rubicundus (Christ)	0.9		10.0	4.2				1.2	12.3				
Halictus tumulorum (L.)	1.6												
Lasioglossum xanthopus (Kirby)	3.8			17.4	23.6				36.1	22.7	25.0		
Lasioglossum subfasciatum (Imhoff)	3.1			8.3	20.0				2.8		6.2		
Lasioglossum nitidum (Panzer)	0.6			4.2	4.2								
Lasioglossum quadrinotatum (Kirby)									1.2				
Lasioglossum lativentre (Schenck)							3.3						
Lasioglossum quadrinotatulum (Schenck)	2.7				8.3	3.1					9.4	4.2	
Lasioglossum leucozonium (Schrank)													
Lasioglossum leucopus (Kirby)													
Lasioglossum lucidulum (Schenck)	0.5								2.4				3.1
Lasioglossum minutissimum (Kirby)										4.2	4.2		
Lasioglossum nitidiusculum (Kirby)										9.4	18.7		

Species	1	2	3	4	5	6	7	8	9	10	11	12	13
Lasioglossum pervulum (Schenck)				1.0	2.7	1.6			1.2	1.7		8.3	
Lasioglossum setulosum (Strand)										3.1			
Lasioglossum nitidulum (Alfken)	2.5									1.0			
Lasioglossum morio (Fabricius)	47.6												9.4
Lasioglossum calceatum (Scopoli)			11.7	2.1	50.0	3.1		1.2	14.9			7.3	18.7
Lasioglossum sexstrigatum (Schenck)									72.0				
Sphecodes divisus (Kirby)			4.2		2.7	1.6			1.2			4.2	3.1
Rhophitoides canus (Eversmann)*													
MELITTIDAE													
Dasypoda hirtipes (Fabricius)	1.0								1.4				
MEGACHILIDAE													
Anthidium manicatum (L.)													
Anthidiellum strigatum (Panzer)	0.6								1.2				12.5
Stelis punctulatissima (Kirby)													
Osmia rufa (L.)	7.8		4.2		8.3			2.8					
Osmia aurulenta (Panzer)	0.5								1.4				
Megachile versicolor Smith													
ANTHOPHORIDAE													
Nomada goodeniana (Kirby)												6.2	
Nomada signata Jur													
Nomada moeschleri Alfken	3.1		2.8						7.2	0.7			
Nomada flavoguttata Kirby													
Nomada fabricina L.													3.1
Anthophora plumipes (Pallas)		68.7	1.7	2.1							1.0	6.2	
Anthophora furcata (Panzer)									1.2		13.5		
Melecta albifrons (Fösster)		6.2											
Ceratina cyanea (Kirby)									1.2				
APIDAE													
Bombus terrestris (L.)	188.8	6.2	4.2	2.1	33.3	15.1		5.3	42.1	24.6	49.0	22.9	6.2
Bombus lucorum (L.)	34.1							4.7	39.2	31.2	9.4	52.1	6.2
Bombus hypnorum (L.)	0.5	18.7		3.1						3.1			
Bombus pratorum (L.)	211.8	18.7		2.1						2.1			
Bombus lapidarius (L.)	0.6		155.8	25.0	27.8	27.6		5.0	281.3	3.1	24.5	41.7	6.2
Bombus hortorum (L.)	9.2		3.3	6.2	8.3			1.2	2.4				
Bombus muscorum (L.)	50.0	6.2	38.3		19.4	7.8			3.8		3.1		
Bombus pascuorum (Scopoli)	47.7	6.2	20.8	3.1		3.1		16.9	40.5			61.5	12.5
Bombus ruderarius (Muller)	47.5			1.0		12.5		1.2	5.5				
Bombus sylvarum (L.)	0.5					1.6			7.5				
Bombus pomorum (L.)									1.2				
Psithyrus bohemicus (Seidl)									2.4				
Apis mellifera L.	112.8	162.5	405.0	169.5	72.2	678.1	11.1	102.8	388.7	470.9	794.8	170.1	503.1

Woodlots and shelterbelts

The studies on these habitat types were carried out in four stands including two shelterbelts and two woodlots:

Shelterbelt I — acacia and oak belt planted by Chłapowski in 19th century. The bush layer consisted mainly of *Sambucus nigra* and single plants of *Crataegus monogyna*. In the herb layer 24 species of flowering plants visited by bees were found. However, due to considerable shadowing of this layer the plants occured in small density (Tab. 6) and mostly on the edges of the shelterbelts (tall herb layer) and in clearances. In the discussed habitat 12 *Apoidea* species were observed (Tab. 6). The dominant species was *Apis mellifera* L. (69.8 %) which visits mostly *Chelidonium maius*. The remaining species appeared in very low density which averaged 44.7 ind./ha.

Table 6. Comparison of *Apoidea* density and diversity of studied woodlots and shelterbelts. (A and B see tab. 2)

woodlot and shelterbelt	total area (ha)	number of food plant species	mean cover by food plants (%)	mean density of *Apoidea* (ind./ha)		H'		number of *Apoidea* species
				A	B	A	B	
shelterbelt I	3.60	24	20	146.3	44.7	0.97	1.31	12
shelterbelt II	0.30	18	10	613.1	142.2	0.88	1.35	17
woodlot I	1.61	16	50	986.0	597.3	1.89	1.83	29
woodlot II	0.23	14	35	1022.3	227.5	1.05	1.49	14

Shelterbelt II — was much smaller than the previous one. The tree stand consisted mainly of *Quercus robur*, *Tilia cordata*, *Malus domestica*, *Pirus communis*, *Populus alba*, *Betula verrucosa*. The bush layer was made by *Sambucus nigra*, *Crataegus monogyna* and *Ribes schlechtendalii*. The herb layer developed only on the edges in contact with arable fields. In this habitat 16 bee species visited 13 herbaceous plant, 3 tree and 2 bush species. The higest density reaching 2200 ind./ha was observed in Spring during tree (apple, pear trees) and bush (currant, hawthorn) flowering. Besides this season the density was much smaller which was related to small number and density of food plants (Tab. 6). The mean density was 613.1 ind./ha of which only 23.2 % constituted wild *Apoidea*.

Woodlot I — was made mostly of *Betula verrucosa*, *Quercus robur*, *Pinus silvestris*, *Populus tremula*. The stand covered about 75 % of the area. The remaining area was taken by sward communities of the *Artemisietea*, *Sedo-Scleranthetea* and *Festuco-Brometea* class. Flowering plants in these communities constituted the main source of food for bees. 16 plants species were visited by bees and occurred in considerable density (Tab. 6). 29 *Apoidea* species were found there which created a community with even domination and relatively high

coefficient of species diversity. The maximal density was observed in July and August (3625 ind./ha) during flowering of large patches of *Ballota nigra* the plant particularly attractive for bumblebees. The mean density should be considered as very high (986.0 ind./ha) particularly that mostly wild species appeared (60.9 %).

Woodlot II — surrounded a small water hole in shape of a ring. The tree layer consisted mainly of *Populus nigra*, and a dense bush layer was made of *Sumbucus nigra*. Due to high density of bush plants (shadowing) the food plants occurred mostly on the edges. Relatively high density of insects was decided by honey bee (Tab. 6) (77.7 %) which flew from the nearby apiares for rich food from *Arctium lappa*, *Arctium minus* and *Cirsium arvense* reaching the density of 8750 ind./ha. The dynamics of wild bee number was more stable and their mean density was 227.5 ind./ha.

Generally it should be stated that in each woodlot and shelterbelt 12 to 29 species were found and in all of them number was 43 bee species. Also the density ranged within broad limits as seen from Table 6. It was found that the number and diversity of *Apoidea* living in the woodlots and shelterbelts was related mainly to the edge plant communities or those from the clearings which created rich food sourse during the whole vegetation season (Tab. 7). Trees and bushes undisputably enriched the list of food plants. Trees and bushes as a source of food for wild bees are discussed in the works by Banaszak (in press) and Banaszak and Cierzniak (in press). This rich source of food was rather short term as compared to multispecies herbaceous plant communities where food plants were being found througout the whole vegetation season (Tab. 7).

Table 7. Flowering spectrum of plants visited by bees in shelterbelt I. (Data from 1987— —1990)

plant species	IV			V			VI			VII			VIII			IX		
	ten day period																	
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Gagea lutea (L.) Ker-Gav.			+															
Ficaria verna Huds.			+															
Taraxacum officinale Web.		+	+	+														
Prunella vulgaris L.		+	+	+														
Chelidonium maius L.		+	+	+	+	+	+	+	+	+	+							
Capsella bursa-pastoris (L.)				+														
Crataegus monogyna Jacq.				+	+													
Ranunculus sp.					+													
Veronica chamaedrys L.				+	+	+	+											
Potentilla anserina L.								+	+	+								
Potentilla reptans L.								+	+	+								
Medicago sativa L.									+									

continued tab. 7

plant species	IV			V			VI			VII			VIII			IX		
	ten day period																	
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Anthemis arvensis L.							+											
Hypericum perforatum L.								+	+	+	+							
Cirsium arvense (L.) Scop.									+	+	+							
Ballota nigra L.										+	+	+	+					
Trifolium repens L.										+	+	+	+					
Onopordon acanthium L.											+	+	+					
Achillea milefolium L.												+	+					
Anchusa officinalis L.													+					
Linaria vulgaris (L.) Mill.													+	+	+			
Arctium lappa L.														+	+	+		
Lamium purpureum L.															+	+		

Table 8. Comparison of *Apoidea* densities inside and on the edge in studied shelterbelts and woodlots

shelterbelts and woodlots	density of *Apoidea* (ind./ha)	
	edge	inside
shelterbelt I	177.1	115.5
shelterbelt II	840.0	386.2
woodlot I	1899.0	73.0

The inside parts of discussed habitats were significantly less attractive for *Apoidea*. Table 8 presents the found differences in densities of bees inside and on the edges of the studied shelterbelts and woodlots (in the woodlot II density of *Apoidea* was not determined due to very high bush concentration).

The *Apoidea* density found inside the woodlot and shelterbelts is comparable to the bee number found in forests (Pawlikowski 1985, Banaszak 1987) while the density in the tall herb communities even exceeded the values for the xerothermic swards (Pawlikowski 1985, Banaszak 1987). Taking into account significant differentiation of the density between the inside part of the woodlots and shelterbelts and its brims it is possible to state that the nutritious attractiveness of a given stand is not decided by its area but the plant communities related to it which are located on its edges or in clearings.

These habitats also provide appropriate places for nesting of wild bees and since the disturbance level is here much lower than in roadsides (see page 38, 39) they play an important role in preserving natural resources of *Apoidea*.

The studies were carried out in the years 1989–90 in two mid–field forest located in the agricultural landscape with complex structure in the viccinity of Turew. Great differentiation of these habitats and their large area make it possible to present only estimated results.

In the studied forests pine monocultures from various age class — mainly 40–60 years old predominated. The samples were taken considering a wide range of plant communities starting from their roads to typically ecotonous habitats on the forest edge. The general density and diversity is given in Table 9.

As in the woodlots and shelterbelts also in the forests considerable differences between bee density inside the forest and ecotonous habitats were observed (Tab. 10). The environment inside the pine stands was poor fauna of bees. This due to small food resources characteristic for these habitats. The main bee food plants in the forests — *Vaccinium myrtillus* and *Caluna vulgaris* (Szklankowska 1973, Banaszak, Cierzniak in press) occured in minimal amounts.

The density of wild bees living there was low which is in agreement with the results of the earlier studies on these forest communities (Banaszak 1987). Much higher densities were observed on the ecotonous habitats (forest edge, forest roads). High density of *Apoidea* was decided by the honey bee (forest I — 42.5 %, forest II — 84.7 %) dominating both in forest edges as well as inside the forest complex, on the clearings and forest roads which is related to relatively small area of the studied forests. In the conditions of the Wielkopolska agricultural landscape the forests are usually located on sandy soils not useful for farming. Hence the poor pine monocultures are most frequently encountered which have small resources of *Apoidea* fauna. The element enriching the bee fauna of these forests are undoubtedly the ecotonous habitats.

Table 9. Comparison of *Apoidea* density and diversity in studied mid–field forests.
(A and B see tab. 2)

forest	total area (ha)	number of food plant species	mean cover by food plants (%)	mean density of *Apoidea* (ind./ha)		H'		number of *Apoidea* species
				A	B	A	B	
forest I	54.0	20	20	400.0	229.2	1.58	1,89	14
forest II	14.0	22	20	593.4	90.3	0.78	1.87	12

Table 10. Comparison of *Apoidea* densities inside pine monocultures and on the ecotones of studied mid—field forests

forest	mean density of *Apoidea* (ind./ha)	
	ecoton	pine monoculture
forest I	647.5	158.2
forest II	945.0	242.6

The effect of selected elements of agricultural landscape structure on *Apoidea* communities

The effect of refuges isolation on *Apoidea* communities

From the point of view of lanscape ecology small refuge habitats of bees on the agricultural areas can be considered as, so called, habitat islands. This term was introduced in to ecology by Mac Arthur (1972) and it defines local habitat patches isolated by different surrounding biotopes. According to this definition the refuges of wild *Apoidea* discussed in this work and surrounded by vast cultivated fields can be treated as habitat islands.

In the agricultural landscape such islands are basic habitats where numerous species of wild bees nest, feed and develope (Banaszak 1983). Arable fields can also constitute nesting areas but the number of nesting bees is small (Śnieżek 1894, Majewski 1963, Ryszkowski, Karg 1977 after Banaszak 1983) and due to frequent cultivation operations the nests are often destroyed. Only long term crops (e.g. alfalfa) provide better place for nesting of *Apoidea* (Pawlikowski 1989).

Basing on the data obtained from 13 investigated refuges with different degree of spatial isolation (Tab. 11) an attempt was made to prove and determine the effect of the refuges isolation on *Apoidea* communities.

It was assumed that if there is spatial isolation restricting accessibility of given refuges for bees then the more isolated habitat islands should, due to periodical anthropogenic and natural disturbances eliminating some species, have smaller degree of species diversity than the habitats where exchange of bees with the surrounding refuges is easier. This assumption was based on similar observations concerning the effect of isolation on insect species (Van Velden, Mabelis after Opdam 1988) and on birds (Lynch, Whigham 1984, Opdam et al. 1985, Askin et al. 1987).

Since species diversity can also be determined by a refuge area, food resources (Forman, Godron 1986) the multiple regression analyses was employed which facilitates statistical determination of the effect of each co—operating factor on the investigated variable, i.e. species diversity of the bee communities. The influence of disturbances was neglected by rejecting the data collected during and after disturbance occurence.

Table 11. Comparison of wild bees density and diversity and food resources in studied refuges with different degree of spatial isolation and area.(The data collected during and after disturbance was neglected)

refuge type	total area (ha)	feeding area (ha)	mean number of food plant species	mean covering by food plants (%)	mean density of wild bees (ind./ha)	H'	isolation of refuges (m)
forest I	54.00	2.50	7.5	20.0	229.2	1.889	100.0
forest II	14.00	3.80	7.5	20.0	90.3	1.868	147.0
shelterbelt I	3.60	0.60	3.8	19.0	42.0	1.304	260.0
woodlot I	1.61	0.30	3.7	50.0	624.3	1.833	260.0
roadside of the track	1.40	1.40	7.4	40.0	708.8	1.728	207.0
dirt road I	1.20	1.20	3.7	55.0	337.3	2.111	187.7
dirt road II	1.00	1.00	6.9	31.6	287.1	1.792	148.0
cherry—tree alley	0.80	0.80	4.7	15.0	125.0	1.527	140.0
highway	0.35	0.35	5.8	15.0	70.1	1.584	172.5
shelterbelt II	0.30	0.12	2.6	10.0	140.2	1.355	422.5
woodlot II	0.23	0.14	3.1	26.2	227.6	1.496	400.0
dirt road III	0.20	0.20	4.6	28.7	135.3	1.598	188.3
dirt road IV	0.10	0.10	2.2	40.0	25.0	0.636	193.0

The multiple regression did not show a statistically significant relationship between the value of spatial isolation and species diversity (Tab. 12). Basing on the initial assumption it was found that the investigated refuges were not sufficiently isolated for bees, i.e. the distances between the habitat islands did not prevent migration of the studied insects to the neighbouring refuges.

Mutual location of the habitat island (their isolation) and the possibility of animal migrations between the habitat patches (recolonization) can be of major importance for functioning and survival of a population (Wrigth, Hubbell 1983, Wright 1985).

The possibility of recolonization of fauna refuges from which disappeared some species seems particulary significant in agricultural landscape with high level of anthropo-preussure where frequently occur strong disturbances lowering the number and diversity of *Apoidea* communities (see page 38, 39).

Table 12. Significant variables in multiple—regression analyses of *Apoidea* diversity, density and number of species.(In parentheses —values of partial correlation, x — p$\leqslant$0.05, xx — p$\leqslant$0.01, xxx — p$\leqslant$0.001 — significance of regression coefficients. NS — not significant)

Depen-dent varia-bles	mean num-ber of food plant species	mean cove-ring by food plants	patch size	feeding area size	isolation	F	R^2	P	df
diversity	x (0.45)	xx (0.40)	NS	x (0.35)	NS	6.8	0.24	0.003	2.35
number of spe-cies	x (0.35)	xxx (0.62)	NS	NS	NS	16.9	0.46	0.0000	2.35
density	xx (0.29)	xxx (0.60)	NS	NS	NS	13.0	0.39	0.0001	2.35

Also Opdam (1988) points out the importance of contact between isolated environmental patches for animal populations. He treats the animal population dispersed in given habitat patches as a metapopulation consisting of subpopulations inhabiting each habitat island (defined by Levins 1970). With such an understanding of a population the author believes that the contact between the habitat islands can be one of the major factors determining survival of the metapopulation in the segmented agricultural landscape.

Considering spatial isolation in case of studies on bees may seem useless taking into account the fact that this group of insects can fly actively. However, even for such perfect fliers as birds the negative effect of spatial isolation on species diversity in forests and woodlots was proven despite the fact that the mean distance of the studied forests and woodlots from greater forests amounting to 1.87 km should not constitute any obstacle for the birds (Van Dorp, Opdam 1987). The negative effect of isolation on species diversity of birds was also noted by Lynch, Whigham (1984), Opdam et al. (1985), Askin et al. (1987). The negative correlation between occurrence of species in habitat islands and their isolation was also found for other group of animals, e.g. for some species of small mammals (Smith 1974), spiders (Webb 1984) or snails (Brönmark 1985).

Concerning *Apoidea* the literature indicate that particularly the species of small *Apoidea* do not fly on greater distances. According to Batra (1966) *Lasioglossum zephyrum* (Smith) flies not farther than 250 m from its nest. Similarily, Münster-Swendsen (1968) observed *Panurgus banksianus* Kirby flying up to 250 m and feeding flights of *Chelostoma maxillosum* did not exceed 150 m (Käpylä 1978).

In case of refuge habitats analysed in this work the lack of isolation of habitat islands can be explained by a relatively „dense" distribution of the refuge habitats. The distances between the refuges from 140 to 422.5 m did not prevent bee migrations.

Distribution of the isolated refuges found in both lanscape types should be considered favourable for survival of each *Apoidea* population.

Also Banaszak (1983) acknowledged the possibility of *Apoidea* fauna exchange between the permanent refuges (forest, natural xerothermic swards) and less stable elements of landscape (roadsides, shelterbelts and woodlots) to be the basic reason of preserving richness of *Apoidea* fauna for the last 50 years.

However, some distribution of refuge habitats in the landscape can produce food limitations for *Apoidea* communities of each habitat island. This problem was investigated on an example of woodlot I (Fig. 2). Basing on rich bumblebee community occurring in this woodlot feeding flights of these insects were determined as well as trophic conditions created by the refuge distribution.

In the studied woodlot 8 bumblebee species were found. At times of the greatest occurrence two common and most characteristic for this biotope type species predominated: *Bombus lapidarius* (L.) and *B. terrestris* (L.). The other species appeared in significantly smaller numbers.

During the two succeeding years, in period of maximal numbers, marking of the bumblebees was carried out. From the marking and repeated catching the numerical size of the community was determined for the time of its maximal developement. The results are given in Table 13.

The number determined with the marking method was on average by 33 % lower than that obtained with the belt method. Teräs (1983) obtained similar results comparing both methods. If we accept the number obtained by means of the marking method it is possible to assume that it included 32.8 % of the community. If the bees migrated to the neighbouring refuges there was high probability of finding the marked individuals in the close refuges aboundant in food. However, despite intense search carried out in the neighbouring refuges in 1988 no marked bumblebees were found. Next year draught caused rapid lowering of food resources in the woodlot. At the same time migrations of blumblebees to the neighbouring refuges were observed. After mowing the rest of food plants in the woodlot this phenomenon intensified. The greatest number of marked individuals was noted in the nearest feeding refuge (Fig. 2).

Table 13. Numbers of blumblebees estimated by the marking method and the belt method in the woodlot I

bumblebees numbers	year day	1988		1989	
		16 VII	8 VIII	30 VII	10 VIII
number based on the belt method		1325	625	600	475
number based on the marking method		888.2	225.5	480.1	391.1
number of marked individuals		268	103	200	200
percent of marked individuals in community		29.7	45.7	41.7	51.3
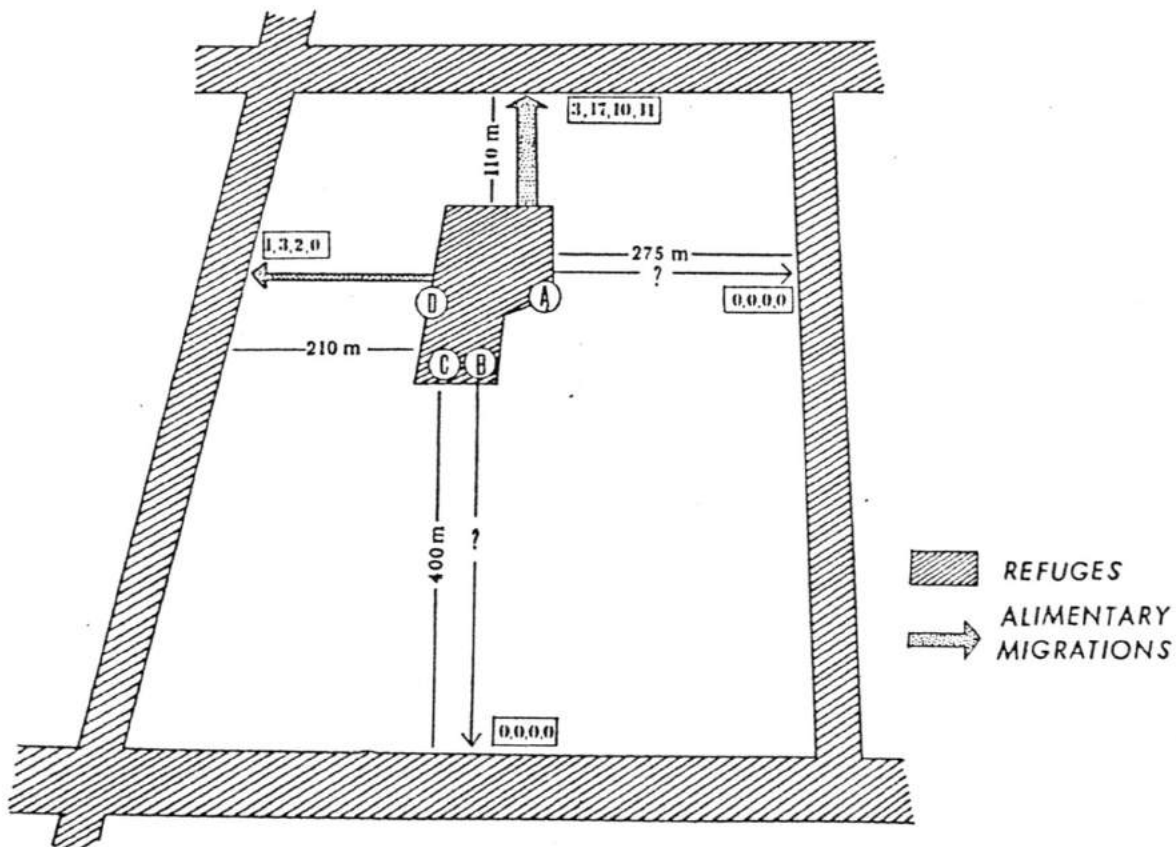
Figure 2. Woodlot I and neighbouring refuges of the bumbebees. A, B, C, D — marking site of the bumblebees. 1, 3, 2, 0 etc. — number of marked bumblebees in the close refuges follwing days after mowing the rest of food plants in the woodlot I

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The experiments proved considerable trophic attachement of the insects to a given habitat island. The reason for this Ranta and Vespäläinen see in feeding behaviour of bumblebees resulting from optimation of energetic gain obtained by an individuals.

The discussed type of trophic behaviour of blumblebees was determined by a specific ,,energetic — time barriers" which accounts for the lack of feeding flights to the neighbouring refuges in the period when in the studied woodlot the amount of food was sufficient. Only due to the disturbances this barrier was broken. The level of this barrier is closely to the distance of feeding flight. According to Butler (1951) the deciding factor of the energetic balance of blumblebees is the time needed to obtain a given portion of food. The energy required for active flight is much less important element due to ,,economical" physiological mechanisms of the flight. According to Heinrich calculations (1979) on an example of *Bombus vosnesenskii* and *Epilobium* plant a bumblebee feeding 3 km from its nest brings 3 times smaller amount of food to the nest due to the loss of time for flying than the individual collecting nectar and pollen in direct neighbourhood of its nest. In Summer during intense developement of a family (numerous larvae) such a lowering of food supply can considerably decrease the family breeding success.

Since the multiple regression indicated no effect of spatial isolation on the whole *Apoidea* communities it should be assumed that also the species of solitary bees were not restricted by the spatial isolation of the refuges. This means that distribution of refuge habitats can create similar energetic—time barriers as those shown for bumblebee communities.

Hence the distribution of the refuge habitats of *Apoidea* is important in shaping general food resources available for bees in the agricultural landscape. The lack of spatial isolation for bees between neighbouring refuges enables them to use the food from the neighbouring refuge habitats what was proven by the above mentioned experiment. This is an important factor increasing chances of developement for *Apoidea* communities in the conditions of intense anthropogenic disturbances in the refuges (frequent destruction to food plants — see page 38, 39) or in case of small refuges poor in food, e.g. narrow roadsides, where the periods of total lack of nectar plants can be encountered (Tab. 4).

Effect of the area and shape of refuge habitats on *Apoidea* communities

The size of habitat island is one of the major issues considered during evaluating their significance for various groups of animals.

The studied bee refuge habitats differed considerably with respect to their area (Tab. 11) which facilitated observation of the effect of this factor on communities of wild *Apoidea*.

The multiple regression indicated no effects (Tab. 12) of the total area a refuge on density and diversity (H') of bee communities.

Studies of various species of animals show that the size of habitat islands considerably affects diversity and density of fauna (Forman et al. 1976, Burgess, Sharpe 1981, Ambuel, Temple 1983, Dąbrowska-Prot 1987).

In the literature on the effect of the size of habitat island on species diversity predominate reports noting an increase of species diversity with the increase of the island area. This is mostly related to the division of the island into clearly ecotone and inside zones which involves occurrence of a group of species related to the inside part of island type besides the ecotone species (Forman 1981 after Kozakiewicz and Szacki 1987, Van Dorp, Opdam 1987, Forman, Godron 1986).

The size of the investigated refuges of bees, besides the mid–field forests, was too small for this phenomenon to influence rise in diversity. On the other hand increase in the area of the field forests did not cause the rise in diversity since the inside portions of the dry pine monocultures was the habitat with small density and diversity of *Apoidea*.

Besides the total area of each studied environment, so called, feeding area was calculated which is the area of a given refuge habitat taken by communities of food plants. In case of the open habitats – roadsides – herbaceous plants with numerous food plants of bees appeared on the whole refuge area so the feeding and total areas were equal. In shelterbelts and woodlots the feeding area was mainly limited to their tall herbs at rims, clearances and treeless spots.

Analysis of correlation indicated a positive correlation (Tab. 12) between the size of feeding area and the coefficient of species diversity (H'). This relation has an indirect character and reflects direct relationships between the size of a feeding area and the number of species of food plants found in a given refuge and between the number of food plant species and the coefficient of species diversity H'. It was found that the number of food plant species depended on the size of the feeding area. A rise in the size of the feeding area in bee refuge resulted in an increase of the mean number of food plant species (Fig. 3). In turn, enrichment of food base caused higher species diversity of *Apoidea* in the studied refuges (Tab. 12). Similar relationship between the number of *Apoidea* species and the number of food plant species was pointed out by Banaszak (1983). Kosior (1987) and Pawlikowski (1989).

The density of wild bees was clearly dependent on the amount of food in a given habitat. Statistically significant relation between the amount of food plants (area cover) and the density of wild bees was found (Tab. 12). Basing on the above mentioned relations it is possible to state from the point of view of landscape structure the factor deciding of *Apoidea* resources in the studied refuge habitats was the size of feeding area and not the total area of a refuge.

$r = 0.88$

$\alpha = 0.05$

$y = \log 1.735 \, x^{0.310}$

4 [ha]

feeding area

mean number of food
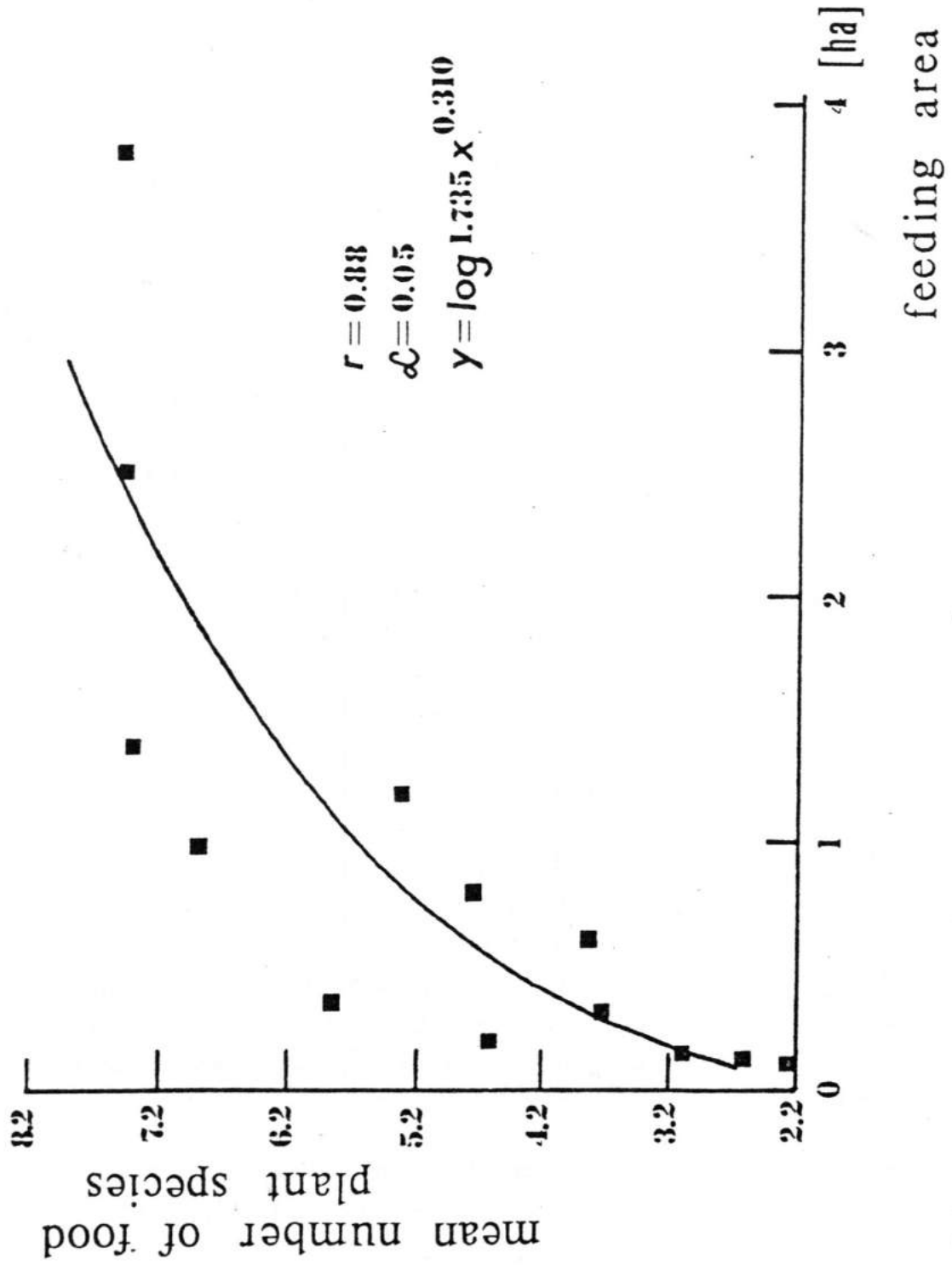plant species

8.2
7.2
6.2
5.2
4.2
3.2
2.2

Figure 3. Correlation between the feeding area of bee refuges and the mean number of food plant species recorded in bees refuges

In case of shelterbelts, woodlots and mid—field forests enrichment of *Apoidea* fauna was decided by the amount of tall herb communities on the edge of these habitats, clearings and open space in tree stands since the feeding area was limited to these environments. The importance of tall herb communities in enriching *Apoidea* was also indicated by Kosior and Fijał (1991). The feeding area of roadsides overlapped their total area and if it was appropriately large these habitats had relatively high diversity and density of the insects (Tab. 2).

The size of feeding area is directly related to a refuge shape particularly concerning shelterbelts, woodlots and forests. Since food plants occurr here in the zone adjacent to fields the shape (circumference) of these habitats decides about the zone lenght, hence about food resources and richness of *Apoidea* fauna. Similar enrichment of *Diptera* fauna of mid—field woodlots with increase of the ecotone area was found by Dąbrowska-Prot (1987) in agricultural landscape of the Mazurian Lake District.

The ratio of circumference to area increases with transfer from circle and square to elongated rectangles (Fig. 4). From the point of view of practice of landscape management to protect *Apoidea* fauna the most appropriate would be planting out narrow shelterbelts which occupy small area and so do not take much arable land and have long contact zone where tall herb communities could develop.

| AREA (ha) | 1 | 1 | 1 | 1 |
| CIRCUMFERENCE (m) | 354 | 400 | 500 | 850 |
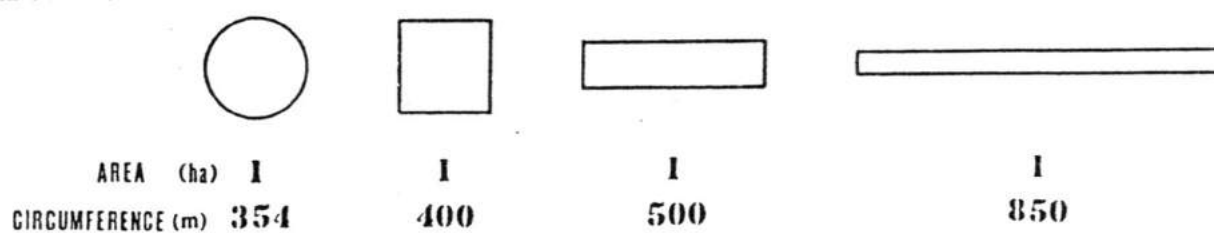
Figure 4. The ratio of circumference to area increases with transfer from circle and souare to elongated rectangles

Developement of tall herb communities itself is a separate issue. Formation of the tall herb communities and the mantel communities on the limit of shelterbelt (woodlot or forest) and a field is mostly related to location of the border line of disturbances (the border of farming operations (Tuxen 1967, Wilmans, Brunhod 1982, Ranney et al. 1981 after Forman and Godron 1986). If this line runs under tree crowns close to their stems the tall herb community and the mantel community does not develop. In case when the border line runs outside the tree crown zone there is enough place for these communities to develop. Another factor forming the rim communities is their exposure. The southern and western edges of shelterbelts have better developed rim communities than the nor- thern and eastern ones.

Effect of anthropogenic disturbances on *Apoidea* communities in refuge habitats

The disturbances, i.e. significant and usually rapid changes of ecological conditions are one of the basic elements of a landscape characteristics (Pickett. White 1985, Forman, Godron 1986). Agricultural physiocenoses are an example of the areas totally under high level of the disturbances (farming operations) which keep the agrocenoses on the initial phases of succesion beneficial for intensive farming (Trojan 1976).

The refuge habitats for fauna of agricultural landscape have, in contradistinction to the surrounding fields, much lower level of the disturbances which enables populations of different animal species to survive and develop.

Basing on the studied refuge habitats the effect of the elementary direct disturbances on *Apoidea* communities of these habitats was studied.

During four year long investigation the most common disturbances occurring in the fauna refuges were: mowing of herbaceous plants and grasses, b) spring burning out of grasses and perennials, c) partial destruction of plants and soil by farming machines, d) total destruction of plants and soil during road construction, building silos etc.

These disturbances can affect *Apoidea* communities by means of alterning two environmental factors having decisive meaning for *Apoidea* developement: a) food resources, and or b) nesting sites. These elements of environment have basic importance for the development of *Apoidea* (Tepedino, Stanton 1981, Pawlikowski 1985, 1989).

A — disturbances in food resources.

Dimnishing of food resources resulted from mowing both purposeful and accidental during harvesting the adjacent fields. This type of disturbances caused only short time lowering of the number of *Apoidea* noted in the refuges (Fig. 8 A, B, C) due to tentative lack of food. This forced the bees to search for food in the neighbouring refuges. Observing the number dynamics it is impossible to prove that mowing permanently affected *Apoidea* communities. Nest destruction may concern only the species nesting on plant stems (e.g. *Hylaeus* Fabr., *Megachile* Latr., *Ceratina* Latr.) however this species group had a minimal proportion in *Apoidea* communities of the agricultural landscape (Tab. 5).

The other most frequently meet disturbance in refuge habitat is spring burning out of dry grasses and perennials. In the studied refuges 6 cases of this disturbance were observed. Despite the drastic character of this operation no observable changes in *Apoidea* communities were noted after the disturbance occured (Fig. 5 A, B, C). Small data base however, prevents generalization of this situation.

B — disturbances in food plants and nesting sites.

In the group of disturbances affecting simultaniously food resources and nesting site was included destruction of plants and soil by agricultural machinery and total destruction of subsoil and plant cover during reconstruction (construction) of roads.

This type of disturbances caused clear and permanent decrease in the number of *Apoidea*. Due to transfer of subsoil rich communities with *Artemisietea, Festuco-Brometea, Sedo-Scleranthetea* class species were destroyed and replaced by initial communities poorer in food plants. Soil transfer was also responsible for destruction of nests. Summaric effect of these operations is clearly reflected in the dynamics of *Apoidea* number in the refuges subjected to these disturbances (Fig. 5 C, D). Apparently negative effect of destruction to soil and vegetation of roadsides on the number and diversity of blumblebees was also found by Kosior (1987). Among the main causes of the phenomenon the author includes destroying rich communities of roadside plants and direct destruction to the nests during road reconstruction. An important feature of the discussed type of disturbances is their long time negative effect. This is related to the type of secondary succession of flowering plants. Kosior (1987) proved on an example of reconstruction of roads in the Bieszczady Mountains that after destruction of the roadsides bumblebees communities needed 9 years to archieve the numerical level of those from not destroyed ones.

The data obtained from observation of 20 km of roadsides in both landscape types indicate that narrow roadsides 0.5 — 1 m wide are most often susceptible to considerable or total destruction by machine wheels, ploughing and raking (Tab. 14).

For this type of fauna refuges the anthropogenic disturbances are an important factor influencing the number and diversity of species.

This type of disturbances, however, was not observed during four year long study in shelterbelts, woodlots and forests (Tab. 14). This justifies including these refuges into the group of more stable habitats in agricultural landscape.

Table 14. Comparison of the level of antropogenic disturbances in refuge habitats of studied agricultural landscapes

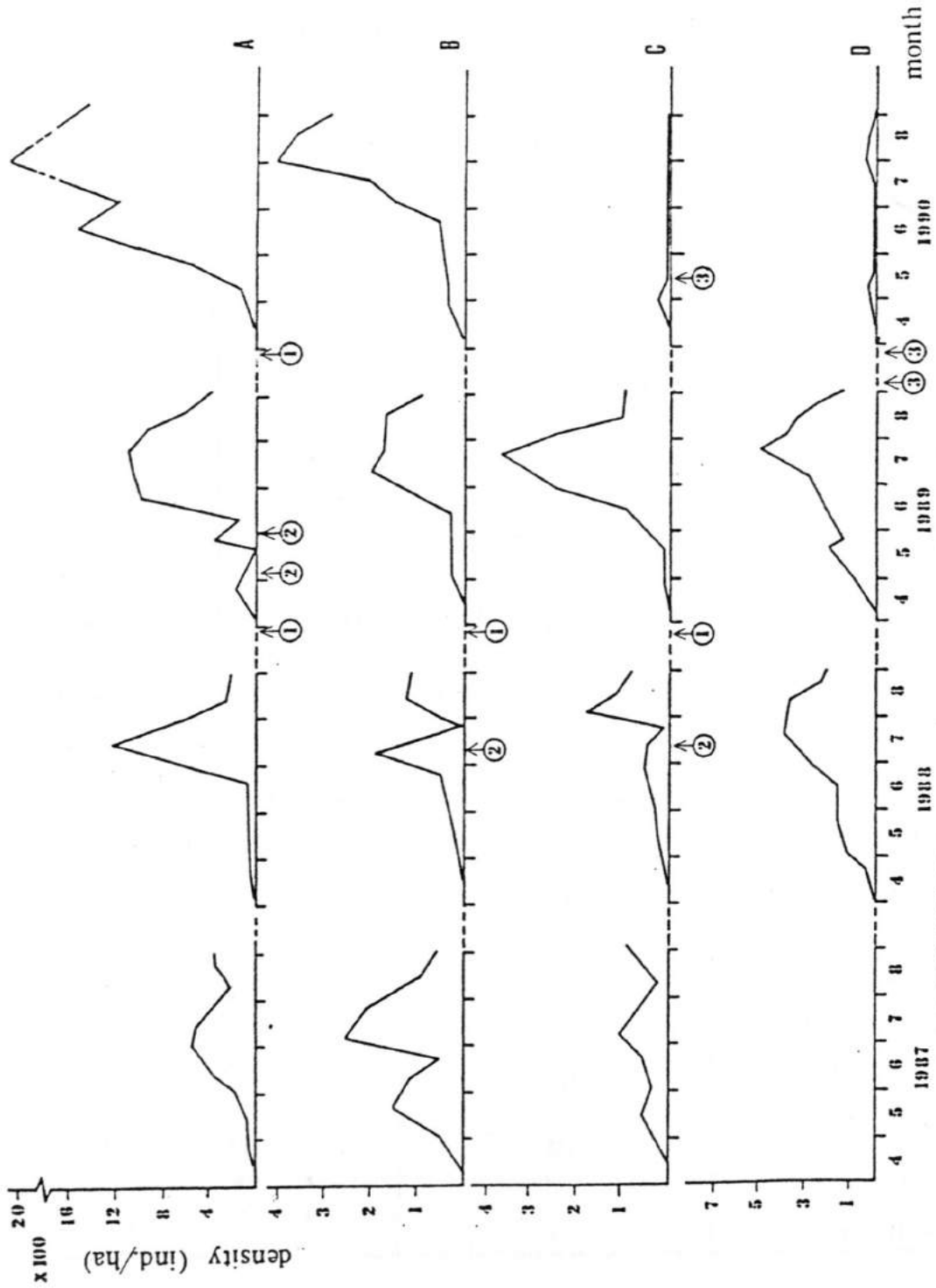| refuge type	percentage of area subjected to disturbance	
	mowing and burning of plants	destruction of plants and soil by machinery
roadsides—width 0.5—1 m	50	35
roadsides—width 2 m	25	5
roadsides—width 3—4 m	10	0
roadsides—width 5 m	10	10
woodlots and shelterbelts	5	0

Figure 5. Changes in the wild bees density in refuge habitats subjected to the disturbances. A – roadside of the track, B – roadside of highway, C – roadside of dirt road IV, D – roadside of dirt road I. 1 – burning of grasses. 2 – mowing of herbaceous plants and grasses, 3 – disturbances of plants and soil

Evaluation of natural resources of *Apoidea* in two types of agricultural landscape

Establishment of density of wild *Apoidea* in the refuge habitats of agricultural landscape and of the total area of these refuges (Tab. 15) facilitates estimation of the general quantitative resources of *Apoidea* in the studied physiocenoses. In case of countryside parks, meadows and settlements the data used was collected by Banaszak on the same area (1983).

Table 15 presents results of extrapolation of the data obtained in each refuge habitat onto landscape level. The mean number of bees for the total landscape area was calculated by multiplying mean density in each refuge by total area a given type of refuge and summing up the results.

The numbers are burdened with some error. Firstly they do not include the part of *Apoidea* population nesting in crops particularly the perennial ones (e.g. alfalfa). It is very diffcult to determine the number of *Apoidea* living on crops. The density found during alfalfa flowering does not reflect the actual density of the bees since the majority of observed insects comes from the neighbouring refuge habitats. The studies by Banaszak (1983) indicated that the *Apoidea* found on entomophilic plant plantation came from the surrounding habitats of the following areas: in case of sunflower − 32 ha, redclover − 27.4 ha, flax − 3 ha, buckwheat − 4 ha, alfalfa − 1.3 ha, rapeseed − 0.6 ha. Determining actual number of bees it is also important to consider the investigation methodology. The belt method used here registers only the insects outside their nests. In case of blumblebees from 1/3 to 2/3 of the individuals can remain in the nest (Brian 1952, Heinrich 1979). In case of solitary bees small number of available literature data prevents determination what proportion of their population is not registered due to females remaining in nests to build them and provide for. However, this phenomenon must cause lowering of the density established at sampling.

Taking into account the determined mean densities of bees in refuge areas and total area of these habitats it is possible to calculate the general mean number of wild *Apoidea* living on 875 ha of each studied type of agricultural landscape. In the landscape with simplified structure the general mean number was 12222.2 insects while that for the complex landscape 44766.0 ones.

The results of the data extrapolation onto the total area of the studied landscape should be mainly treated as a basis for comparing natural resources of the two types of agricultural landscape.

The estimation of quantitative natural resources of *Apoidea* indicated 3.6 times higher level of wild bees in the agricultural landscape with more complex structure. These differences result mainly from different total area of refuge habitats. The total area of refuges in the complex landscape was more than 6 times higher than that in the simplified one. The greatest differences concern the area of shelterbelts, woodlots and meadows and mid−field forests which are absent in the landscape with simplified structure (Tab. 14).

Table 15. Comparison of natural resources of wild bees in two types of agricultural landscape
A — complex landscape (875 ha), B — simplified landscape (875 ha). a — after Banaszak (1983)
b — after Banaszak (1985)

type of refuge habitat	total area of refuges (ha)		density of bees in refuges (ind./ha)		mean number of bees in refuges	
	A	B	data	mean	A	B
roadsides—width 0.5 m		0.12	10.0	10.0		1.2
roadsides—width 1 m	0.27	1.10	81.8	81.8	22.1	90.0
roadsides—width 3—4 m	2.46	5.49	88.2 168.3 194.0[a]	150.2	369.5	824.6
roadsides—width 5—7 m	6.70	5.35	287.9 240.1 702.5 288.0[a]	379.6	2543.3	2030.9
shelterbelts	5.10	0.92	44.7 142.2 106.0[a]	97.6	497.8	89.8
woodlots	17.28	0.32	597.3 227.5	412.4	7126.3	132.0
mid—field forests	26.74	—	90.3 229.2	157.7	4216.9	—
parks	1.50	3.80	276.7[b]	276.7	415.1	1051.5
meadows	78.35	—	132.0[a]	132.0	10342.2	—
buildings and ruderal habitats	19.04	8.03	997.2[b]	997.2	18986.7	8007.5
total	157.44	25.13			44519.8	12227.4

The significance of the ruderal habitats related to houses calls our attention (Tab. 15). The high density of *Apoidea* found on those areas and their considerable area make them a landscape elements of great importance for *Apoidea* increasing their natural resources.

In the complex landscape mowed meadows and pastures play an important role in shaping quantitative resources of bees. Part of grassland, namely damp mowed meadows do not create conditions favourable for *Apoidea* developement (Banaszak 1983) and prevent their nesting (high moisture content, high level of ground water table), but their large total area despite low number of bees makes them a significant factor affecting *Apoidea* resources (Tab. 15). The shelterbelts and woodlots also considerably influence the number of bees in the complex landscape (16 %) which results both from high mean density of bees in this habitats and their large total area.

In the simplified landscape the number of bees is mostly decided by the ruderal habitats (65 %) and roadsides (24 %) (Tab. 15).

In the complex landscape the proportion of blumblebees grows rapidly since they can find there appropriate biotopes in afforestated areas. Also the species related to trees, forests and their ecotones such as *Hylaeus communis* (Nyl.), *H. confusus* (Nyl.), *H. gracilicornis* Mor., *Megachile versicolor* Sm., *Anthidium manicatum* (L.), *Nomada moeschleri* Alfk., *Ceratina cyanea* (K.) were found only in the complex landscape.

Comparison of mean densities of bees belonging to different families indicates high differences concerning *Apidae* (bumblebees) — 3.7 times higher density in the complex landscape, and also *Colletidae, Melittidae, Megachilide* and *Anthophoridae* whose total density was 4 times higher in the complex landscape than in the simplified one. Whereas the mean densities of *Halictidae* and *Andrenidae* are comparable in the both types of landscape (Tab. 16).

Table 16. Comparison of the participation of *Apoidea* families in communities of refuge habitats in complex and simplified agricultural landscape

family of *Apoidea*	complex landscape			simplified landscape		
	mean density (ind./ha)	%	numebrs of species	mean density (ind./ha)	%	number of species
Apidae	216.9	71.63	11	58.2	44.25	9
Halictidae	43.1	14.23	16	45.3	33.92	15
Andrenidae	19.4	6.41	10	22.3	16.96	7
other[x]	23.4	7.73	18	5.7	4.87	6
total	302.8	100.0	55	131.5	100.0	37

x — *Colletidae, Melittidae, Megachilidae, Anthophoridae*

Larger total area of refuge habitats of bees and consequently their higher diversity significantly increases richness of bee fauna and their density.

General increase in natural resources of *Apoidea* with increase in refuge habitats was also pointed out by Banaszak (1986). The author suggests that the most favourable for *Apoidea* is such a landscape structure where the proportion of refuges reaches 25 % of the total area. The proportion close to the optimal one was found in the landscape with complex structure (Tab. 2) where the total area of refuge habitats constituted 18 % of the landscape.

Also Pawlikowski (1989) found higher diversity and density of *Apoidea* with greater parcelation of arable fields. Higher parcelation of the fields increased the area of bounduary strips and roads with roadsides which provide sites for developement of this group of insects.

The differences in natural resources of *Apoidea* between the studied types of agricultural landscapes affected the density of wild *Apoidea* found on plantations of entomophilic plants (mostly of alfalfa) located in these physiocenoses.

Significant differences concerned alfalfa plantations (Tab. 17). This plant was visited mainly by blumblebees whose numbers showed the greatest differences between the landscapes (Tab. 17). No significant differences in *Apoidea* densities were found on plantation of winter rapeseed. During flowering of this plant the number of blumblebees was small (mostly females) and did not affect the density of *Apoidea* while the densities of *Andrenidae* and *Halictidae* in the both landscapes were similar what could result in similar, though very low, densities on rapeseed fields located in the landscapes.

Banaszak and Cierzniak (in press) proved, on an example of 6 plantations of winter rapeseed, that higher contact of a plantation with refuge habitats of bees significantly increased density and diversity of wild *Apoidea* on it.

The wild *Apoidea* densities on studied alfalfa plantations indicate that appropriately rich landscape structure can considerably increase the possibilities of pollinating seed plantations. It is particulary important in case of the plants for which flights by honey bee proved ineffective, e.g. red clover or alfalfa.

Table 17. Density of wild bees on rapeseed and alfalfa plantations in two types of agricultural landscape

Type of agricultural landscape	density of wild bees (ind./ha)	
	rape	alfalfa
complex landscape	33.4	1116.7
simplified landscape	35.0	550.0

CONCLUSION

1. General structure of a landscape affected natural resources of *Apoidea*. In the complex landscape the number of wild bees was 3.6 times higher than that in the simplified one. Also the qualitative resources of *Apoidea* in the complex clearly exceeded the analogous resources of the simplified landscape.

Differences in natural resources influenced density of wild *Apoidea* on alfalfa plantations.

2. It was found that spatial isolation occurring in the studied landscape types between refuge habitats did not limit exchange of *Apoidea* fauna between the refuges. This increases:

a) possibilities for survival of bumblebee populations in fragmented agricultural landscape with high level of anthropogenic disturbances

b) food base of bees by enabling them to use food plants resources dispersed in spatially isolated refuges.

3. It was proven that diversity and density of wild bees was not related to the total area of a refuge. It was positively correlated with the amount of food of a refuge habitat (number of food plant species and percentage of covering by food plants). In tree habitats the factor deciding about diversity of bees were the tall herb communities of the habitat edge and sward plant communities of clearings and openings of a stand.

Density depended on the size of food base — density of food plants (cover of food plants).

4. Analysis of the effect of anthropogenic disturbances on *Apoidea* communities indicated that:

a) destruction to food plants and nesting sites (moving of soil during agrotechnical and technical operation) caused a clear and long term fall in the number of wild bees.

From observation of the disturbance levels in the refuge habitats of bees it was found that it decreases significantly according to the following scheme: narrow roadsides (0.5 — — 2 m)⟶ wide roadsides (over 3 m)⟶woodlots and shelterbelts.

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STRESZCZENIE

Praca przedstawia wyniki czteroletnich badań nad zgrupowaniami *Apoidea* w krajo- · brazie rolniczym. Badania prowadzono na dwóch powierzchniach badawczych, które obejmowały dwa typy krajobrazu rolniczego: krajobraz o strukturze złożonej, gdzie środowiska refugialne stanowiły 18 % ogólnej powierzchni oraz krajobraz o strukturze uproszczonej, gdzie refugia fauny zajmowały jedynie 2,8 % powierzchni. W wymienionych typach krajobrazu rolniczego badaniami objęto 13 biotopów, które reprezentowały najczęściej występujące w badanym krajobrazie środowiska refugialne *Apoidea*: przydroża, zadrzewienia śródpolne, lasy śródpolne.

Stwierdzono, że:

— Ogólna struktura krajobrazu kształtowała zasoby naturalne *Apoidea*. W krajobrazie o strukturze złożonej zasoby ilościowe dziko żyjących pszczół były 3,6–krotnie wyższe od zasobów ilościowych *Apoidea* w krajobrazie o strukturze uproszczonej. Również zasoby jakościowe krajobrazu złożonego przewyższały wyraźnie analogiczne zasoby krajobrazu o strukturze uproszczonej.

— Izolacja przestrzenna, występująca w badanych typach krajobrazu rolniczego, między środowiskami ostojowymi nie ograniczała wymiany fauny *Apoidea* między refugiami pszczół.

— Zróżnicowanie i zagęszczenie dziko żyjących pszczół nie było związane z wielkością powierzchni całkowitej refugium. Wykazywało natomiast dodatnią zależność od powierzchni pokarmowej środowiska refugialnego, tzn. od powierzchni zajętej przez zespoły roślinności pokarmowej pszczół. W środowiskach zadrzewionych decydującym elementem zwiększającym zróżnicowanie były okrajki oraz zbiorowiska roślinności murawowej polan i luk w zwartym zadrzewieniu. Zagęszczenie pszczół kształtowane było przez wielkość bazy pokarmowej — zwarcie roślin pokarmowych pszczół.

— Niszczenie roślinności pokarmowej wraz z miejscami gniazdowania (przemieszczanie podłoża podczas prac agrotechnicznych), powodowało wyraźny i trwały spadek liczebności dziko żyjących pszczół. Na podstawie obserwacji poziomu zaburzeń w środowiskach refugialnych pszczół stwierdzono, że maleje on wyraźnie według schematu: wąskie przydroża ⟶ szerokie przydroża ⟶ zadrzewienia śródpolne.