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SOIL AND LITTER MACROFAUNA IN SHELTERBELTS AND IN ADJACENT CROPLANDS: CHANGES IN COMMUNITY STRUCTURE AFTER TREE PLANTING

ABSTRACT: Studies were carried out in the vicinity of Turew near Poznań (Western Poland) in the years 2003 and 2004 in three midfield shelterbelts of different age (150, 11, 6 years old) and along two transects across shelterbelt (6 and 11 years old) >ecotone> field at distances 15 and 50m from the shelterbelt. The field located in deforested area was treated as the control. The studies were aimed at estimating the changes in community structure (composition, density, biomass) of soil and litter macrofauna, (mainly dipteran larvae), related to shelterbelt age both within shelterbelts as in adjoining fields. The results were compared to previous studies carried out in 1999–2000 in the same agricultural landscape.

The density and biomass of soil and litter macrofauna were many times higher in shelterbelts (2827–870 ind. m^{-2} and 3782–521 mg.d.wt. m^{-2}) than in fields (483–53 ind. m^{-2} and 101–12 mg.d.wt. m^{-2}) and increased with the age of planted trees. The same was true for taxonomic richness. Ecotone zone of both transects was characterised by the greatest density and biomass of animals, mainly those of mobile epigeic animals, particularly the ants. The density and biomass values were declining in the field with the increasing distance from the shelterbelt. Across the transect of an older (10–11 years old) shelterbelt and adjacent field the density and biomass of studied animals were higher in all plots than across the younger (5–6 years old) one. It can be concluded, that the effect of the shelterbelt increases with age of planted trees. The results confirm the previous suggestions of the enhancement of the field macrofauna by forested strips.

The highest similarity in taxonomic and dominance structure was found between the shelterbelts and their ecotones and they differed significantly from those in the field.

KEY WORDS: midfield shelterbelts, macrofauna, dipteran larvae communities, density, biomass, dominance structure, trophic structure, individual body mass

1. INTRODUCTION

Forested strips planted near Turew, Poznań Province, Western Poland in the 19th century as shelterbelts against wind erosion play many other important functions in agricultural landscape as demonstrated by later studies – modify climatic conditions, reduce eutrophication of ground waters, increase organic matter content in soil (Ryszkowski and Kędziora 1987, Bartoszewicz and Ryszkowski 1996, Karg and Ryszkowski 1996a, Ryszkowski *et al.* 2001). New planting of midfield shelterbelts in this area initiated in 1993 (Kujawa and Karg 1998) allowed for study of plant and animal succession within shelterbelts and for

Table 1. Chemical properties of soil in shelterbelts and in adjacent cereal fields and cultivated crops (after Bernacki unpublished). S– shelterbelt, following number – number of years after trees planting, FC –control field, located in deforested area, Field 15m, field 50m – distance to shelterbelt edge.

pH (KCl)

	S150	S11	S6	FC
Shelterbelt (S)	3.6	5.0	5.0	
Ecotone (E)		6.5	5.8	
Field 15m (F15)		6.2	4.8	
Field 50m (F50)		5.6	5.6	6.0

organic matter (%)

Shelterbelt	7.76	2.24	1.91	
Ecotone		1.74	1.78	
Field 15m		1.47	1.37	
Field 50m		1.55	1.50	1.81

phosphate content (mg $100g^{-1}$)

Shelterbelt	3.52	9.55	13.19	
Ecotone		14.39	15.33	
Field 15m		12.38	9.77	
Field 50m		17.29	13.01	18.01

Crops in study fields

	Fields adjacent to shelterbelt of age (yrs):			Field in deforested area
Study year	150	11	6	Control field
2003	rapeseed	maize	wheat	wheat
2004	wheat	wheat	wheat	barley

evaluating the effect of increasing landscape heterogeneity on soil processes (Karg 1995, 1998, 2004, Karg and Ryszkowski 1996b, Ryszkowski *et al*. 2003, Bernacki 2004, Nowak 2004, Olejniczak 2004). Soil invertebrates are known as sensitive bioindicators of changes in the habitat (Lobry de Bruyn 1997, Szujecki *et al*. 1977, Stork and Eggleton 1992, Paoletti 2001) and they appeared to be very useful for assessing the effect of shelterbelts on adjacent fields.

The present paper is a continuation and broadening of my studies on soil and litter macrofauna in the agricultural landscape provided in 1999–2000 in this area (Olechowicz 2004a, b).

The objective of the present study was to evaluate the effect of shelterbelts' age (i.e. time from tree planting) on community structure of soil and litter macrofauna within shelterbelts and in adjoining fields. The previous studies suggested, that shelterbelts enhance the biomass and diversity of soil macrofauna in adjacent fields (Olechowicz 2004a). These results were aimed to be checked basing on extended number of sites, including comparison of the fields adjacent to shelterbelts with the field located in the deforested area. Investigations were carried out in the same shelterbelts as before, now 4 years older and along two transects across shelterbelts (5–6 and 10–11 years old) and adjacent cere-

al fields. The field located in deforested area was treated as a control.

2. STUDY AREA

Studies were carried out in the vicinity of Turew near Poznań (16°45'to 16°50'E and 52°00' to 52°06'N) in the years 2003 and 2004. In the study region, prevail Glossoboric Hapludalf soils on loamy sand over light loam (Marcinek 1996). They are slightly acid, poor in organic matter, with low water holding capacity (Table 1). Present investigations were carried out in the same shelterbelts as in the years 1999/2000: in an old shelterbelt (150 years old) and in two young ones (10–11 and 6–7 years old), as well as along two transects traversing: young shelterbelts, their ecotones (edges of a shelterbelt and field) and adjacent cereal fields at distances of 15 and 50 m from the tree line. A field located in the deforested area was treated as a control. In all fields mainly cereals were cultivated (Table 1).

The shelterbelts included:

1. Old shelterbelt– (S150) – (ca 150 years after planting) consisted mainly of black locust (*Robinia pseudoacacia* L.) with elder (*Sambucus nigra* L.) and hawthorn (*Crategus sp.*) in the shrub layer, and couch grass (*Agropyron repens* L.) in the herb layer (Ryszkowski *et al.* 2003, Karg 2004).

2. Shelterbelt (S11) 10 – 11 years old, planted in December 1993. It is 340 m long, 17.5 m wide of an area of 5980 m^2. There are 13 tree species, planted in 11 rows. (Karg 1999).

3. Shelterbelt (S6) 5–6 years old, planted in October 1998, 800 m long and 15 m wide of an area of 9600 m^2. Fifteen tree and 3 shrub species were planted there in 7 rows.

4. Control field (FC) located in deforested area.

The composition of trees in young shelterbelts (S6, S11) was diverse, the basic species being oak (*Quercus robur* L.), accompanied by marple (*Acer pseudoplatanus* L. and *A. negundo* L.), birch (*Betula verrucosa* Ehrh.), beech (*Fagus sylvatica* L.), elm (*Ulmus minor* Mill.), linden (*Tilia cordata* Mill.), whitebeam (*Sorbus intermedia* Pers.), larch (*Larix deciduas* Mill.), pine (*Pinus sylvestris* L.), and spruce (*Picea abies* Karst.) Trees formed patches of several species (10–15 trees) replicated along the strip. All woodlots have a character of north-south running strips.

Soil organic matter increased within the forested strips and in the adjacent fields with years after tree planting. However, a relatively high carbon content was found also in the control field (Table 1).

3. METHODS

In each of these plots 10 soil-litter samples of an area of 100 cm^2 and 15 cm deep were collected on every sampling occasion. Samples were taken three times a year. Animals were extracted from soil with the method of Kempson *et al.* (1963) during 10 days – until the soil was completely dry. Picric acid was used to preserve invertebrates.

Biomass was obtained by dessication of animals in 85°C and weighting. In some cases the biomass was calculated as a product of density and mean individual body weight in a given size class of particular taxa.

Statistical verification of results involved:

– analysis of variance ANOVA,

– comparison of two samples with the LSD test,

– Shannon-Wiener H' diversity index,

– similarity indices for animal communities:

1) of Marczewski and Steinhaus (1959) according to the formulae: $s=w/(a+b)w$ to compare community composition and

2) modified by Romaniszyn (1970) according to the formulae: $Si=100C/200-C$ to compare domination structure

where: s and Si – similarity of the two compared sets, a – the number of taxa in set A, b – the number of taxa in set B, w – the number of taxa common for sets A and B, C – the sum of lower percentage shares of particular taxon in two compared sets,

3) similarity of communities was also evaluated with the agglomeration method (Euclidean distances).

The object of this study were soil and litter invertebrates, which can be classified (van der Drift 1951) as macrofauna (2–20 mm). Two groups were distinguished among these animals:

– Group I – soil animals closely associ-

Table 2. Composition and mean density (ind. m^{-2}) of soil (Group I) and litter (Group II) macrofauna in the studied plots
S– shelterbelt, following number – years after trees planting, F15, F50 – field at distances 15 and 50m to shelterbelt, FC – control field located in deforested area

			Field adjacent to S11				Field adjacent to S 6			
Taxon	S150	S11	E	F15	F50	S6	E	F15	F50	FC
Group I Insect larvae:										
Diptera	420.0	603.3	73.3	170.0	20.0	160.0	390.0	30.0	3.3	53.3
Coleoptera	196.7	326.8	226.8	80.0	23.3	143.3	156.7	90.0	6.7	36.6
Heteroptera	10.0	3.3	23.3			16.7	13.3			
Homoptera	3.3	3.3		3.3			13.3			
Others	13.3	16.7	13.3			3.3	6.7	6.7		
Lumbricidae	16.7		3.3				3.3			
Enchytraeidae		3.3	3.3	16.7			13.3		3.3	20.0
Symphyla	456.6	270.0	33.3	10.0	10.0	263.4	330.0			20.0
Chilopoda	66.7	23.3	6.7			30.0	36.7			6.7
Diplopoda	10.0									6.7
Total	1193.3	1250.0	383.3	280.0	53.3	616.7	963.3	126.7	13.3	143.3
Group II Insect imagines:										
Diptera	10.0	6.7	30.0	10.0	13.4	6.7	36.7	26.6	10.0	13.4
Coleoptera	86.7	73.3	83.3		3.3	50.0	73.3	10.0	20.0	10.0
Staphylinidae	150.0	116.7	113.4	20.0	10.0	70.0	113.3	20.0	3.3	20.0
Aphidoidea		10.0	23.3			6.7				3.3
Heteroptera		10.0	13.3			10.0	3.3			
Hymenoptera	26.7	16.7	16.7			16.6	10.0		3.3	3.3
Formicidae	106.6	1223.3	4160.0	170.0	3.3	33.3	866.7	6.7		
Thysanoptera	10.0	50.0	23.3			40.0	26.7	6.7		
Araneae	43.3	70.0	16.7	3.3		20.0	10.0		3.3	3.3
Pseudoscorpionidae	26.7									
Total	460.0	1576.7	4480.0	203.3	30.0	253.3	1140.0	70.0	40.0	53.3
All macrofauna	1653.3	2826.7	4863.3	483.3	83.3	870.0	2103.3	196.7	53.3	196.6
Number of taxa (20)	17	17	17	9	7	15	17	8	8	12
H' index	3.01	2.50	1.05	2.18	2.54	3.04	2.62	2.37	2.60	3.08

Table 3. Statistical significance of the differences of mean values of macrofauna densities. A – between plots – spatial and temporal series of data (analysis of variance ANOVA test), B – between pairs of plots (LSD – test). S –shelterbelt, following number – years after trees planting, E- edge of shelterbelt, F15, F50 – field at distances 15 and 50 m from the shelterbelt. Group I – soil fauna, Group II – epigeic fauna.

A.

Communities	Spatial	Temporal
a) All macrofauna	****	*
b) Group I	****	n.s
c) Group II	****	*
d) Diptera larvae	*	n.s
e) Coleoptera larvae	****	*
f) Symphyla	****	n.s
g) Chilopoda	***	***
h) Coleoptera imagines	****	n.s

B.

				Field adjacent to S 11				Field adjacent to S6		
	Study plots	S150	S11	E	F15	F50	S 6	E	F15	F50
	S 11	e** f* g*								
Field adjacent to S 11	E	a** f**** b* g*** c****	a* e* b** f** c**							
	F15	b* g**** e** h*** f****	a** f** b** h** e****	a**** e** h***						
	F50	b** f**** d* g**** e****h***	a** e**** b*** f** d* h**	a**** e**** h***	c****					
	S 6	a* f* g*	a* e***	a**** f**	c**** f** h*	d* h* e* f**				
Field adjacent to S 6	E	–	e***	a** f***	b* g* c*** h** f***	a* e** b** f*** d* h**				
	F15	b** g**** e** h** f****	a** f** b*** h** e****	a**** e** h**	c***	–	f**	a* g* b* h** f***		
	F50	b** f**** d* g**** e**** h**	a** e**** b*** f** d* h*	a**** e**** h**	c****	–	e** f**	a* f*** b** g* e*** h*	–	
	FC	b** g*** e*** h** f****	a** f** b*** h** e****	a**** e**** h**	c****	–	e* f**	a* f*** b* h** e**	–	–

* $P< 0.05$ ** $P< 0.01$ *** $P< 0.001$ **** $P< 0.0001$, n.s. – not significant, a – h animal communities as in Table 3 A.

ated with soil and litter where they develop and feed,

– Group II – litter or epigeic animals present mainly on the litter surface and able to move to other layer of the ecosystem (Table 2).

4. RESULTS

4.1. Taxonomic composition and animal density

Altogether 20 taxa of soil and litter animals were noted in studied sites. Common for all sites were dipteran (larvae and imgines) and coleopteran larvae as well as Staphylinidae imagines (Table 2). The greatest diversity of animals was found in shelterbelts and their ecotones (15–17 taxa). Much smaller taxonomic richness was noted in adjacent fields (7–9). Relatively high number of taxa (12) was recorded in the control field (Table 2).

Mean density of all animals in studied sites varied from 53 to 4863 ind. m $^{-2}$ (Table 2). High densities of animals were noted in shelterbelts, particularly in older ones (S150 and S11) and in both ecotones. The density of animals in ecotones was nearly two times higher than in respective shelterbelts mainly due to the contribution of ants. In fields animal densities were smaller and decreased with the distance from shelterbelts. Across the transect of the older shelterbelt (S11) and the adjacent field animal density was greater than in the younger one (S6-6 years old). Between-plots ratios of densities of all macrofauna were 0.5, 5.8 and 33.9 for S-E, S-F15, S-F50 respectively. Ratios for the younger shelterbelt and adjacent field were 0.4, 4.4 and 16.3 (Table 2).

The density of soil animals (Group I) gradually decreased from the older shelterbelt (S11) to the field plot 50 m apart. In the younger shelterbelt (S6) the highest densities of these animals were recorded in the ecotone (E). As in the former transect, animal densities in the field decreased with the distance from the shelterbelt.

Dipteran and coleopteran larvae were most numerous animals of Group I. In some plots (shelterbelts and ecotones) Symphyla were also numerous. Formicidae were main dominants of litter animals (Group II) in shelterbelts and especially in ecotones. Imagines of Coleoptera were numerous in all sites.

Differences between animal densities in studied plots (total macrofauna, as well as of the particular groups and most of the taxa) were highly significant while the sampling date was less important (Table 3 A and B). The greatest are the differences between the values for shelterbelts and for the fields, while differences between plots situated within fields were not significant (Table 3).

Similarity indices of macrofauna composition *(s)* between studied sites varied between 0.89 and 0.33 (Table 4). Communities of macrofauna in shelterbelts of different age and in ecotones were most similar in composition. The greatest differences were usually recorded between the shelterbelt and adjoining field, particularly in its most distant plot (Table 4).

Similarity index of the domination structure *(Si)* varied between 77.5 and 6.1. Shelterbelt (S11) and ecotone (E-S6) communities as well as the oldest shelterbelt (S150) and the youngest shelterbelt (S6) were most similar in that respect. The lowest indices i.e. the greatest differences in the structure of macrofauna were found between the ecotone of the older shelterbelt (E-S11) and all other sites. In most cases control field (FC) was more similar in composition and domination structure of macrofauna to shelterbelts than to other field sites (Fig. 1).

The diversity of animal communities measured with the Shannon-Wiener *H*' index was the greatest in the oldest (S150) and youngest (S6) shelterbelts as well as in the control fields (FC) (3.08–3.01). The lowest diversity (1.05) was recorded in the ecotone bordering 11 years old shelterbelt (S11). It was an effect of high (84%) dominance of ants. In the remaining sites the index varied from 2.17 to 2.62 (Table 4).

Dipteran larvae were one of the most numerous taxa of studied macrofauna comprising 17 families in analysed sites (Table 5). None of the families was present in all sites. As many as four families occurred in only one out of ten studied sites. Most numerous and present in the greatest number of sites were Cecidomyiidae and Dolichopodidae. Most families (8) inhabited the ecotone (E)

Table 4. Similarity of macrofauna communities between the studied plots measured by two indexes: *s* – similarity index of composition after Marczewski and Steinhaus (1959), *Si* – similarity index of domination structure after Romaniszyn (1970) (see Methods). Symbols explanation – Tables 1, 2.

						Field adjacent to S 11								Field adjacent to S 6					
		S150		S11		E		F15		F50		S6		E		F15		F50	
		s	Si	s	Si	s	Si	s	Si	s	Si	s	Si	s	Si	s	Si	s	Si
	S11	0.7	47																
Field	E	0.7	40	0.9	40														
adjacent	F15	0.4	35	0.5	61	0.4	29												
to S 11	F50	0.4	49	0.4	36	0.4	8	0.6	36										
	S6	0.7	73	0.9	40	0.9	10	0.4	30	0.5	46								
Field	E	0.8	45	0.9	78	0.9	38	0.5	55	0.4	36	0.8	43						
adjacent	F15	0.5	30	0.5	25	0.5	8	0.4	26	0.7	59	0.5	36	0.5	24				
to S 6	F50	0.4	21	0.5	16	0.5	6	0.6	17	0.5	29	0.4	22	0.5	15	0.4	28		
	FC	0.5	53	0.6	36	0.6	7	0.5	39	0.5	58	0.6	50	0.5	33	0.3	39	0.5	30

Table 5. Composition and mean densities (ind. m^{-2}) of dipteran larvae in the studied plots. Symbols explanation – Tables 1, 2.

			Field adjacent S 11				Field adjacent to S 6			
Family	S150	S11	E	F15	F50	S6	E	F15	F50	FC
Anthomyiidae									3.3	
Asilidae	6.7	20.0			3.3		3.3			
Bibionidae	310.0	503.4		3.3						33.4
Cecidomyiidae	43.4	53.3	43.3	36.7	13.4	130.0	303.4	26.7		13.3
Chironomidae	3.3		10.0							3.3
Dolichopodidae	20.0	16.7	13.3	30.0	3.3	16.8	30.0			3.3
Muscidae						3.3				
Phoridae				3.3						
Psychodidae						3.3				
Rhagionidae	3.3	3.3								
Scatopsidae				83.4						
Sciaridae	33.3			6.7		3.3	23.3			
Sphaeroceridae			3.3	3.3			6.7			
Therevidae		3.3	3.3	3.3			10.0			
Tipulidae		3.3								
Trichoceridae							3.3	3.3		
Others						3.3	10.0			
Total	420.0	603.3	73.3	170.0	20.0	160.0	390.0	30.0	3.3	53.3
Number of families (17)	7	7	5	8	3	6	8	2	1	4
H' index	1.37	0.96	1.69	2.05	1.25	1.05	1.30	0.50	0.0	1.42

Table 6. Similarity of dipteran larvae communities between the studied plots measured by two indices: *s* – Marczewski and Steinhaus (1959) and *Si* – Romaniszyn (1970) (see Methods). Symbols explanation – Tables 1, 2.

						Field adjacent to S 11								Field adjacent to S 6					
		S150		S11		E		F15		F50		S6		E		F15		F50	
		s	*Si*	*s*	*Si*	*s*	*Si*	*s*	*Si*	*s*	*Si*	*s*	*Si*	*s*	*Si*	*s*	*Si*	*s*	*Si*
	S11	0.5	78																
Field	E	0.3	9	0.3	6														
adjacent	F15	0.4	10	0.4	8	0.4	27												
to S 11	F50	0.4	9	0.4	8	0.3	61	0.2	24										
	S6	0.3	9	0.2	6	0.2	21	0.3	21	0.3	62								
Field adjacent	E	0.4	12	0.4	7	0.4	56	0.4	23	0.4	61	0.4	81						
to	F15	0.1	5	0.1	5	0.2	42	0.1	12	0.2	50	0.1	68	0.2	65				
S 6	F50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		
	FC	0.6	65	0.4	59	0.5	23	0.3	17	0.4	18	0.2	18	0.2	18	0.2	14	0.0	0.0

Table 7. Mean biomass (mg.d.wt. m^{-2}) of soil (Group I) and litter (Group II) macrofauna in the studied plots. Symbols explanation – Tables 1, 2.

Taxon			Field adjacent to S11				Field adjacent to S6			
	S150	S11	E	F15	F50	S6	E	F15	F50	FC
Group I										
Insect larvae:										
Diptera	683.3	1759.7	37.0	82.0	11.3	57.0	205.3	15.4	3.3	138.0
Coleoptera	178.3	373.0	178.3	42.7	35.7	106.0	208.3	122.3	6.7	25.7
Heteroptera	1.0	0.7	4.7			2.3	1.7			
Homoptera	1.0	0.7		0.7			1.7			
Others	76.7	41.7	15.0			1.3	51.7	33.3		
Lumbricidae	233.3		116.7				58.3			
Enchytraeidae		1.0	1.7	6.7			5.0		1.0	4.0
Symphyla	46.0	28.3	3.3	1.0	1.0	27.3	35.0			2.0
Chilopoda	227.3	10.0	8.3			28.3	19.7			2.0
Diplopoda	66.7									93.3
Total	1513.6	2215.1	365.0	133.1	48.0	222.2	586.7	171.0	11.0	265.0
Group II										
Insect imagines:										
Diptera	2.0	1.3	4.7	1.3	1.3	0.7	10.7	10.8	2.3	3.0
Coleoptera	215.0	225.0	117.7		5.0	212.7	344.7	21.7	36.7	33.3
Staphylinidae	105.3	52.3	47.0	8.0	2.7	34.7	47.3	9.3	1.0	7.0
Aphidoidea		1.0	2.3			1.3				0.3
Heteroptera		25.0	30.0			18.3	16.7			
Hymenoptera	3.7	2.0	1.7			1.7	1.0		0.3	0.3
Formicidae	53.3	1223.3	4160.0	83.3	3.3	16.7	428.3	6.7		
Thysanoptera	1.7	5.0	2.3			4.0	5.3	1.3		
Aranea	22.0	31.7	7.0	8.3		8.7	5.0		1.0	1.7
Pseudoscorpionidae	10.0									
Total	413.0	1566.6	4372.7	100.9	12.3	298.8	859.0	49.8	41.3	45.6
All macrofauna	1926.6	3781.7	4737.7	234.0	60.3	521.0	1445.7	220.8	52.3	310.6

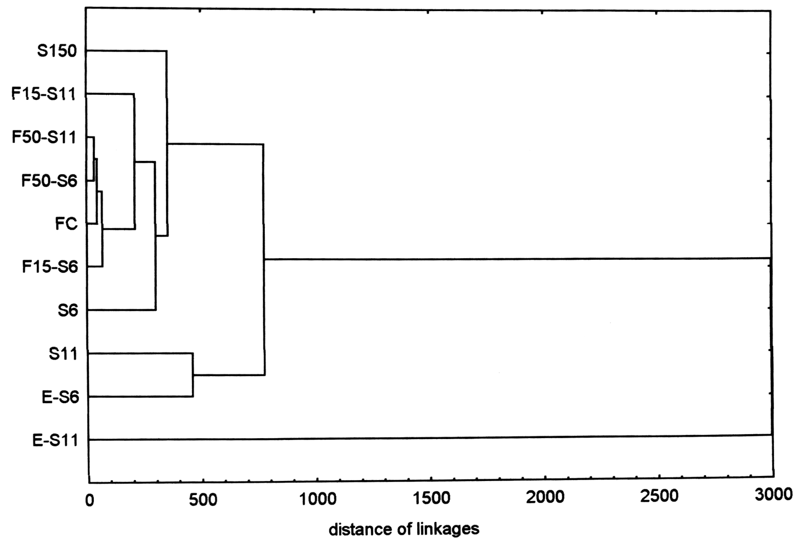

Fig. 1. Similarity (Euclidean distance) between communities of macrofauna in midfield shelterbelts (S) differentiated by age (150, 11, 6 years old), in adjacent fields at the distances 15 and 50 m (F15, F50) from the shelterbelt edge (E) and in control field (FC) located in deforested area.

of the youngest shelterbelt (S6) and the field 15 m (F15) apart from older shelterbelt (S11). Shelterbelts were characterised by relatively high diversity of dipteran larve (6–7 families). One to four families inhabited fields (Table 5).

Shannon-Wiener (*H'*) diversity index was relatively low – it varied between 0.0 (the case when one taxon was found only) and 2.048 and did not show any directional changes in studied sites (Table 5).

Great differences were found in the density of dipteran larvae between studied sites. In general, the density ranged from 3.3 to 603.3 individuals m^{-2}. The highest densities of dipteran larvae were noted in older shelterbelt (S11) and in the ecotone of the youngest one (S6). The lowest density (3.3–53.3 ind. m^{-2}) was found in fields, particularly in sites distant from shelterbelts. The larvae of Bibionidae were the dominants in older shelterbelts while in the youngest shelterbelt and in its ecotone most numerous were the larvae of Cecidomyiidae.

Between-site comparison showed that only the strip composed of black locust (S 150) and 10–11 years old shelterbelt (S11) significantly differed in the density of dipteran larvae from field sites 50 m apart along both transects (Table 3B).

Community composition of dipteran larvae in studied sites was diverse. Similarity index (*s*) varied from 0.0 to 0.57 (Table 6). The greatest similarity of larval communities was observed between black locust strip (S150) and 10–11 years old shelterbelt (S11) ($s = 0.55$) and between the former and the control field ($s = 0.57$) (Table 6).

Domination structure in the communities of dipteran larvae (*Si*) was most similar for the sites: the youngest shelterbelt (S6) and its ecotone ($Si = 81$) and between the oldest shelterbelt (S150) and 11 years old (S11) – ($Si = 78$) (Table 6). The index values varied between 0.0 and 81 in all studied sites. In the field F50 adjacent to the young shelterbelt (S6) the community of dipteran larvae was totally different from that in remaining sites – both indices were equal 0.0. The reason of that was a great poverty of species and numbers of larvae there (1 family – occurring in this site only, at a density of 3.3 ind. m^{-2}) (Fig. 2).

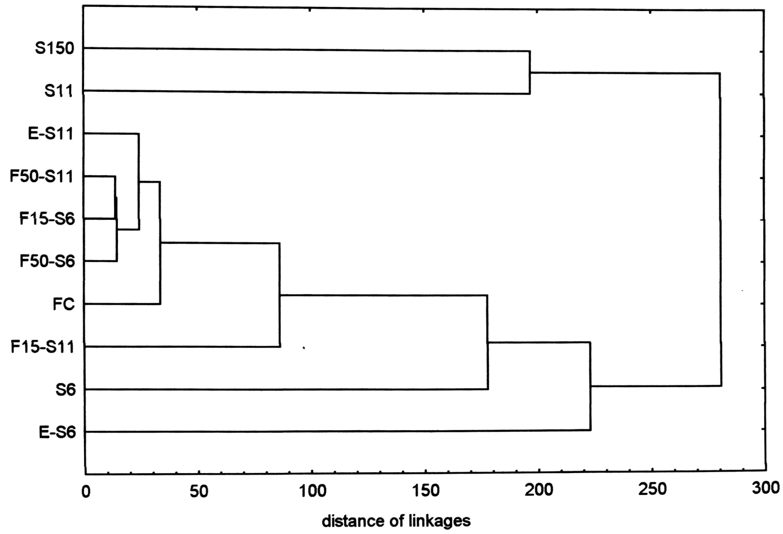

Fig. 2. Similarity between communities of Diptera larvae in different sites (explanations as in Fig. 1).

4.2. Animal biomass and mean individual weight

The changes of biomass of total macrofauna followed similar trend as the changes of their density. The mean biomass in studied sites varied considerably between 52 and 4738 mg dry wt. m^{-2} (Table 7). The highest biomass was found in the ecotone of the older shelterbelt (S11) and was also high in other shelterbelts, particularly in older ones (S150, S11). The biomass of macrofauna in both ecotones was higher than in respective shelterbelts. The biomass values decline significantly across the transect: ecotone → field 50 m. Relatively high animal biomass was recorded in the control field (FC), higher than in the fields neighbouring shelterbelts. In general, larvae of Diptera and Coleoptera from Group I and Formicidae as well as imagines of Coleoptera from Group II dominated in the total biomass of most sites (Table 7).

Mean value of biomass of dipteran larvae was different in studied sites ranging from 3.3 to 1760 mg dry wt. m^{-2} (Table 8). In four plots (S150, S11, and adjacent field – F15 and in the control field FC) dipteran larvae dominated clearly (35–47% of the total invertebrate biomass). Larvae of Bibionidae (86–97% of the total biomass of dipteran larvae) were the main dominants among dipteran larvae in three sites (Table 8). Therevidae highly contributed to the biomass of fauna in ecotones of both shelterbelts and in the field 15 m adjacent to the older belt (S11). Dolichopodidae and Cecidomyiidae dominated in the youngest shelterbelt (S6), the biomass in particular sites was dominated by different families of Diptera (Table 8).

The mean body mass of individuals of the total macrofauna ranged between 0.48 and 1.58 mg d. wt., being the highest in the older shelterbelts (S150, S11) and in the control field, and the lowest in the young shelterbelt (S6) and in the adjacent field (F15) (Fig. 3). The body mass of individuals of Group I followed the same pattern. There was a tendency of declining body mass across the transect through shelterbelt → field in case of older shelterbelt (S11) and of increasing – in the case of younger transect (S6 – adjacent field). The individuals of the soil fauna (Group I) were larger than of epigeic fauna (Group II).

4.3. Trophic structure of macrofauna

Analysed animals were divided into three basic trophic groups: saprophages, phytophages and zoophages (including parasitoids) according to their food preferences

Table 8. Mean biomass (mg.d.wt. m $^{-2}$) of dipteran larvae in the studied plots (explanations as in Tables 1, 2).

			Field adjacent to S11				Field adjacent to S6			
Family	S150	S11	E	F15	F50	S 6	E	F15	F50	FC
Anthomyiidae									3.3	
Asilidae	5.3	100.0			8.3		28.3			
Bibionidae	620.0	1510.0		6.7						133.4
Cecidomyiidae	5.3	5.7	6.3	4.7	1.7	18.7	36.3	3.7		2.3
Chironomidae	0.7		3.3							1.0
Dolichopodidae	5.0	64.0	2.7	8.7	1.3	31.0	10.0			1.3
Muscidae						5.0				
Phoridae				0.3						
Psychodidae						0.7				
Rhagionidae	35.0	28.4								
Scatopsidae				16.7						
Sciaridae	12.0			3.3		1.3	7.0			
Sphaeroceridae			1.3	1.7			1.7			
Therevidae		33.3	23.4	40.0			116.7			
Tipulidae		18.3								
Trichoceridae							3.3	11.7		
Others						0.3	2.0			
Total	683.3	1759.7	37.0	82.0	11.3	57.0	205.3	15.4	3.3	138.0

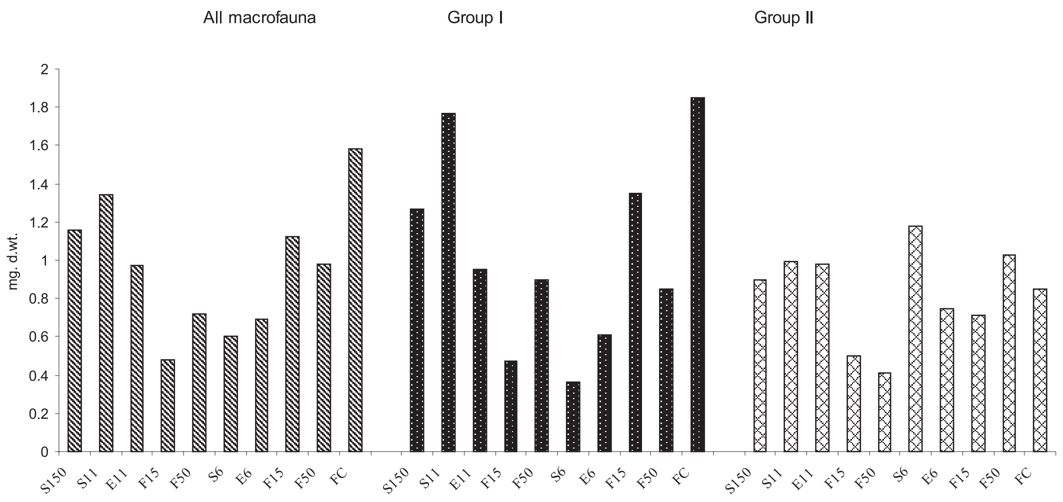

Fig. 3. Mean individual body mass (dry weight) of all macrofauna and separately for soil (Group I) and litter (Group II) fauna (explanations as in Fig. 1).

and – in the case of dipteran and coleopteran larvae – the trophic status of recorded families.

Saprophages dominated (in terms of numbers) on most studied sites. Their highest contribution to the total fauna was noted in the control field (64%), in the field 50 m from the older shelterbelt (S11) (66%) and in the oldest shelterbelt S150 (59%) (Fig. 4). In both transects the contribution of saprophages decreased from shelterbelt to ecotone to increase again in the adjacent field with increasing distance to the shelterbelt. The reverse trend was observed in the case of predators whose contribution was the highest in ecotones and declined in fields with

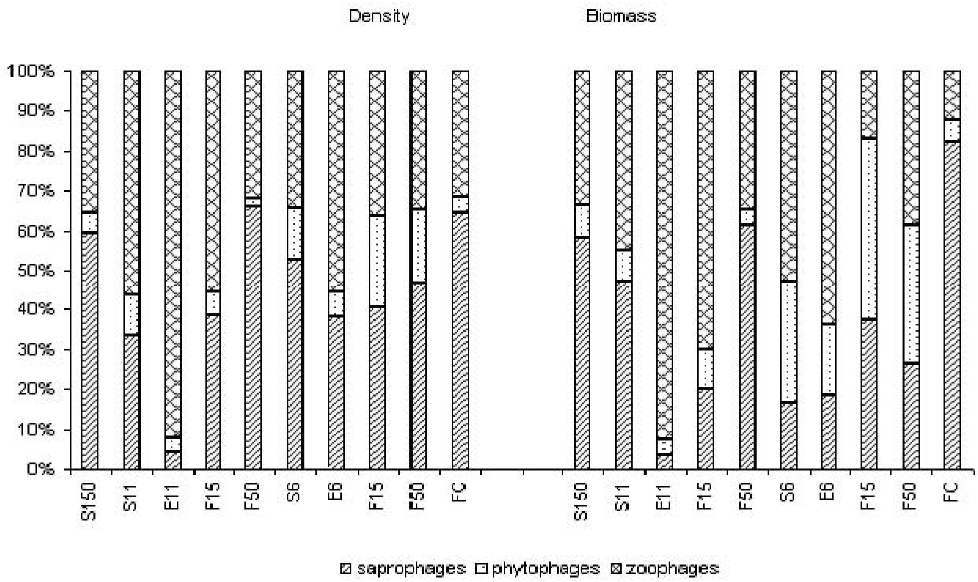

Fig. 4. Trophic structure of macrofauna in soil/litter interface in agricultural landscape. Percentage contribution of different trophic groups in total numbers and biomass.
S – shelterbelt, E- ecotone between shelterbelt and field, F15, F50 – adjacent field at the distances 15 and 50m form the edge of shelterbelt. Numbers 150, 11, 6 – shelterbelt age in years.

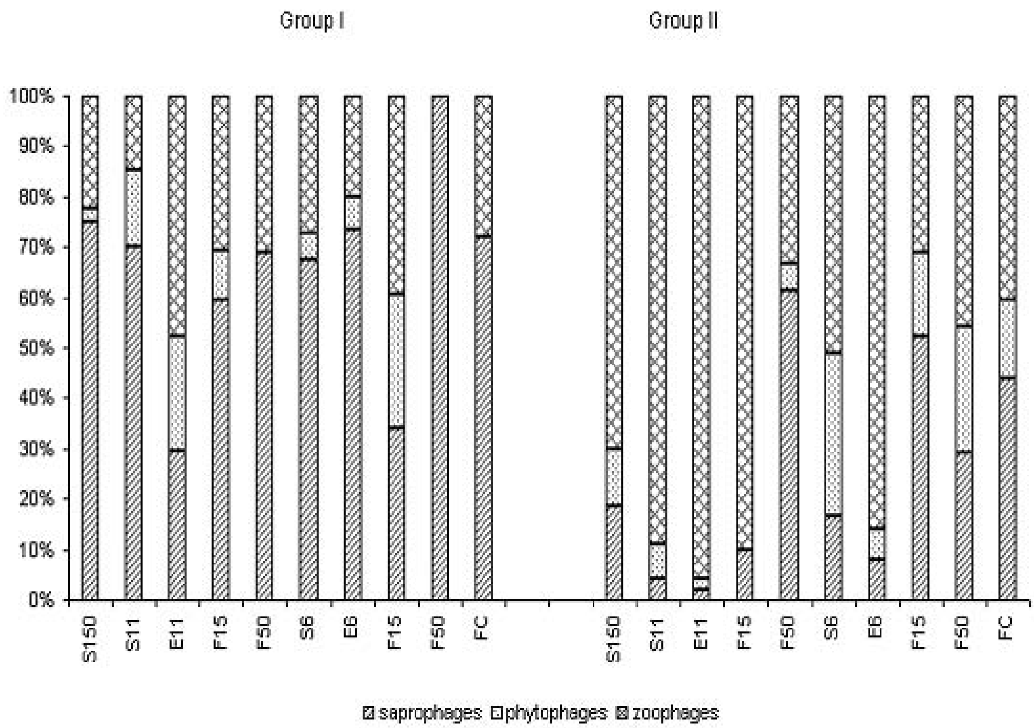

Fig. 5. Trophic structure of soil (Group I) and epigeic (Group II) communities – percent contribution to the total numbers (explanations as in Fig. 3).

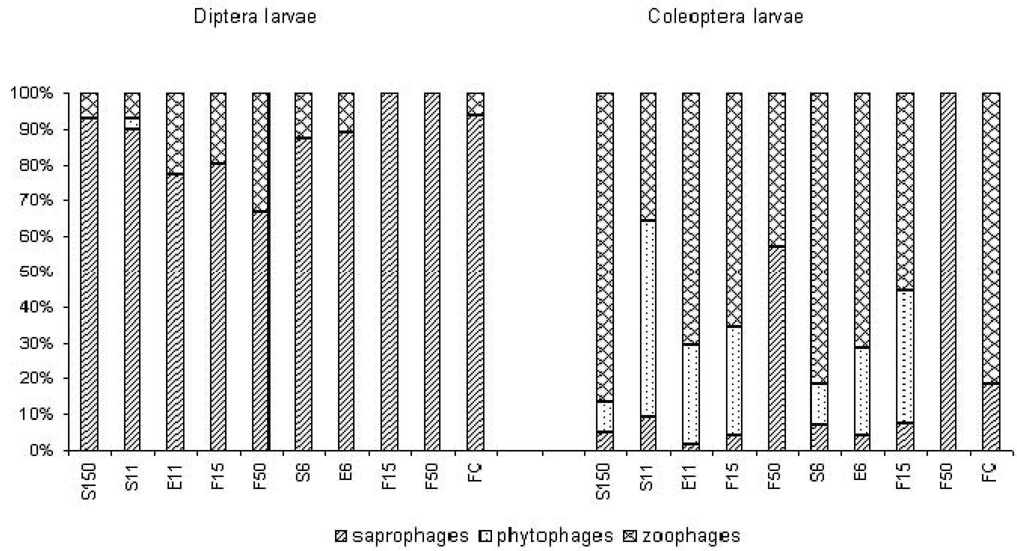

Fig. 6. Trophic structure of communities of Diptera and Coleoptera larvae – percent contribution to the total numbers (explanations as in Fig. 3).

the increasing distance from shelterbelt. Biomass of trophic groups of soil and litter macrofauna followed the same pattern, especially across the transect through the older shelterbelt (S11) to the its field (F50). Moreover, contribution of the biomass of herbivores in the sites along the transect connected with S6 was significant particularly in the field site. The biomass of saprophages increased and that of predators decreased with the age of shelterbelts (Fig. 4).

Comparison of the trophic structure of both Groups showed that in most sites saprophages were the dominants in Group I (soil fauna) while predators in epigeic fauna (Group II) (Fig. 5). Trophic structure of the two taxa – dipteran and coleopteran larvae was also similar. Among dipteran larvae saprophages dominated, particularly in the density (Fig. 6). Their contribution ranged from 67 to 100%. In most plots the community of dipteran larvae was composed of saprophages and predators, in two plots only saprophages were recorded and in one plot (S11) all three trophic groups were present. In the communities of coleopteran larvae predators predominated over saprophages with a large contribution of herbivores (Fig. 6). The share of herbivores increased from shelterbelt to field 15 m (S-F15) in both transects. Farther in the field (F50) herbivore coleopteran larvae were not found (Fig. 6).

5. DISCUSSION

This study is the continuation and extending for new sites the previous investigations carried out in the vicinity of Turew near Poznań in the years 1999–2000 (Olechowicz 2004 a, b). Samples were collected in the same shelterbelts as before (S150, S11 and S6) now older by 4 years. This time two transects across shelterbelt and field 50 m apart have been studied (S11→°F50 and S6→°F50). The study was undertaken to get the answer whether the decline in biomass in the fields with increasing distance to the shelterbelt and changes in structure of macrofauna observed before are confirmed and to recognise whether and in what way the age of shelterbelts affect macrofauna of adjacent fields. For comparative purposes samples were also collected in a large field located in the deforested area (FC). According to the hypothesis, densities, biomass and diversity of analysed animals in such a field should be the lowest. However it was not so. This field differed from the fields adjacent to shelterbelts in soil properties – organic matter and phosphate content, were higher as well as pH (Table 1).

Different cereal species in studied fields could also affect the results. In consequence, the results obtained from the control field do not support this hypothesis. Animal densities in this field were slightly higher (though difference was not statistically significant) than in fields adjoining shelterbelts (Table 2). High taxonomic richness, high diversity index and the trophic structure of macrofauna were more similar to those in shelterbelts than to other fields. Its remains difficult to explain. Other authors recorded the similar results from studies on meso- and microfauna (Dmowska 2007, Olejniczak 2007).

Presented data demonstrate that the density and biomass of soil and litter macrofauna, as well as their particular groups (Group I and II – see Methods) and taxa were many times higher in shelterbelts than in fields. This was also true for taxonomic richness (Tables 2 and 5). This regularity confirms earlier findings from this area (Olechowicz 2004a) and literature data (Górny 1968 a, b, Wallwork 1970, Ryszkowski 1985, Szujecki 1990, Dangerfield 1990). It appears that diversity, density and biomass of macrofauna communities is lower in agroecosystems compared with seminatural terrestrial ecosystems. This pertains also to entomofauna of the field layer (Dąbrowska-Prot 1987, 1991, Ryszkowski and Karg 1977, Ryszkowski *et al.* 1993, 1999, Karg and Ryszkowski 1996a, b).

Values of densities, biomass and the number of taxa found in shelterbelts fall within the range recorded in pine and mixed forests (Olechowicz 1998). The number of taxa noted in 16 pine forests of various regions of Poland varied between 12 and 21, density – between 72 and 2325 ind. m^{-2} and biomass – between 635 and 2263 mg dry wt. m^{-2}. The same is true for the most numerous taxa i.e. the larvae of Diptera and Coleoptera (Paplińska 1980, 1987, Olechowicz 1986, 1998).

The increase of biomass and density of the soil and litter macrofauna with the age of midfield shelterbelts observed in previous studies (Olechowicz 2004b) was confirmed herein. The oldest black locust shelterbelt (S150) in the former studies was characterised by the highest density of macrofauna as compared with younger ones. Howewer now the opposite relation was found: the density in the oldest shelterbelt is lower than in 10 –11 years old shelterbelt (S11), although the difference is not significant (Table 3B). Significantly lower density of animals was noted in the youngest shelterbelt (S6) than older ones. Noteworthy, the oldest shelterbelt differs from others not only in age but also in the character of tree stand – it is dominated by one tree species *Robinia pseudoacacia* while in the young shelterbelts several species were planted. Thick layer of litter of high C and N content and of low pH of soil and litter is typical for the oldest shelterbelt as compared with younger tree stands (Table1).

To evaluate the effect of shelterbelt's age on adjoining fields and to check the reproducibility of previous results two transects were set up crossing: shelterbelt → ecotone → field 15 m and field 50 m from the shelterbelt's edge. In this study – density, biomass and even animal diversity were higher in the shelterbelts and ecotones (between the shelterbelt and the field) than in the adjacent fields. Higher values were recorded in the field at the distance 15 m from the shelterbelt than at 50 m. This result was repeated in both transects. An increase of density and biomass of the whole community and of animals of Group II (mainly Formicidae) in the ecotone and then remarkable decline in the field was also observed in both transects. Animals of Group I and its most numerous taxa – dipteran and coleopteran larvae – and Symphyla behaved in a different manner. No increase of their density and biomass in the ecotone of older shelterbelt (S11), was found as it was before. Such change of density was found only in the ecotone of younger shelterbelt (S6). It was probably associated with the shelterbelt's age. Ecotones are known to have higher densities, biomass and species diversity than neighbouring ecosystems (Dąbrowska-Prot 1999).

The effect of shelterbelt's age on adjoining fields was distinctly visible. Densities, biomass and diversity of all animals and of most taxa in all compared plots were lower in the transect connected with the younger than with the older shelterbelt. In both transects changes in the density and biomass of animals in subsequent plots relative to shelterbelt followed the same pattern.

The greatest similarity in composition and domination structure of communities was found between shelterbelts and their ecotones and relatively low – between shelterbelts and adjoining fields. In both transects a decline of both indices (*s* and *Si*) i.e. decreasing similarity of the communities of macrofauna with distance from the shelterbelt was observed. Similar results were obtained in former studies (Olechowicz 2004a).

Trophic structure of studied macrofauna did not show directional changes. Observed trends disagree with earlier results. Predominance of saprophages among soil fauna (Group I) and of dipteran larvae and predators among animals of Group II (epigeic fauna) and of coleopteran larvae were the only confirmed findings (Olechowicz 2004a, b).

Mean body weight of average individual in animal community in a given habitat is considered an important biocoenotic index (Szujecki 1990). Present studies confirmed that individual body mass was lower in younger than in older shelterbelts (Olechowicz 2004b). A decrease of body mass was observed, as before, but only along the transect from the older shelterbelt (S11) to field 50 m apart. It is hard to explain whether the age of shelterbelts was responsible for such an effect.

Regularities of the succession of soil animals in new planted shelterbelts (Olechowicz 2004b) observed earlier have been fully confirmed. In the first and second year after shelterbelt planting dipteran larvae dominated, and they constituted 90% of total macrofauna. The larvae of Chironomidae and Sciaridae were distinct dominants (over 90% of the whole dipteran larvae community). After successive four years the structure of the whole community and of dipteran larvae has changed according to the earlier described succession stages (Olechowicz 2004b). The contribution of dipteran larvae has decreased to 18%, and proportion of Symphyla and Coleoptera has increased to 30 and 16%, respectively, and Chilopoda, characteristic for older woodlots, have appeared in the site.

The structure of dipteran larvae has also changed – the share of Sciaridae markedly decreased to 6%, pioneers of succession – the larvae of Chironomidae were absent but the density and relative contribution of Cecidomyiidae (characteristic for later stage of succession) significantly increased to 78%. Such a course of succession in young woodlots or fallows is also confirmed by the other results (Struve-Kusenberg 1981, Frouz 1994, 2001, Borowski 1995, Paquin and Coderre 1997).

6. CONCLUSIONS

1. The density and biomass of total macrofauna, and of particular taxa were many times greater in shelterbelts than in fields and decreased gradually with increasing distance from the ecotone. This was also true for taxonomic richness. Respective between-plots differences in density were statistically significant. The greatest density and biomass were recorded in ecotones. These results, as well as those obtained in the previous studies provided in the same area suggest, that wood strips planted in agricultural landscape enhance macrofaunal soil community.

2. The density and biomass of soil and litter animals increased with the age of midfield shelterbelts, both within the forested strips and in adjacent fields. Differences between respective plots were statistically significant.

3. In the ecotones of both transects the density and biomass of the total macrofauna and of Group II -epigeic fauna (mainly ants) increased as compared with the shelterbelts to decline farther in the field.

4. Shelterbelts and their ecotones were most similar to each other in composition and domination structure of the communities of macrofauna and of dipteran larvae. They markedly differed, however, from fields.

5. A tendency was observed of decreasing contribution of saprophages in the total number of individuals and increasing proportion of predators in ecotones as compared with shelterbelts followed by increasing proportion of saprophages farther in the field. Animals of Group I (soil fauna) and dipteran larvae were dominated by saprophages, those of Group II (epigeic fauna) and coleopteran larvae – by zoophages.

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