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VOL. **78**: 351-368   Bydgoszcz   30 December 2009

Prevalence of eugregarines (Apicomplexa: Eugregarinida) parasitizing in ground beetles (Coleoptera, Carabidae) in various habitats*

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ABSTRACT. Differences in the prevalence of eugregarines parasitisation in epigeic communities of the Carabidae beetles family were studied. Host insects were collected from six sites differing in the level of plant cover and humidity. It was proved that the level to which Carabidae were parasitized by eugregarines was significantly influenced by the plant cover of the land. The Carabidae way of feeding was a less important factor influencing the prevalence. Large size zoophages and hemizoophages were parasitized at higher level than small zoophages.

KEY WORDS: parasitic protozoans, Eugregarinida, prevalence, Coleoptera, Carabidae, ground beetles communietes, anthropopressure, plant cover.

INTRODUCTION

Due to relatively large cell size eugregarines have been an easy object of many taxonomic and faunistic studies. According to the study by CLOPTON (2002) almost 1,700 gregarine species have been described out of about 3,200 species of invertebrates. Among insects only 0.32% of the known taxa have been checked for eugregarines. Along with taxonomy, various aspects of their ecology are being studied (CLOPTON, JANOVY 1993, CLOPTON, GOLD 1995, TOSUNO et al. 2008, KUBILAY & GÖKCE 2005). Also an extensive study of eugregarines' life history is being carried out.

* Research supported by grant No. 2PO6R06630 from Polish Ministry of Science and Higher Education

However, there is little information on the influence of eugregarines on their host species' populations (HARRY 1970, 1971, BROOKS & JACKSON 1990, HECKER et al. 2002, ZUK 1987, JOHNY et al. 2000), and also on the influence of hosts' habitat on the prevalence of eugregarines (FOERESTER 1939 a, b, VAN RHEI et al. 2000). Such study can be justified with the biology of those protozoans, which in their

full developmental cycle also live as spores outside their host's body. Then they depend on habitat conditions and availability of their specific hosts (FOERSTER 1939a). The study assumed that the level of Carabidae infestation by eugregarines depends most of all on the extent of habitat's greenery cover. The denser and higher the cover, the higher the humidity, due to lower insolation. Dryness and over-insolation diminish the chance of spores' survival (FOERESTER 1939a). Another factor helping infestation according to FOERSTER (1939a) is humidity, whose influence was also taken into account in the study. It was also assumed that of the Carabidae the large species, feeding of soil invertebrates on a higher biomass, will most often be infected. Such a way of feeding should help spores to penetrate their hosts' bodies more than hemizoophagous feeding. In the latter case the diet of potential gregarine hosts plays a significant role. This is also related to beetles' periodic stay on plants.

Study areas

Collecting of gregarine host insects for microscopic studies was conducted in Wielkopolska Region (western Poland). Six permanent study sites were selected: two in Wielkopolska National Park, two in NATURA 2000 "Biedrusko" site, and two on cultivated fields of the Institute of Plant Protection in Poznań, located near the village of Winna Góra. The study sites differed in plant cover, which is related to different levels of anthropopressure and humidity. A list of sites and their characteristics and abbreviation are presented in Table 1.

Material and methods

In 2006-2007 in six study sites adults of ground beetles were caught in soil traps made with plastic pots of 20 cm diameter and 17 cm high. The trap bottoms were covered with soil and moss in order to ensure that the trapped insects survived. In each study site six such traps were maintained. During vegetation seasons (April to October) adult beetles were caught twice a month. After identifying the insects in a laboratory their digestive tracts were dissected in saline solution and microscope-checked for the presence of eugregarines. Their species was specified. Immediately after putting them out their digestive tract was prepared. Altogether 3,530 adult Carabidae specimens belonging to 89 species were examined and 12 species of eugregarines were identified in them (Table 2)

The insects were divided into trophic groups according to LEŚNIAK (1984, 1997) and SKŁODOWSKI (1994), i.e. classified as large zoophages, small zoophages and hemizoophages (feeding largely on plants). The share of trophic groups in particular sites is presented in Table 5. In order to prove differences the ANOVA variance analysis was performed. All the values expressed as percentage were then converted into Bliss angle values prior to the statistical analysis. The calculations were performed with STATISTICA 8 programme.

Table 1. List and description of habitats where during 2006-2007 Carabidae were collected.

UTM Code	Research plot number	Locality	Type of habitat	Abbreviation
XT19	1	Wielkopolska National Park	Humid forest – well-preserved fragment of natural alder and oak forest (*Ribo nigri – Alnetum*)	WM
XT19	2		Dry forest habitat – community of sub-continental pine forest (*Peucedano - Pinetum*) on sun-exposed moraine slope	WS
XT31	3	”Biedrusko”–NATURA 2000 site	Intensely wet semi-natural meadow in a hollow	PM
XT31	4		Semi-natural, dried sward on sand (psammophile) on a hill	PS
XT68	5	Institute of Plant Protection near Winna Góra, Środa Wielkopolska county	Arable fields with wheat in a fertile and wet fragment of the field in a hollow	IM
XT68	6		Arable fields with rye on poor and dried sandy soil	IS

RESULTS

Eugregarine parasitization was recorded in 50 host ground beetles species out of 89 species (Table 2). Depending on habitat type the prevalence of eugregarines in community-forming specimens was different (Table 3, Fig. 1). The largest parasitisation level was observed among insects collected in well-preserved fragment of swamp alder wood (*Ribo nigri-Alnetum*), where on an average over 50 % of individuals contained eugregarines. A surprisingly high level of parasitisation was recorded among the beetles collected in the *psammophila* sward (PS) of semi-natural character, reaching even 28.7% of the studied individuals. The lowest host parasitization level was observed on cultivated fields (2-9.5%), so in areas strongly transformed by man. A two-way variance analysis (Table 5) proved that the most significant factor influencing the level of parasitization of ground beetles communities was the extent to which the area was covered by plants (56 % of the explained diversity). The habitat humidity could have had only a small modifying impact on the prevalence.

Table 2. List of studied Carabidae species and their abundance in 2006-2007 with consideration of Eugregarinida species recorded (abbreviations of sites as in Table 1).

Host species	Eugregarinae**	Habitat											
		IS		IM		PS		PM		WS		WM	
		examinated	partasitized	examinated	partasitized	examinated	partasitized	examinated	partasitized	examinated	partasitized	examinated	partasitized
-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-	-14-
Agonum versutum (STURM)	in process of identification	-	-	-	-	-	-	-	-	-	-	1	1
Agonum viduum (PANZ.)	in process of identification	-	-	-	-	-	-	-	-	-	-	2	1
Amara aenea (DE GEER)	in process of identification	30	5	16	7	-	-	-	-	-	-	-	-
Amara aulica (PANZ.)	*Gregarina lipai* LEVINE	-	-	-	-	1	1	5	3	-	-	-	-
Amara bifrons (GYLL.)	*Gigaductus exiguus* WELL.	4	2	3	2	7	1	-	-	-	-	-	-
Amara communis (PANZ.)	*Gigaductus exiguus* WELL.	1	0	-	-	10	1	46	3	-	-	2	0
Amara convexior STEPH.	*Torogregarina* sp.	-	-	-	-	4	3	23	3	-	-	-	-
Amara equestris (DUFT.)	in process of identification	-	-	-	-	4	1	-	-	-	-	-	-

-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-	-14-
Amara famelica ZIMM.	in process of identification	2	0	5	2	1	0	-	-	-	-	1	0
Amara familiaris (DUFT.)	in process of identification	-	-	2	1	-	-	-	-	-	-	-	-
Amara lunicollis (SCHOED.)	*Gregarina amarae* (HAMM.)	2	0	-	-	9	4	11	1	-	-	1	0
Amara ovata (FABR.)	in process of identification	1	0	-	-	-	-	-	-	-	-	-	-
Amara plebeja (GYLL.)	in process of identification	3	0	9	3	1	0	-	-	-	-	-	-
Amara similata (GYLL.)	in process of identification	1	0	2	0	-	-	-	-	1	0	-	-
**Amara spreta* DEJ.	-	-	-	-	-	1	0	-	-	-	-	-	-
**Anisodactylus binotatus* (FABR.)	-	1	0	1	0	-	-	-	-	-	-	-	-
**Asaphidion flavipes* (L.)	-	2	0	-	-	-	-	-	-	-	-	-	-
**Badister bullatus* (SCHRANK)	-	-	-	-	-	-	-	3	0	-	-	-	-
**Badister lacertosus* STURM	-	-	-	-	-	-	-	-	-	3	0	2	0
**Badister sodalis* (DUFT.)	-	-	-	-	-	-	-	-	-	-	-	1	0
**Bembidion gilvipes* STURM	-	-	-	-	-	-	-	36	0	-	-	-	-
**Bembidion lampros* (HERBST)	-	42	0	38	0	-	-	-	-	-	-	-	-
**Bembidion properans* (STEPH.)	-	44	0	23	0	-	-	-	-	-	-	-	-
**Bembidion quadrimaculatum* (L.)	-	-	-	1	0	-	-	-	-	-	-	-	-
**Bembidion tetracolum* SAY	-	-	-	1	0	-	-	-	-	-	-	-	-

-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-	-14-
**Broscus cephalotes* (L.)	-	1	0	-	-	-	-	-	-	-	-	-	-
Calathus ambiguus (PAYK.)	in process of identification	155	0	201	1	-	-	-	-	-	-	-	-
Calathus erratus SAHLB.	in process of identification	1	0	3	0	9	1	-	-	-	-	-	-
Calathus fuscipes (GOEZE)	*Gigaductus elongatus* (MOR.)	13	0	109	1	36	6	-	-	-	-	1	0
Calathus melanocephalus (L.)	*Gigaductus elongatus* (MOR.)	9	1	18	0	6	4	1	0	-	-	-	-
**Calosoma auropunctatum* (HERBST)	-	x	x	8	0	-	-	-	-	-	-	-	-
**Carabus cancellatus* ILL.	-	1	0	3	0	1	0	-	-	-	-	-	-
Carabus convexus FABR.	*Ancyrophora gracilis* (SCHNEID.)	-	-	-	-	-	-	-	-	30	4	-	-
Carabus coriaceus L.	*Actinocephalus permagnus* WELL.	-	-	-	-	-	-	-	-	3	3	20	13
Carabus granulatus L.	*Ancyrophora gracilis* (SCHNEID.) *Ancyrophora stelliformes* (SCHNEID.) *Actinocephalus permagnus* WELL.	-	-	1	0	-	-	5	4	-	-	110	66
Carabus hortensis L.	*Ancyrophora gracilis* (SCHNEID.) *Actinocephalus permagnus* WELL	-	-	-	-	-	-	1	1	51	10	6	1
Carabus nemoralis MUELL.	*Ancyrophora gracilis* (SCHNEID.) *Ancyrophora stelliformes* (SCHNEID.) *Actinocephalus permagnus* WELL.	-	-	-	-	38	32	76	60	115	15	59	25
**Clivina fossor* (L.)	-	-	-	8	0	-	-	-	-	-	-	-	-
Cychrus caraboides (L.)	in process of identification	-	-	-	-	10	0	3	0	20	4	2	0

-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-	-14-
**Dolichus chalensis* (SCHALL.)	-	1	0	8	0	-	-	-	-	-	-	-	-
Harpalus affinis (SCHRANK)	*Gregarina lipai* LEVINE *Gigaductus elongatus* (MOR.)	37	2	90	7	2	1	2	0	-	-	-	-
**Harpalus anxius* (DUFT.)	-	2	0	-	-	-	-	-	-	-	-	-	-
**Harpalus autumnalis* (DUFT.)	-	-	-	-	-	-	-	-	-	2	0	2	0
**Harpalus froehlichii* STURM	-	1	0	-	-	-	-	-	-	-	-	-	-
Harpalus griseus (PANZ.)	in process of identification	-	-	1	0	2	1	-	-	-	-	-	-
Harpalus latus (L.)	*Actinocephalus echinatus* WELL.	5	1	-	-	3	0	21	3	2	0	3	0
**Harpalus progrediens* (SCHAUB.)	-	1	0	1	0	-	-	-	-	-	-	-	-
**Harpalus distinguendus* (DUFT.)	-	1	0	5	0	-	-	-	-	-	-	-	-
Harpalus quadripunctatus DEJ.	in process of identification	-	-	-	-	1	0	-	-	4	0	9	2
Harpalus rubripes (DUFT.)	*Gregarina lipai* LEVINE	1	0	-	-	111	17	5	1	-	-	-	-
Harpalus rufipes (DE GEER)	*Clitellocephalus ophoni* (TUZ. et ORM.) *Gregarina amarae* (HAMM.)	47	2	237	16	13	2	6	1	-	-	2	0
**Harpalus smaragdinus* (DUFT.)	-	-	-	-	-	1	0	-	-	-	-	-	-
Harpalus tardus (PANZ.)	*Gigaductus elongatus* (MOR.) *Gregarina amarae* (HAMM.) *Gregarina polyaulia* WELL.	29	11	6	0	12	4	1	0	-	-	-	-

-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-	-14-
**Harpalus vernalis* (DUFT.)	-	-	-	1	0	1	0	-	-	-	-	-	-
Harpalus winkleri SCHAUB.	in process of identification	1	0	-	-	1	0	5	0	-	-	1	0
Idiochroma dorsalis (PONT.)	in process of identification	3	0	24	1	-	-	-	-	-	-	1	0
**Leistus terminatus* (PANZ.)	-	-	-	-	-	-	-	-	-	3	0	-	-
Licinus depressus (PAYK.)	in process of identification	-	-	-	-	1	0	2	0	5	2	-	-
**Loricera pilicornis* (FABR.)	-	2	0	3	0	-	-	2	0	-	-	1	0
**Metophonus laticollis* MANN.	-	-	-	-	-	-	-	-	-	-	-	5	0
**Metophonus seladon* SCHAUB.	-	-	-	-	-	-	-	-	-	-	-	1	0
**Microlestes minutulus* (GOEZE)	-	2	0	-	-	1	0	-	-	-	-	-	-
Nebria brevicollis (FABR.)	in process of identification	-	-	-	-	1	0	-	-	-	-	36	1
**Notiophilus biguttatus* (FABR.)	-	-	-	-	-	-	-	-	-	1	0	-	-
**Notiophilus germinyi* FAUV.	-	-	-	-	-	3	0	-	-	-	-	-	-
**Oodes helopioides* (FABR.)	-	-	-	-	-	-	-	3	0	-	-	-	-
**Oxypselaphus obscurus* (HERBST)	-	-	-	-	-	-	-	2	0	-	-	-	-
**Panagaeus bipustulatus* (FABR.)	-	-	-	-	-	7	0	1	0	-	-	-	-

-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-	-14-
Platynus assimilis (PAYK.)	in process of identification	-	-	-	-	2	0	-	-	-	-	25	4
Poecilus cupreus (L.)	*Gigaductus elongatus* (MOR.)	12	1	128	3	-	-	-	-	-	-	-	-
Poecilus lepidus (LESKE)	in process of identification	38	1	15	3	-	-	-	-	-	-	-	-
Poecilus punctulatus (SCHALL.)	in process of identification	16	1	58	0	-	-	-	-	-	-	-	-
Poecilus versicolor (STURM)	*Gregarina poecilii* (RAUCH.)	32	0	6	0	-	-	147	14	-	-	1	0
**Pterostichus anthracinus* (ILL.)	-	-	-	-	-	-	-	-	-	-	-	2	0
**Pterostichus gracilis* (DEJ.)	-	-	-	-	-	-	-	2	0	-	-	-	-
Pterostichus melanarius (ILL.)	*Ancyrophora gracilis* (SCHNEID.)	9	0	136	0	3	0	187	15	3	0	68	26
**Pterostichus minor* (GYLL.)	-	-	-	-	-	-	-	-	-	2	0	-	-
Pterostichus niger (SCHALL.)	*Ancyrophora gracilis* (SCHNEID.)	-	-	-	-	2	0	17	10	8	4	111	69
**Pterostichus nigrita* (PAYK.)	-	-	-	-	-	-	-	3	0	2	0	1	0
Pterostichus oblongopunctatus (F.)	*Gigaductus exiguus* WELL. *Gigaductus elongatus* (MOR.)	-	-	-	-	1	0	14	4	39	6	4	0
**Pterostichus strenuus* (PANZ.)	-	1	0	-	-	1	0	2	0	-	-	-	-
**Pterostichus vernalis* (PANZ.)	-	1	0	-	-	-	-	1	0	-	-	1	0
Semiophonus signaticornis (DUFT.)	in process of identification	1	0	9	2	-	-	-	-	-	-	-	-
**Stenolophus mixtus* (HERBST)	-	-	-	-	-	-	-	-	-	-	-	1	0

-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-	-14-
Syntomus foveatus (FOURCR.)	in process of identification	-	-	3	0	2	1	2	0	-	-	-	-
Syntomus truncatellus (L.)	in process of identification	2	0	1	0	16	5	-	-	1	0	-	-
**Synuchus vivalis* (ILL.)	-	-	-	-	-	-	-	-	-	-	-	1	0
**Trechus quadristratus* (SCHRANK)	-	6	0	4	0	-	-	1	0	-	-	-	-
Zabrus tenebrioides (GOEZE)	*Gregarina vizri* LIPA	31	20	8	0	-	-	-	-	-	-	-	-
	Razem:	595	47	1196	49	325	85	636	123	295	48	481	207

* - species where no Eugregarinida were found during study;
** - a list of parasitoid species that were not specified;

On the other hand, no significant influence of both the factors on the infestation level was found.

In terms of trophic characteristics of Carabidae statistically significant correlations also occurred between the food of host specimens and the prevalence of eugregarines (Table 5, 6, Fig. 2). In overall material both large zoophages and hemizoophages were frequently infected. For small zoophages the average prevalence was only 8.1%, however, on particular sites the dispersion of values was considerable (Fig. 2).

As could have been assumed before, a higher prevalence was reported for the trophic group characteristic of the type of the studied habitat. Large zoophages as typical representatives of the forest fauna in 80 - 90% were infected in forest habitats. The highest prevalence among hemizoophages was reported on cultivated fields, i.e. in the habitat typical of this group of Carabidae.

Among the Carabidae species abundant in the material (over 40 specimens) the highest parasitization level was observed in species of the genera *Carabus* L. and *Pterostichus* BON. The Carabidae living in open areas (mainly fields) were infected at lower level or not infected at all (Table 7). The most frequently recorded eugregarines were *Actinocephalus gracilis* (SCHNEID.) (Photo 1) in *Carabus* spp. and *Pterostichus* spp. and *Actinocephalus permagnus* WELL. (Photo 2) in *Carabus* spp.

Table 3. The number of species, abundance and prevalence of eugregarines on Carabidae communities examined in 2006-2007 (abbreviations as in Table 1).

L.p.	Habitat	Year	Number of species	Number of specimens	Prevalence of communities [%]
1	WM	2006	26	398	32.9
		2007	16	116	67.2
average prevalence					**50.0**
2	WS	2006	19	222	10.8
		2007	16	74	32.4
average prevalence					**21.6**
3	PM	2006	29	457	12.9
		2007	15	179	34.1
average prevalence					**23.5**
4	PS	2006	28	164	28.7
		2007	28	167	24.6
average prevalence					**26.6**
5	IM	2006	34	587	6.8
		2007	29	609	2.0
average prevalence					**4.4**
6	IS	2006	30	336	9.5
		2007	34	259	5.8
average prevalence					**7.6**

Fig. 1. Comparison of mean eugregarines prevalence in Carabidae communities in various habitats (abbreviations like in Table 1).

Table 4. Two-way ANOVA analysis for the factors: green cover of the area (A factor) and humidity (B factor) in relation to gregarine prevalence in Carabidae communities.

Source of Variation	**SS**	**F**	**Share of explained diversity**
Factor A	1046.3048	**6.7387***	56.1
Factor B	41.3294	0.5324	2.2
Factor A x B	311.1851	2.0042	16.2
Within Groups	465.8034		
Total	864.6227		

* - statistically significant result

Table 5. Share of Carabidae trophic groups in gregarine-infected specimens in particular study sites (abbreviations as in Table 1).

L.p.	Habitat	Year	Large zoophages	Small zoophages	Hemizoophages
1	*2*	*3*	*4*	*5*	*6*
1	WM	2006	95.4	3.1	1.5
		2007	97.4	2.6	0.0
		Average	**96.4**	**2.9**	**0.8**
2	WS	2006	87.5	12.5	0.0
		2007	79.2	20.8	0.0
		Average	**83.4**	**16.7**	**0.0**
3	PM	2006	72.9	3.4	23.7
		2007	77.0	3.3	19.7
		Average	**74.9**	**3.4**	**21.7**
4	PS	2006	27.7	19.1	53.2
		2007	46.3	24.4	29.3
		Average	**37.0**	**21.8**	**41.25**
5	IM	2006	5.0	7.5	87.5
		2007	0.0	0.0	100
		Average	**2.5**	**3.6**	**93.8**
6	IS	2006	0.0	0.1	96.9
		2007	0.0	0.0	100
		Average	**0.0**	**0.1**	**98.5**
Average of total			**49.0**	**8.1**	**42.7**

Table 6. One-way ANOVA for gregarine prevalence in trophic groups (A factor) of Carabidae communities.

Source of Variation	**SS**	**F**	**Share of explained diversity**
Factor A	5827.51	**3.7311***	18.4
Within Groups	25771.26		
Total	31598.70		

*- statistically significant result

Fig. 2. Share of trophic groups among the Carabidae parasitized by eugregarines in various habitats types (abbreviations like in Table 1).

Table 7. Prevalence of Eugregarinidae in most frequently examined Carabidae during 2006-2007 (habitat abbreviations as in table 1).

Host species	**Habitat**					
	IS	**IM**	**PS**	**PM**	**WS**	**WM**
	prewalence [%]					
Amara communis	-	-	-	6.52	-	-
Bembidion lampros	0.00*	0.00*	-	-	-	-
Bembidion properans	0.00*	-	-	-	-	-
Calathus ambiguous	0.00*	0.49	-	-	-	-
Calathus fuscipes	-	0.92	-	-	-	-
Carabus granulatus	-	-	-	-	-	60.00
Carabus nemoralis	-	-	84.21	78.94	13.04	42.37
Harpalus affinis	-	7.77	-	-	-	-
Harpalus rubripes	-	-	15.31	-	-	-
Harpalus rufipes	4.25	6.75	-	-	-	-
Poecilus cupreus	-	2.34	-	-	-	-
Poecilus punctulatus	-	0.00*	-	-	-	-
Poecilus versicolor	-	-	-	9.52	-	-
Pterostichus melanarius	-	0.00*	-	8.02	-	38.23
Pterostichus niger	-	-	-	-	-	62.16

* specimens examinaed but free from eugregarines

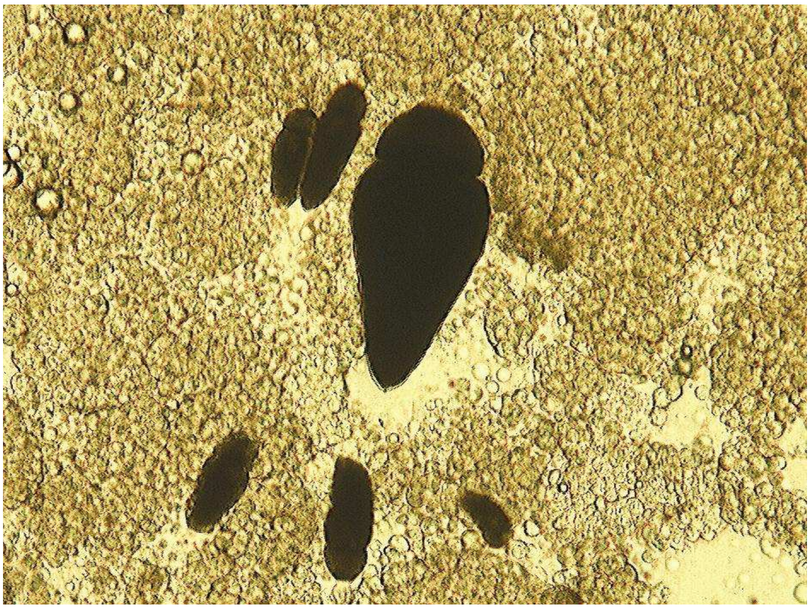

Photo. 1. Trophozoites of *Ancyrophora gracilis* (SCHNEID.) in intestinum of *Pterostichus niger* (SCHALL.)

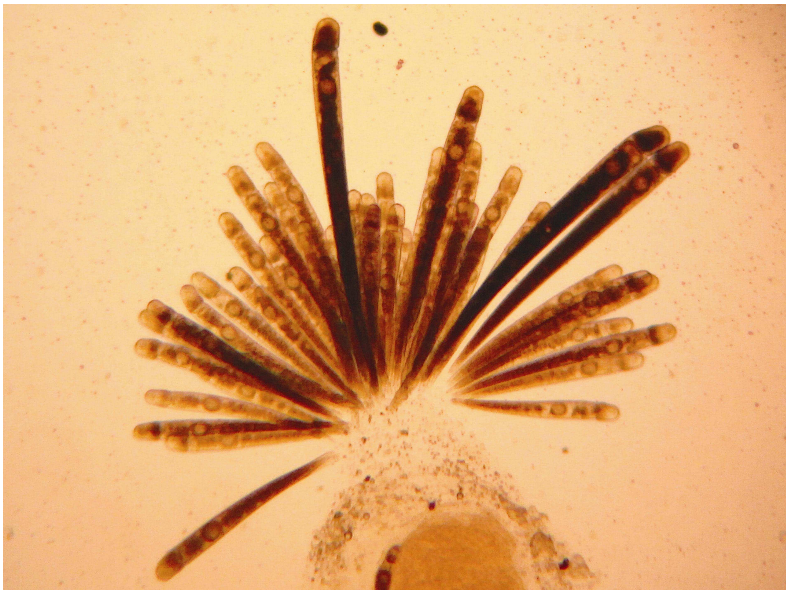

Photo. 2. Trophozoites of *Actinocephalus permagnus* WELL. in intestinum of *Carabus nemoralis* MUELL.

DISCUSSION AND CONCLUSIONS

Eugregarines are among the invertebrates closely related to their hosts, as they cannot develop without them. They are cosmopolitans that occur in geographic zones of all their hosts. As part of their development cycle occurs outside of their host's body (GEUS 1969), their successful infestation of consecutive host individuals will depend on the conditions of spores placement and their chances of penetrating into their host's body with food. According to FOERSTER's (1939 a, b) observation the host's location and way of living are of primary importance for the survival of eugregarines in the environment. He reported, for example, that antophile insects are not infected by eugregarines, which is also true for many species inhabiting tree and bush leaves. This is so because they feed in places where the spores do not occur or have no chance to survive. On the other hand, epigeic insects, particularly predators or coprophages are infected very often, with results from their direct contact with the soil, where gregarine spores are deposited with excrements.

All the studied carabid species lead an epigeic life, so they have direct contact with the soil, also through the invertebrates they prey on (earthworms, snails and slugs, sprongtails and small insects in various developmental stages etc.). So, as a rule, eugregarines should occur abundantly in all the studied species, acquiring a high share of infestations. However, no such rule was observed during the study. It was observed that significant differences occurred in the level of Carabidae infestation by eugregarines depending on the character of biotope the hosts inhabited. Also the most significant factor differentiating the level of Carabidae infestation by eugregarines was the extent of plant cover. In Poland, where historically the natural biotope are forests, this is closely related to anthropopressure. A reduction in plant cover results in higher insolation and lower humidity. An extreme case are cultivated fields, where plant and animal species except for the cultivated plant are eliminated. There the prevalence was the lowest (Table 3, 7, Fig. 1). The highest prevalence was reported from the most natural of the studied habitats, namely the alder-oak forest. Similar results were obtained by studying the impact of forest habitats fragmentation on the level of parasitizing of forestal dragon flies. The prevalence of eugregarines in fragmented landscapes was significantly lower than in uniform woods (TAYLOR & MERRIAM 1996). So it can be inferred that, as is true for other groups, the level of anthropopressure is a significant factor influencing the abundance of eugregarines. In the analysed case this is expressed by a smaller extent of plant cover. For cultivated fields there is an additional factor: chemization of agrocenoses and change in soil characteristics resulting from cultivation. Apart from the abiotic changes mentioned above the availability and kind of feed for Carabidae (mainly soil invertebrates) which can enable parasite spores to enter the hosts is also lower.

The impact of humidity on the prevalence of eugregarines was also studied, but this ecological factor turned out to be statistically insignificant (Table 5), although before it had been highlighted as important (FOERSTER 1939a, b). Such a result could have been expected, as otherwise only higrophile species would have been infected by eugregarines. On the contrary, eugregarines occur also in species of dry habitats, where the prevalence can still reach high values (e.g. JOHNY et al. 2000, ZUK 1987, GEUS 1969).

The results of the present studies confirm the way of Carabidae feeding as a significant influence on their level of infestation (Table 6). The differences reported, although statistically significant, considered mainly the comparison of prevalence for large zoophages and hemizoophages versus small zoophages. Due to the fact that large zoophages eat large amounts of earthworms, snails, slugs and other soil invertebrates (including detrituophages), it could have been assumed that they would have been infected much more than small zoophages or hemizoophages. However, a similar level of prevalence was observed for hemizoophages. Only small zoophages were slightly infected (Table 5, Fig. 2). The correlation between the frequency of infestation for trophic groups and habitat type can also be seen (Fig. 3). In forest habitats the highest prevalence was reported for large zoophages, which are characteristic for those habitats. On cultivated fields, so in habitats strongly transformed, hemizoophages are dominant and they are the most frequently infested trophic group, although the infestation is most often low. The above observations are also confirmed by a prevalence analysis for the most abundant Carabidae in the material. The most infected were species of the genera *Carabus* and *Pterostichus*, which occurred in the least transformed habitats. Field Carabidae were infected slightly or not infected at all.

In conclusion it should be said that for epigeic Carabidae the prevalence of their communities was most influenced by the green cover of the habitat. In forest the average prevalence was definitely higher than on fields and definitely higher than on meadows. The level of humidity did not have a significant impact on the prevalence. Also the way of Carabidae feeding had some impact on the level of eugregarine infestation. Small zoophages were infected definitely less often than large zoophages and hemizoophages. The trophic group characteristic for the habitat was also the most infected group of beetles.

Eugregarines will than have the strongest controlling impact on the abundance of Carabidae communities in forest habitats, and the impact will grow with the fall of anthropopressure.

REFERENCES

BROOKS W.M., JACKSON J.J. 1990. Eugregarines: current status as pathogens, illustrated in corn rootworms. [in:] PINNOCK DE (ed.) Vth International Colloquium on Invertebrate Pathology and Microbial Control. Adelaide, Australia. Pp. 512-515.

CLOPTON R.E. 2002. Phylum Apicomplexa Levine, 1970: Order Eugregarinorida Léger, 1900, 205-288 pp [in:] Illustrated Guide to the Protozoa, 2 nd ed. J.J. LEE, G.LEEDALE, D. PATTERSON, P.C. BRADBURY, (eds.) Society of Protozoologists, Lawrance, Kansas.

CLOPTON R.E., JANOVY J. 1993. Developmental niche structure in the gregarine assemblage parasitizing *Tenebrio molitor*. J. Parasitol. **79**: 701-709.

CLOPTON R.E., GOLD R.E. 1995. Effects of pH on excystation in *Gregarina cuneata* and *Gregarina polymotpha* (Eugregarinida: Gregarinidae). J. Eucariotic Microbiol. **42**:540-544.

FOERSTER H. 1939a. Beobachtingen über das Auftreten von Gregarinen in Insekten. Z. Parasitenk. **10**: 644-673.

FOERSTER H. 1939b. Gregarinen in Schlesischen Insekten. Z. Parasitenk. **10**: 157-209.

GEUS A. 1969. Sporentirchen, Sporozoa - Die Gregarinen der land- und süßwasserbewohnenden Arthropoden Mitteleuropas. Die Tierwelt Deutschlands. VEB Gustav Fischer Verlag. 608 pp.

HARRY O.G. 1970. Gregarines: their effects on growth of the desert locust, *Schistocera gregaria*. Nature **225**: 964-966.

HARRY O.G. 1971. Studies on infection and reinfection by eugregarines. Parasitology **63**: 213-223.

HECKER K.R., FORBES M.R., LÉONARD N.J. 2002. Parasitism of damselflies (*Enallagma boreale*) by gregarines: sex biases and relation to adult survivorship. Can. J. Zool. **80**: 162-168.

JOHNY S., MURALIRANGAN M.C., SANJAYAN K.P. 2000. Parasistization potential of two cephaline gregarines, *Leidyana subramanii* PUSHKALA and MURALIRANGAN and *Retractocephalus dhawanii* sp. n. on the tobacco grasshopper, *Atractomorpha crenulata* (FAB.). J. Orthoptera Res. **9**: 67-70.

KUBILAY M., GÖKCE A. 2005. Effect of *Diplocystis tipulae* (Eugregarinida: Apicomplexa), a coelomic gregarine pathogen of tipulids, on the larval size of *Tipula paludosa* MEIGEN (Tipulidae: Diptera). J. Invert. Pathol. **89**: 112-115.

LEŚNIAK A. 1984. Organizacja a stabilność zgrupowań na przykładzie Carabidae (Coleoptera). III Sympozjum Ochrony Ekosystemów Leśnych. SGGW - AR Warszawa, 139-153.

LEŚNIAK A. 1997. Metody analizy zgrupowań biegaczowatych (Carabidae, Col.) w zooindykacji procesów ekologicznych. VI Sympozjum Ochrony Ekosystemów Leśnych, Jedlnia - grudzień 1996, 29-41.

SKŁODOWSKI J. 1994. Wpływ chemizacji środowiska na zgrupowania biegaczowatych (Coleoptera, Carabidae) młodników sosnowych. Sylwan **9**: 81-95.

TAYLOR P.D., MERRIAM G. 1996. Habitat fragmentation and parasitism of a forest damselfly. Landsc. Ecol. **11**: 181-189.

TOSUNO O., YAMAN M., ADYIN C. 2008. Parasites of *Phyllotreta atra* (FABRICIUS, 1775) (Coleoptera, Chrysomelidae) in Trabzon. Türkye Parazit. Dergisi **32**: 153-157.

VAN RHEIN S., FLANARY E. B., JULIANO A. S., 2000. Effects of habitat type and drying on *Ascigregarina baretti* (Eugregarinida: Leucudinidae) infection in *Aedes tisseriatus* (Diptera: Culicidae). J. Med. Entomol. **37**: 950-956.

ZUK M. 1987: Seasonal and individual variation in gregarine parasite levels in the field cricets *Gryllus veletis* and *G. pennsylvanicus*. Ecol. Entomol. **12**: 341-348.

Received: November 13, 2009
Accepted: November 30, 2009