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Influences of the behaviour of epigeic arthropods (Diplopoda, Chilopoda, Carabidae) on the efficiency of pitfall trapping

Andreas Gerlach[1*], Karin Voigtländer[1] & Christa M. Heidger[2]

[1] *Senckenberg Museum für Naturkunde Görlitz, P.O. Box 300154, 02806 Görlitz, Germany;*

e-mail: Andreas.gerlach@senckenberg.de

[2] *University of Applied Sciences Zittau (FH), Theodor-Koerner Allee 16, 02763 Zittau, Germany*

[*] *Corresponding author*

Abstract

The behavioural response at pitfall traps and the attracting or repellent effect of fixing solutions were studied on seven species of epigeic arthropoda (Diplopoda, Chilopoda, Carabidae) in laboratory experiments. The tests were done individually with 30 males and 30 females (in exceptional case 20) under different illumination.

Tests with empty traps resulted in six different behavioural patterns. Their frequency was highly different between species as well as between sexes. It is remarkable that specimens of all species were able to avoid the traps or even rescue themselves out of the traps (with unlike skill). The behaviour pattern depends on visual and tactile inputs of the trap, the illumination and the characteristics of the specimens themselves.

Furthermore, four different fixing solutions (water, ethylene glycol, formaldehyde, acetic acid-ethanol-water-mixture) were tested. Only the mixture seemed to be repellent to millipedes and centipedes, but not to Carabidae. Attraction was not detectable for any of the species.

As a consequence of the very different behaviour pattern of specimens at the traps, it must be considered that pitfall trapping does not reflect the number of specimens being active in the surroundings of the trap. Therefore, this method is inappropriate for quantitative investigations of the arthropods living at a site (‘activity abundance’).

Keywords: locomotory activity, specimen reactions, fixing solutions, catching results

1. Introduction

Soil zoological research uses different methods for qualitative and quantitative collecting of epigeic arthropods. With the introduction of pitfall trapping by Barber (1931) and the methodological improvement by Stammer (1948), this method became more important. At present pitfall trapping is one of the most common, but also most intensely discussed method for investigations on epigeic arthropods.

A lot of studies deal with the pros and cons of pitfall traps (e.g. Tretzel 1955, Dunger 1963, Geiler 1964, Adis 1979). According to some investigations a large number of factors (for example the form, the size and the material of traps, the surroundings, microclimate, disturbance physiological status of animals) influence the efficiency of pitfall trapping (e.g. Bombosch 1962, Luff 1975, Waage 1985, Digweed et al. 1995), whereas the influence of the behaviour of the animals themselves has mostly been neglected.

The present study demonstrates species-specific behaviour of selected epigeic arthropods on pitfall traps, their locomotory activity and running speed as well as their reaction on different fixative solutions and discusses the impact of these factors for catching results.

2. Materials and methods

The material used in the experiments was obtained by hand catches in deciduous forests near Görlitz and Zittau, Eastern Germany, and belongs to Diplopoda (*Glomeris hexasticha* Brandt, 1833; *Julus scandinavius* Latzel, 1884; *Megaphyllum projectum* Verhoeff, 1907; *Enantiulus nanus* (Latzel, 1884), Chilopoda (*Lithobius mutabilis* L. Koch, 1862) and Carabidae (*Abax parallelepipedus* (Piller et Mitterbacher, 1783); *Pterostichus burmeisteri* Heer, 1841). This results were used to compare them with a former study (Gerlach et al. 2009) in which the following species were used: *Polydesmus inconstans* Latzel, 1884; *Strongylosoma stigmatosum* (Eichwald, 1830); *Lithobius forficatus* (Linné, 1758); *Lithobius microps* Meinert, 1868; *Carabus granulatus* Linné, 1758; *Carabus hortensis* Linné, 1758; *Harpalus rufipes* (De Geer, 1774); *Oniscus asellus* Linné, 1758; *Armadillidium opacum* (C.L. Koch, 1841) and *Staphylinus erythropterus* Linné, 1758.

All tests were done under constant conditions (temperature 20 °C, humidity 45 %). An electric bulb (75 watt) was installed as a central light source over the test boxes.

Locomotory activity (Fig. 1A). A round arena (diameter 50 cm) with a plaster underground covered with a layer of soil and small amounts of litter and dead wood was placed in a water-filled bowl in a way that the plaster layer was in contact with the water, so that the area would not run dry during the test. The interior was divided into two sectors with a passage of 10 cm breadth in the centre. The specimens which went through this centre were videotaped.

In each run, 10 adult specimens were placed into the arena separately for each species and sex. Before the beginning of the tests the specimens were allowed to acclimatise to the new environment for 24 hours. Each test run for 72 hours with light-dark rhythm (L:D = 12:12 h) (light: 7 00 AM to 7 00 PM, dark: 7 00 PM to 7 00 AM).

The differences in the locomotory activity between the sexes were tested for significance with the chi^2-test.

Running speed. The running speed of the species was tested in a long and narrow arena (35 x 5 cm) on millimetre paper. The front of the arena was closed by a flap which was opened after a short acclimatisation phase of the specimens. In preliminary tests an appropriate running distance was established for each species: for Carabidae and the centipede 10 cm, for *J. scandinavius* and *M. projectum* 5 cm and for *E. nanus* and *G. hexasticha* only 3 cm.

20 males and 20 females of each species were tested individually and only once under light conditions.

The average running speed were tested for significant differences between the species (Welch-test) and between the sexes (Student-t-test).

Behaviour at the trap-margin (Fig. 1B). For the tests we used a timber box (30 x 25 x 25 cm) with smooth inner surfaces (glass). This box was open at the top and filled with a thin ground-layer of moist soil. In the centre of the test arena an empty plastic pitfall trap with a diameter of 6 cm was installed with the surface on the same level with the soil layer. To raise the probability that the animals get into contact with the pitfall trap, a wall, which ends 4 cm before the trap margin, was placed on the one side of the test arena in order to lead the individuals to the pitfall trap. While the specimens were placed in the test arena, the trap was closed for a short time.

30 males and 30 females of each species were tested individually and only once each under light conditions and in darkness (exception: *E. nanus* and *L. mutabilis* each with 20 individuals of each sex). The behaviour was videotaped.

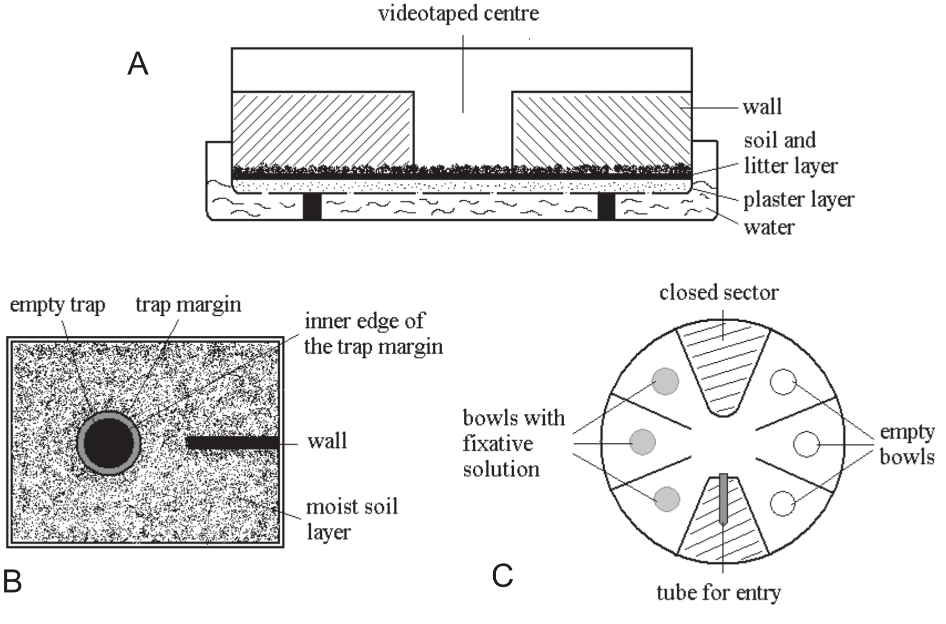

Fig. 1 Experimental setup: A: Locomotory activity; B: Behaviour at the pitfall trap; C: Preference.

Effect of different fixative solutions (Fig. 1C). For the tests a round arena (diameter 50 cm) with an underground of plaster was used. It was divided into 8 sectors with a circular free area (diameter 10 cm) in the centre. One sector was closed. Plastic bowls (diameter 6 cm) empty or filled with cotton wools, soaked with the solutions, were placed flush in each 3 sectors at both sites. A plastic tube (length 10 cm, diameter 3 cm) was placed in the middle of the last sector. The individuals went into the arena through this tube.

The tested fixative solutions were water, a 30 % ethylene glycol solution, a 3 % formaldehyde solution and an acetic acid-ethanol-water-mixture (AEW) in a ratio 5 : 50 : 45. The solutions were successively presented: 3 filled plastic bowls on one site against 3 empty bowls on the other site. To eliminate the influence of unknown factors (for example different light intensities) and therefore preferences to one site (Naguib 2006), the sites were changed after 5 tests. The tests were done under light conditions.

The number of the preferred sites was tested for rectangular distribution with the chi^2-test.

3. Results

3.1. Locomotory activity (Tab. 1)

In the investigations 38 319 'events' were recorded altogether. Between the species there are clear differences in the total activity. The carabid beetles, especially *A. parallelepipedus,* show very high activity (60 % of all events). The diplopod species *G. hexasticha, M. projectum* and *J. scandinavius* are much less active (4 to 9 % of all events). *L. mutabilis* and *E. nanus* are the most inactive species (1.5 and 0.75 % of all events).

Between the sexes there are highly significant differences ($p < 0.001$) in the locomotory activity (exception: *M. projectum* and *L. mutabilis*).The males of most species were more active than the females. Only the females of *P. burmeisteri* showed a higher locomotory activity than males.

With the exception of males of *G. hexasticha* the millipedes and centipedes showed a clear nocturnal activity both in males and females, whereas the carabid beetles were active under both light conditions.

Tab. 1 Locomotory activity during 72 hours. Number of 'events' in total, for each sex and nocturnal activity in %.

Species	Total	Locomotory activity of the sexes		Nocturnal activity of the sexes	
		♂♂	♀♀	♂♂	♀♀
G. hexasticha	1651	1122	529	68.54	93.38
J. scandinavius	3492	1984	1508	87.95	87.6
M. projectum	1687	849	838	95.88	98.33
E. nanus	289	186	103	90.32	87.38
L. mutabilis	575	269	306	96.65	98.04
A. parallelepipedus	23 162	12 604	10 558	54.05	54.76
P. burmeisteri	7463	2723	4740	60.82	67.95

3.2. Running speed (Tab. 2)

In the average running speed there are highly significant differences ($p < 0.001$) between Carabidae, Diplopoda and Chilopoda and also between the species within these groups (exception: between the diplopods *G. hexasticha* and *E. nanus*). The carabid beetles show the highest values, whereas *P. burmeisteri* is the fastest species. On contrary the millipedes are very slow: *G. hexasticha* and *E. nanus* showed the lowest values. *J. scandinavius* was the fastest millipede. The centipede *L. mutabilis* has an intermediate position between Carabidae and Diplopoda.

There are no significant differences of the arithmetic mean between the sexes.

Tab. 2 Average running speed, minimum and maximum of 20 males and 20 females of each investigated species in mm s^{-1}.

Species	Average running speed [mm s^{-1}]		Maximum		Minimum	
	♂♂	♀♀	♂♂	♀♀	♂♂	♀♀
G. hexasticha	2.3 ± 0.4	2.4 ± 0.3	2.9	3.2	1.6	1.9
J. scandinavius	8.7 ± 1.4	8.8 ± 1.2	12.3	11.1	6.1	7
M. projectum	5.2 ± 0.5	5.2 ± 0.7	6	6.4	4.5	4
E. nanus	2.5 ± 0.3	2.5 ± 0.3	3.3	3	2.1	2.1
L. mutabilis	18.3 ± 1.2	18.3 ± 1.7	21.5	22.5	15.7	16.2
A. parallelepipedus	31.2 ± 5.5	27.9 ± 4.9	40	40.3	16.7	21.6
P. burmeisteri	56.6 ± 10.8	55.5 ± 6.9	82	67.61	43.5	46.1

3.3. Behaviour at the trap margin (Figs 2–4)

Altogether 759 behavioural reactions (‘events’) could be observed, they were grouped in 6 different types of behaviour:

A the specimen changes its running direction approx. 1 cm before the trap (Avoidance)

B the specimen touches the trap margin carefully and changes its course (Behaviour at the trap margin)

C the specimen overruns the trap margin past the trap hole without a reaction

D the specimen exceeds the trap margin until the inner edge and changes its course (Reaction at the trap hole)

E the specimen crosses the trap margin and hangs with nearly the whole body inside the trap but is able to pull itself out (Self-Rescue)

F the specimen falls into the trap (Catch)

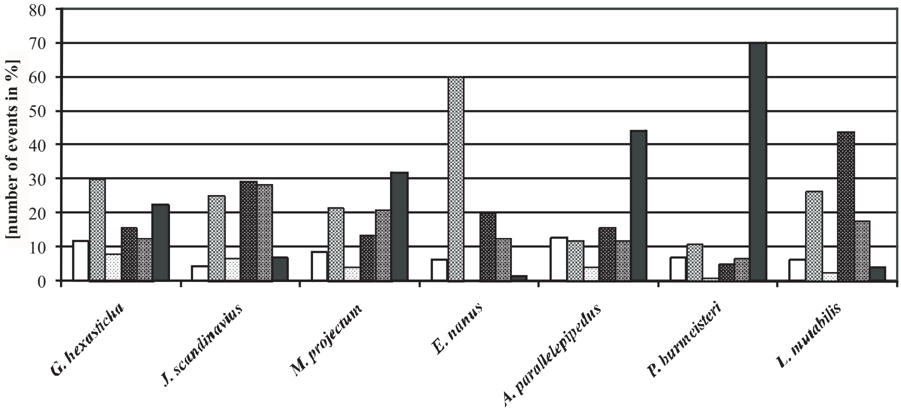

Fig. 2 Behaviour at the trap.

A: Avoidance; D: Reaction at the trap hole;

B: Behaviour at the trap margin; E: Self-Rescue;

C: Overrun; F: Catch

'Avoidance' (A). This type of reaction could be observed in all investigated species, but altogether with only 8 % of all events. The differences in frequency between the species are relatively small (Fig. 2). They range from 4 (*J. scandinavius*) to 15 (*A. parallelepipedus*). *G. hexasticha* and *A. parallelepipedus* avoided the trap a little more often. All species react only (*E. nanus*, *P. burmeisteri*) or mostly under light conditions (Fig. 4).

Behaviour at the trap margin (B). Touching the trap margin made many individuals to turn back. With 25 % of all events the reaction B was the second highest after the 'Catching' (reaction F). The diplopod species show the most intensive reaction on the touch of the trap margin. Remarkable is *E. nanus* with the highest value.

All investigated diplopods show a higher deterrence in darkness (Fig. 4), whereas the chilopod *L. mutabilis* reacts mostly under light conditions. In carabid beetles no differences between light and darkness were observed.

Only a very small number of specimens **run over the trap margin along the trap hole (C)**. The trap does not initiate a reaction: in *G. hexasticha* and *J. scandinavius* at most, in *E. nanus* not at all (Fig. 1). With the exception of *G. hexasticha* this behavioural pattern was much more frequent in light (Fig. 4).

Reaction at the trap hole (D). Besides of B the reaction immediately at the inner edge of the trap margin was with 19 % of all events the most frequent pattern of behaviour. *J. scandinavius* and *L. mutabilis* showed this reaction most frequently (Fig. 2). With exception of *E. nanus* all species showed a stronger response to the trap hole in darkness (Fig. 4).

Self-Rescue (E). 16 % of all events were Self-Rescues. All investigated species were able to rescue themselves, but with different skills (Tabs 3 and 4). Most often it was observed in *J. scandinavius* and *M. projectum* (34 and 25 events) in contrast to *E. nanus* and *P. burmeisteri* with only 10 and 8 observed events.

Rate of Self-Rescue (Tab. 4). More meaningful than the absolute numbers are the 'Rates of Self-Rescue' (RSR). The rate shows the ability of the species to pull itself out the trap. It is calculated as the quotient from the number of events with rescuing themselves after entering into the trap with parts of the body and all specimens falling into the trap:

RSR = E x 100 %/ (E + F).

Most successful were *E. nanus*, *J. scandinavius* and *L. mutabilis*. The millipedes *G. hexasticha* and *M. projectum* had lower rates with only minor differences. The carabid beetles showed the smallest values.

Catching (F). In 28 % of all events a catch of specimens was observed. There were very clear and most important differences between the species: The highest numbers of caught specimens were observed in carabid beetles, especially in *P. burmeisteri*. The myriapod species *E. nanus*, *J. scandinavius* and *L. mutabilis* showed the smallest values; the most frequently caught millipede was *M. projectum* (Fig. 2).

With exception of *E. nanus* all investigated species were caught more frequently under light conditions (Fig. 4).

3.4. The behaviour of sexes under light/dark conditions (Tab. 3, Figs 3, 4)

In *G. hexasticha*, both sexes were a little more careful under light conditions. The males have a higher ability for self rescue than females both under light and in darkness. The number of caught females is higher than that of males independent of light or not.

In *J. scandinavius*, we could find only minor differences between the sexes. Small avoidance reactions were observed mostly in light. Both sexes react in darkness more carefully. In darkness the males responded more to the trap margin, the females more to the trap hole. The highest rate for self-rescue the males was shown under light conditions. In contrast, the females were not caught in darkness and showed a Self-Rescue Rate of 100 % (Tab. 4).

In *M. projectum*, avoidance reactions took place nearly exclusively in light. Both sexes were more careful at the trap in darkness and were therefore caught in lower quantities. The males reacted stronger at the trap than females, whereas the females have more skilfulness to rescue themselves. Both sexes showed nearly the same number of caught individuals.

In *E. nanus*, avoidance reactions could only be observed in light. There were no differences between females and males as well in light as in darkness. Both sexes were very careful and reacted promptly at that moment when they came into contact with the trap or they rescued themselves with high slickness (Tab. 4). They have the smallest catching numbers of all investigated species.

In *L. mutabilis*, avoidance reactions in both sexes were observed nearly exclusively in light. This is in general more similar to diplopod species than to the other predatory group which was investigated with Carabidae.

Tab 3 Behaviour of species (number of specimens in total, females and males) under different light conditions.

Behaviour	*A. parallelepipedus*				*P. burmeisteri*				*L. mutabilis*			
	light+ dark		♂♂ + ♀♀		light+ dark		♂♂ + ♀♀		light+ dark		♂♂ + ♀♀	
	♂♂	♀♀	light	dark	♂♂	♀♀	light	dark	♂♂	♀♀	light	dark
A	8	7	10	5	6	2	8	0	3	2	4	1
B	6	8	7	7	4	9	7	6	11	10	14	7
C	3	2	4	1	0	1	0	1	0	2	0	2
D	6	13	7	12	5	1	0	6	16	19	12	23
E	8	6	4	10	4	4	2	6	9	5	8	6
F	29	24	28	25	41	43	43	41	1	2	2	1

Behaviour	*G. hexasticha*				*J. scandinavius*				*M. projectum*			
	light+ dark		♂♂ + ♀♀		light+ dark		♂♂ + ♀♀		light+ dark		♂♂ + ♀♀	
	♂♂	♀♀	light	dark	♂♂	♀♀	light	dark	♂♂	♀♀	light	dark
A	5	9	13	1	4	1	4	1	4	6	9	1
B	20	16	12	24	18	12	10	20	18	8	7	19
C	3	6	4	5	5	3	6	2	3	2	3	2
D	9	10	5	14	13	22	16	19	7	9	3	13
E	12	3	9	6	15	19	19	15	8	17	13	12
F	11	16	17	10	5	3	5	3	20	18	25	13

Behaviour	*E. nanus*			
	light+ dark		♂♂ + ♀♀	
	♂♂	♀♀	light	dark
A	2	3	5	0
B	25	23	22	26
C	0	0	0	0
D	7	9	8	8
E	6	4	5	5
F	0	1	0	1

In darkness the females of *A. parallelepipedus* reacted much stronger on the trap than the males (B, D). Both sexes had higher self-rescue rates in darkness.

P. burmeisteri showed the lowest reactions to the pitfall trap. An avoidance reaction in both sexes could only be observed in light. In darkness especially the males showed the first reaction after they had overstepped the margin. Only minor differences between the sexes could be found for the Self-Rescue Rate and the Catching Rate.

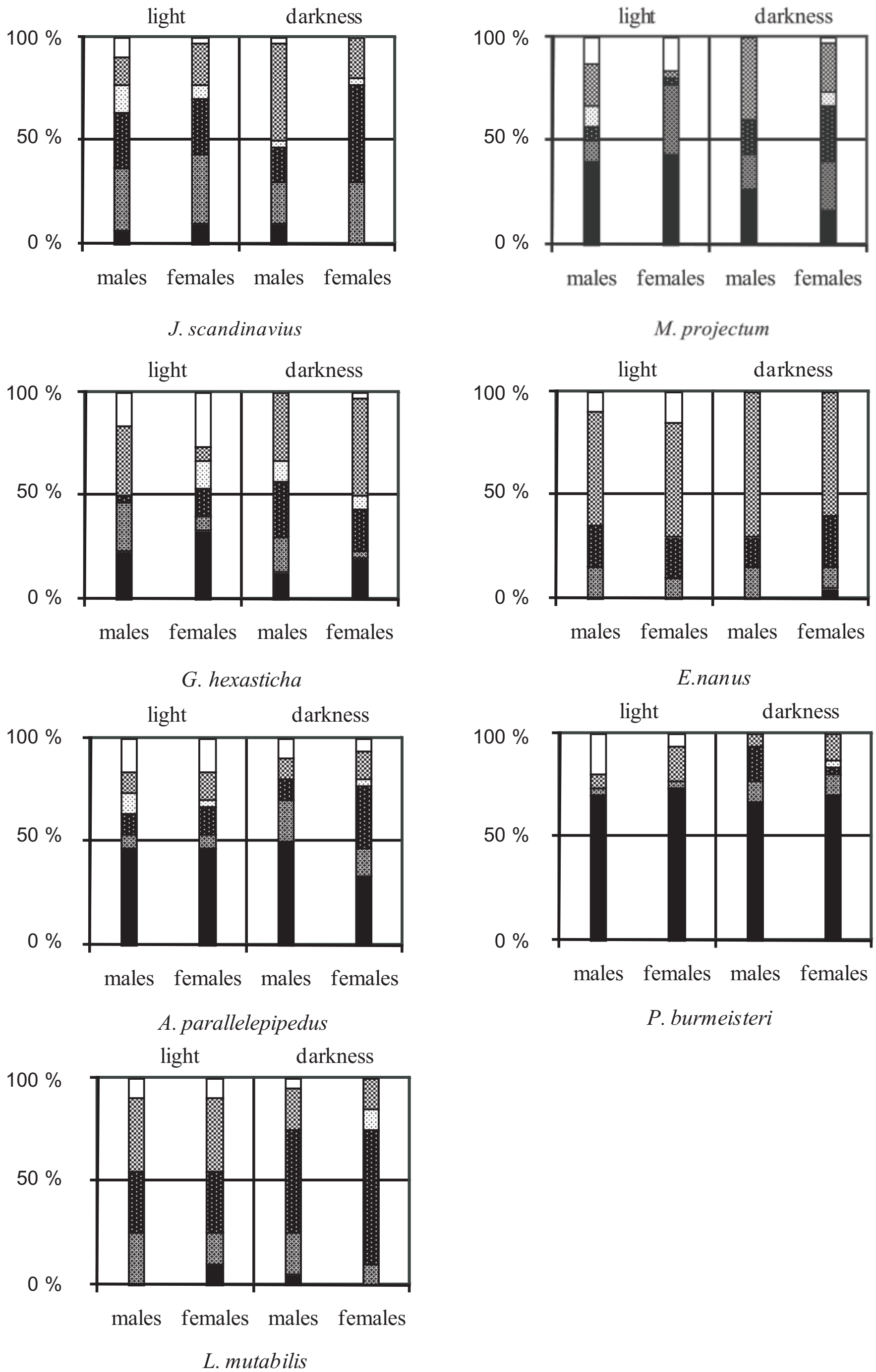

Fig. 3 Behaviour at the trap of the sexes under dark/light conditions (number of events in %). For explanation see Fig. 2.

Tab. 4 Rate of Self-Rescue of investigated males and females in % under the influence of light/darkness, RSR = E x 100 %/ (E + F).

species		♂♂	♀♀	total
G. hexasticha	light	50.00	16.67	34.62
	darkness	55.56	14.29	37.50
J. scandinavius	light	81.82	76.92	79.17
	darkness	66.67	100.00	83.33
M. projectum	light	20.00	43.48	34.21
	darkness	38.46	58.33	48.00
E. nanus	light	100.00	100.00	100.00
	darkness	100.00	66.67	83.33
L. mutabilis	light	100.00	60.00	80.00
	darkness	80.00	100.00	85.71
A. parallelepipedus	light	12.50	12.50	12.50
	darkness	28.57	28.57	28.57
P. burmeisteri	light	4.55	4.35	4.44
	darkness	13.04	12.50	12.77

3.5. Influence of fixative solutions – Attractancy and deterrence (Fig. 5)

Water and **ethylene glycol** had no attraction or repellent effect on most of the species. Specimens' distribution was nearly the same at the 'Water'- (or 'Ethylene glycol'-) site area and the 'Empty'-site of the investigation. Only *E. nanus* preferred the empty bowls more frequently, whereas *L. mutabilis* and *M. projectum* (here especially the females) chose the site with ethylene glycol. All investigated species showed no significant differences in the distribution to the both sites.

Formaldehyde had a repellent effect to the millipedes with exception of *J. scandinavius*. The reaction was especially high in *E. nanus* (significance $p < 0.01$). The centipede and the beetles showed minor, not significant differences in the distribution at both arena sites: *L. mutabilis* (only the males) and *P. burmeisteri* (especially the females) chose the bowls with formaldehyde more often.

All investigated species react more or less negatively to the **acetic acid-ethanol-water mixture** (AEW). It had a very clear, mostly significant ($p < 0.05$) repellent effect to all diplopods. The avoidance reactions near the sectors with AEW were very strong. Differences between the sexes could be found for *L. mutabilis.* The females avoided the arena-site with the mixture, in contrast the males chose this site more often, but clear retreat reactions directly near the bowls with the fluid took place. Carabid beetles were nearly uninfluenced by AEW.

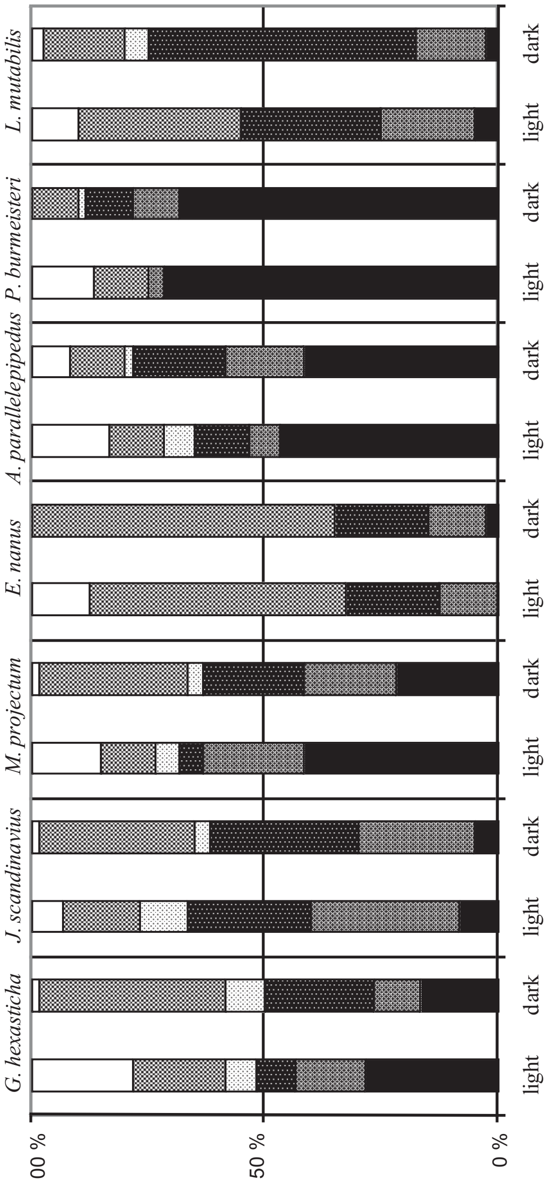

Fig. 4 Behaviour at the trap of the species in % under dark/light. For explanation see Fig. 2.

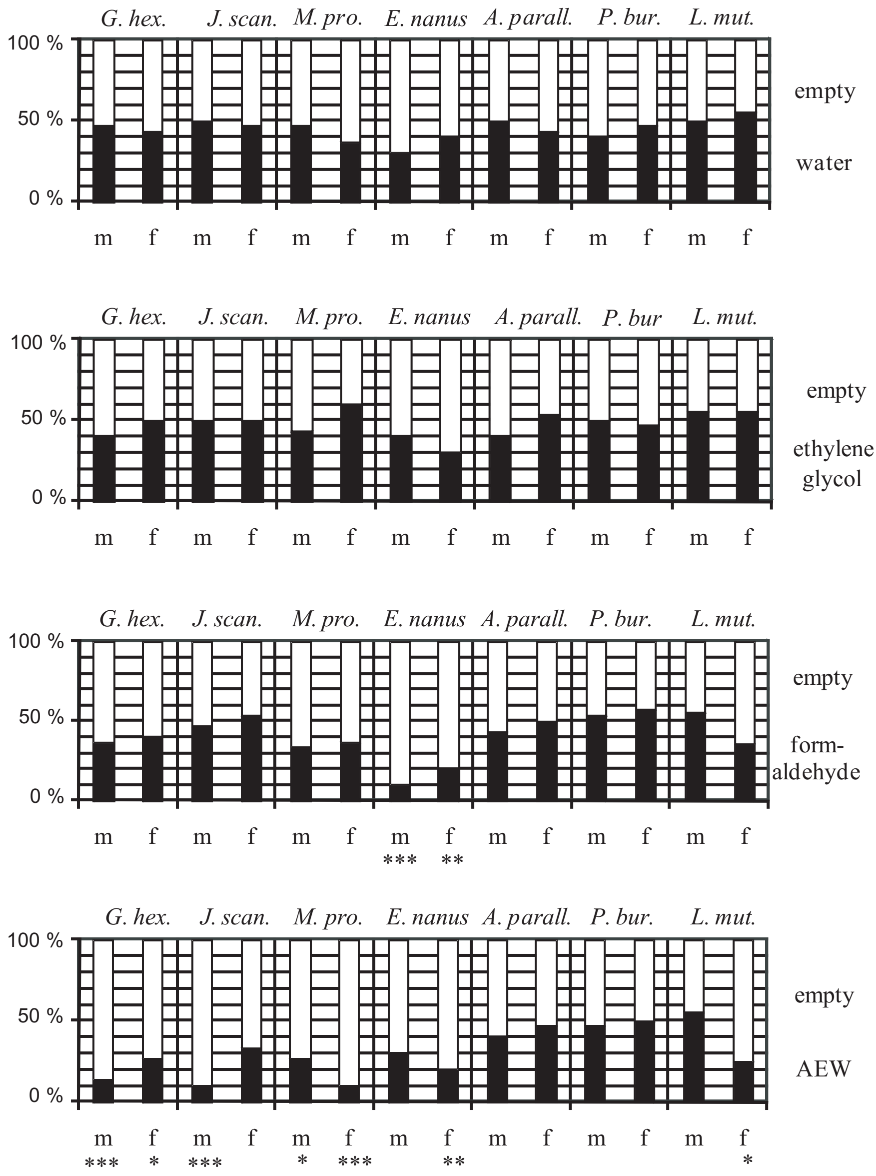

Fig. 5 Attractivity of solutions to females and males of the species (number of specimens in %, which prefer on the side of the investigation area with or without solutions immediately after the start).* – significance

4. Discussion

A large number of studies deals with factors influencing the results of pitfall trapping such as habitat characteristics, disturbances during the digging in or change of the traps (Heydemann 1956, Dunger 1966, Greenslade 1973), the diameter, material and roof of the traps (Bombosch 1962, Luff 1975) or different preservatives (Renner 1982, Teichmann 1994). Information about the behaviour of arthropods at the traps is very rare (Seifert 1990, Gerlach et al. 2009) and mostly they exist as sporadic observations of details only and not as concrete investigations (Bombosch 1962, Haacker 1968, Voigtländer 1987, Benest 1989, Dunger & Fiedler 1997). For example Braune (1974) observed some specimens (Isopoda, Carabidae), which did not overrun the trap margin.

The investigations presented here are complementary to the results of studying the behaviour components of animal activity at trap margins achieved in former studies (Gerlach et al. 2009). They demonstrate inter- and intraspecific differences of the reaction at pitfall traps.

The catching result of the species is influenced by the parameters locomotory activity, running speed, avoidance (due to olfactorical stimuli), retreating (olfactorical and/or tactile stimuli) and self-rescue in a different degree (see also Gerlach et al. 2009). All of these behavioural patterns are influenced by light and darkness respectively. The duration, in which an individual is active, and the quantity of activity (covered distance) determine the radius of activity and therefore the catchment area of a pitfall trap for each species (Müller 1984).

The **activity parameters** are strongly correlated to the foraging behaviour of the species. The predatory Carabidae have the highest activity and the fastest running speed. They capture their prey animals by fast hunting. The predatory Chilopoda are characterised by a low activity but high running speed. As 'couch-hunters' or 'waiting animals' (Simon 1960) they waylay their prey at hiding-places and snap as quickly as a flash. As saprophagous animals the Diplopoda have the lowest activity and the lowest running speed.

The diplopod *E. nanus* is smallest (up to 20 mm) and slowest (2.5 mm s^{-1}) with the lowest catching result of all investigated species. This certifies the assessment as one of the „trap avoidant' species (Voigtländer 1987), whereas big and fast species as *Tachypodoiulus niger*, *Ommatoiulus sabulosus*, *Megaphyllum unilineatum*, *M. projectum* (Haacker 1968) and much more are well known as 'trap prevalent species'. In comparison with our investigations Haacker (1968) measured the same tendencies in running speeds but the animals were faster. It is founded in another method for the measurement. He used a small tube for running, which seems to stimulate the species for higher speed.

The locomotory activity varies with the seasons (Lauterbach 1964, Banerjee 1967, Meyer-Peters 1993) with the highest activity during the reproduction phase (Weber 1968, Müller 1984). In general males show a higher agility whereas the females show a higher affinity to optimal habitats (Heydemann 1962, Mossakowski 1970, Müller 1970, Thiele 1977, Šustek 1984). This is also the case in our investigations, in which the males of most species were not only in the reproductive phase more active than the females. There were no differences in the running speed between the sexes in all species.

The millipedes and centipedes showed a clear nocturnal activity both in males and females, whereas the carabid beetles were active under both light conditions. The increased nocturnal activity is not reflected in a higher catching result, because this is adjusted resp. decreased by increased wariness of the specimens, especially of the females.

Behaviour. Mainly the **retreating** response directly at the trap (behaviour B and D) influences the efficiency of catching. The smaller and slower or more 'wary' the species (*E. nanus*, *Lithobius microps* and *Harpalus rufipes* – Gerlach et. al. 2009; *L. mutabilis*), the larger the influence. In contrast to Thomas et al. (1977) we have never observed a preference for empty traps for use as a refuge.

Methodical conclusions: The retreat on the trap margin can be minimised by fitting the accuracy between soil and trap (Dunger & Fiedler 1997). The investigations give an idea how important and necessary this is.

According to the ability of **self-rescue** the results of former investigations (Gerlach et al. 2009) are substantiated here. In general this ability is true for all species, but in different degrees. The way how the species do it is described in Gerlach et al. (2009). The main factor which influences this behaviour is the running speed, but also the mass and other morphological features of the specimens.

Among the Carabidae, mainly larger and faster species (Tab. 5) show the smallest values. As a result of their fastness and mass they are not able to stop before the trap or hold onto the margin. Morrill et al. (1990) observed that the faster specimens of *Pterostichus corvus* were caught more frequently in traps.

In the relatively slow Diplopoda the Rate of Self-Rescue (RSR) is mainly influenced by body size and number of leg pairs. *G. hexasticha* is the millipede with smallest values (Tab. 5). Its globular form and the smaller number of legs reduce this ability. *E. nanus*, the smallest and slowest millipede with a high number of legs has the highest RSR of nearly 100 %, whereas the larger and faster species *M. projectum* has the lowest rate.

Tab. 5 Rate of Self-Rescue of investigated species in % (sorted after body size).

species	present investi-gation	Gerlach et al. (2009)	species	present investi-gation	Gerlach et al. (2009)
Diplopoda			**Carabidae**		
M. projectum	39.7		*C. hortensis*		14.2
J. scandinavius	80.9	84.6	*C. granulatus*		54.3
S. stigmatosum		66.7	*A. parallelepipedus*	20.9	10.9
E. nanus	90.9		*P. burmeisteri*	8.7	
P. inconstans		88	*H. rufipes*		46.2
G. hexasticha	35.7	37.9	**Staphylinidae**		
Chilopoda			*S. erythropterus*		46.7
L. forficatus		62.9	**Oniscidea**		
L. mutabilis	82.4		*O. asellus*		52.6
L. microps		57.1	*A. opacum*		25

Methodical conclusions: The Rate of Self-Rescue can be minimised by adequate construction and very smooth material of the trap wall. In Carabidae Luff (1975) found a rate of escaping from the trap as 0 % for glass traps, 4 % for plastic traps, and 10 % for metal traps.

Attractancy and deterrence. The **fixing solutions** used in pitfall trapping also influence the behaviour of the species and therefore the catching results (e.g. Adis 1979, Renner 1982). Carabid beetles are studied most intensively, but often with different results. Whereas in some investigations (Luff 1968, Skuhravy 1970, Braune 1974, Teichmann 1994) the beetles were caught more frequently with formaldehyde than with empty or water filled traps, other studies showed only small or no differences in the catching results (Waage 1985, Holopainen & Varis 1986). Some staphylinid species were even caught in lower quantities with formaldehyde than with water filled traps, whereas ethanol had an attracting effect for some species of Staphilinidae (Vogel 1983) and other beetles (Santos et al. 2007). All these results have to be considered very critically, because they based on outdoor investigations with very differing influences of many other factors. For instance, Braune (1974) established contrary results for formaldehyde in his outdoor and laboratory experiments with Carabidae.

In our laboratory studies there was no repellent or attracting effect for water and ethylene glycol. Although formaldehyde has a pungent smell it is only repellent for the millipedes (with exception of *J. scandinavius*). Maybe the diplopods have a higher ability to sense this fluid.

The carabid beetles showed no reaction on AEW. In contrast, a clear repellent effect could be observed for all millipedes. For the centipede *L. mutabilis*, the results do not reflect the real reaction of the animals. It has to be considered that the specimens showed first reactions near the bowls with the mixture. According to Keil (1976), *Lithobius*-species have only a low sense of smell and the individuals orient themselves by tactile stimuli. That is why the specimens do not smell the preservative before they are directly in front of the bowls.

The repellent effect can be caused by the pungent smell of acetic acid as well as ethanol. In this mixture the percentage of ethanol was highest. Ethanol is a very volatile fluid, which has a higher steam pressure (59 mbar by 20 °C, in comparison with water: 23, 4 mbar) than the other investigated liquids (Jessel 1997). Because more molecules escape from the fluid, the specimens can smell this mixture more easily.

The considerable differences in reactions between the sexes which often had been observed (Adis 1976) could not be confirmed in this study.

The results show that the influence of the preservatives is very different between the species. However, a calculation of attractiveness and application to outdoor studies is impossible, because the effect of fixative solutions can be influenced by many external factors. During dry weather periods the fluids can have an attracting effect on the animals. Also the caught individuals, especially in ethylene glycol, can have an impact on the catching results because of the smell of decay (Tretzel 1955, Heydemann 1956), whereby some species could be attracted more strongly by this. In some carabid species, Luff (1986) showed that the emitted secretions (pheromones, defence secretions) have an attracting effect and can have an influence on the catching results. Furthermore, the concentration of the fixative solution can be another factor (Pekár 2002).

5. Conclusions

The study demonstrates that epigeic arthropods respond by very different behavioural reactions to pitfall traps.

Certainly, the study was done under laboratory conditions, but the individuals can definitely show the same reactions under natural conditions, perhaps with other frequencies.

The different behaviour of the species and specimens to pitfall traps even more complicate the interpretation of catching numbers. However, it can clearly be seen that the number of trapped individuals does not directly reflect the real quantity of the species round the trap. Consequently, it is impossible to make quantitative calculations on the basis of trap results – neither as ‘activity dominance’ nor as ‘activity abundance’ – as have been recommended by Heydemann (1953) and Tretzel (1955) (see also Seifert 1990). Quantifiable methods for extraction of soil animals from soil samples or defined soil areas are well known (e.g. Dunger & Fiedler, 1997) but are not replaceable by pitfall trapping.

This faster and easier method remains indispensable in ecological research. It is useful for phenological investigations of ‘no trapping resistant’ epigeic arthropods or to clear up other questions in connection with reactions being directed by behaviour.

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7. References

Adis, J. (1976): Bodenfallenfänge in einem Buchenwald und ihr Aussagewert. – Ökologie-Arbeiten, Berichte, Mitteilungen (Solling-Projekt Zoologische Beiträge) Ulm: 1–49.

Adis, J. (1979): Problems of interpreting arthropod sampling with pitfall traps. – Zoologischer Anzeiger Jena **202** (3/4): 177–184.

Banerjee, B. (1967): Diurnal and seasonal variations in the activity of the millipedes *Cylindroiulus punctatus* (Leach), *Tachypodoiulus niger* (Leach) and *Polydesmus augustus* Latzel. – Oikos **18**: 141–144.

Barber, H. S. (1931): Traps for cave-inhabiting insects. – Journal of the Mitchell Society **46**: 259–266.

Benest, G. (1989): The sampling of a carabid community. I. The behaviour of a carabid when facing the trap. – Revue d’écologie et de biologie du sol **26**(2): 205–211.

Bombosch, S. (1962): Untersuchungen über die Auswertbarkeit von Fallenfängen. – Zeitschrift für angewandte Zoologie Berlin **49**: 149–160.

Braune, F. (1974): Kritische Untersuchungen zur Methodik der Bodenfalle. – Dissertation Kiel: 71 pp.

Digweed, S. C., C. R. Currie, H. A. Cárcamo & J. R. Spence (1995): Digging out the ‘digging-in effect’ of pitfall traps: Influences of depletion and disturbance on catches of ground beetles (Coleoptera: Carabidae). – Pedobiologia **39**: 561–576.

Dunger, W. (1963): Praktische Erfahrungen mit Bodenfallen. – Entomologische Nachrichten **4**: 41–46.

Dunger, W. (1966): Neue Untersuchungen über Methodik und Wert des Boden-Fallenfanges für die quantitative Faunistik. – II. Entomologisches Symposium über die Probleme der faunistischen und entomogeographischen Erforschung der Tschechoslowakei und Mitteleuropas, Opava **18**: 85–103.

Dunger, W. & H. J. Fiedler (1997): Methoden der Bodenbiologie. – 2. Auflage, Gustav Fischer Verlag, Jena/Stuttgart/Lübeck/Ulm: 539 pp.

Geiler, H. (1964): Über die Bedeutung der Bodenfallen-Fangmethode nach Barber für die Erfassung der im Epigaion von Feldern lebenden Wirbellosen. – Tagungsberichte der Deutschen Akademie der Landwirtschaftlichen Wissenschaften Berlin **60**: 81–88.

Gerlach, A., K. Voigtländer & C. M. Heidger (2009): Behavioural response of selected epigeic arthropods on pitfall traps (Diplopoda, Chilopoda, Oniscidea, Carabidae, Staphylinidae). – Soil Zoology in Central Europe, České Budějovice: 41–46.

Greenslade, P. J. M. (1973): Sampling ants with pitfall traps: digging-in-effects. – Insects Society **20**: 343–353.

Haacker, U. (1968): Deskriptive, experimentelle und vergleichende Untersuchungen zur Autökologie rhein-mainischer Diplopoden. – Oecologia **1**: 87–129.

Heydemann, B. (1953): Agrarökologische Problematik (dargetan an Untersuchungen über die Tierwelt der Bodenoberfläche der Kulturfelder). – Dissertation Kiel: 433 pp.

Heydemann, B. (1956): Über die Bedeutung der 'Formalinfallen' für die zoologische Landesforschung. – Faunistische Mitteilungen aus Norddeutschland **7**: 19–24.

Heydemann, B. (1962): Untersuchungen über die Aktivitäts- und Besiedlungsdichte bei epigäischen Spinnen. – Verhandlungen der deutschen zoologischen Gesellschaft (Saarbrücken 1961): 538–556.

Holopainen, J. K. & A.-L. Varis (1986): Effects of a mechanical barrier and formalin preservative on pitfall catches of carabid beetles (Coleoptera, Carabidae) in arable fields. – Zeitschrift für angewandte Entomologie **102**: 440–445.

Jessel, W. (1997): Aus der Praxis: Brennbare Flüssigkeiten und Flammpunkt. – Drägerheft **366**: 51–55.

Keil, T. (1976): Sinnesorgane auf den Antennen von *Lithobius forficatus* L. (Myriapoda, Chilopoda). I. Die Funktionsmorphologie der 'Sensilla trichodea'. – Zoomorphologie **84**: 77–102.

Lauterbach, A. W. (1964): Verbreitungs- und aktivitätsbestimmende Faktoren bei Carabiden in sauerländischen Wäldern. – Abhandlungen des Landesmuseums für Naturkunde Münster **26**(4): 1–103.

Luff, M. L. (1968): Some effects of formalin on the number of Coleoptera caught in pitfall traps. – Entomologist's Monthly Magazine **104**: 115–116.

Luff, M. L. (1975): Some features influencing the efficiency of pitfall traps. – Oecologia **19**: 345–357.

Luff, M. L. (1986): Aggregation of some Carabidae in pitfall traps. – In: Den Boer, P. J. et al. (eds): Carabid beetles, their adaptations and dynamics. – Gustav Fischer, Stuttgart/ New York: 385–397.

Meyer-Peters, H. (1993): Seasonality of circadian locomotor activity in an insect. – Journal of Comparative Physiology A: Neuroethology, Sensory, Neural, and Behavioral Physiology **171**: 713–724.

Morrill, W. L., D. G. Lester & A. E. Wrona (1990): Factors affecting efficacy of pitfall traps for beetles (Coleoptera: Carabidae and Tenebrionidae). – Journal of Entomological Sciences **25**(2): 284–293.

Mossakowski, D. (1970): Ökologische Untersuchungen an epigäischen Coleopteren atlantischer Moor- und Heidestandorte. – Zeitschrift für wissenschaftliche Zoologie **181**(3/4): 233–316.

Müller, G. (1970): Der Sexualindex bei Carabiden als ökologisches Kriterium. – Entomologische Berichte: 12–18.

Müller, J. K. (1984): Die Bedeutung der Fallenfang-Methode für die Lösung ökologischer Fragestellungen. – Zoologische Jahrbücher, Abteilung für Systematik, Ökologie und Geographie der Tiere **111**: 281–305.

Naguib, M. (2006): Methoden der Verhaltensbiologie. – Springer-Verlag, Berlin/ Heidelberg: 233 pp.

Pekár, S. (2002): Differential effects of formaldehyde concentration and detergent on the catching efficiency of surface active arthropods by pitfall traps. – Pedobiologia **46**: 539–547.

Renner, K. (1982): Coleopterenfänge mit Bodenfallen am Sandstrand der Ostseeküste, ein Beitrag zum Problem der Lockwirkung von Konservierungsmitteln. – Faunistische und ökologische Mitteilungen Kiel **5**: 137–146.

Santos, S. A. P., J. E. Cabanas & J. A. Pereira (2007): Abundance and diversity of soil arthropods in olive grove ecosystem (Portugal): Effect of pitfall trap type. – European Journal of Soil Biology **43**: 77–83.

Seifert, B. (1990): Wie wissenschaftlich wertlose Fangzahlen entstehen – Auswirkungen artspezifischen Verhaltens von Ameisen an Barberfallen direkt beobachtet. – Entomologische Nachrichten und Berichte **34**(1): 21–27.

Simon, H.-R. (1960): Zur Ernährungsbiologie von *Lithobius forficatus* (Myriapoda, Chilopoda). – Zoologischer Anzeiger **164** (1/2): 19–26.

Skuhravy, V. (1970): Zur Anlockungsfähigkeit von Formalin für Carabiden in Bodenfallen. – Beiträge zur Entomologie **20**(3/4): 371–374.

Stammer, H. J. (1948): Die Bedeutung der Aethylenglykolfallen für tierökologische und –phänologische Untersuchungen. – Verhandlungen der Deutschen Zoologischen Gesellschaft Kiel: 387–391.

Šustek, Z. (1984): The bioindicative and prognostic significance of sex ratio in Carabidae (Insecta, Coleoptera). – Ekologia (ČSSR) **3** (1): 3–22.

Teichmann, B. (1994): Eine wenig bekannte Konservierungsflüssigkeit für Bodenfallen. – Entomologische Nachrichten und Berichte **38**(1): 25–30.

Thiele, H. U. (1977): Carabid Beetles in their Environments. A study on habitat selection by adaptations in physiology and behaviour. – Springer, Berlin/ Heidelberg/ New York: 369 pp.

Thomas, D. B. Jr. & E. L. Sleeper (1977): The use of Pitfall Traps for Estimating the Abundance of Arthropods, with Special Reference to the Tenebrionidae (Coleoptera). – Annual reports of Entomologist Society of America **70**: 242–248.

Tretzel, E. (1955): Technik und Bedeutung des Fallenfanges für ökologische Untersuchungen. – Zoologischer Anzeiger **155**: 276–287.

Vogel, J. (1983): Zur Köderwirkung von Äthanol auf *Megaloscapa punctipennis* (KR.) und andere Staphylinidae (Coleoptera) in Bodenfallen. – Entomologische Nachrichten und Berichte **27**(1): 33–35.

Voigtländer, K. (1987): Untersuchungen zur Bionomie von *Enantiulus nanus* (Latzel, 1884) und *Allajulus occultus* C. L. Koch, 1847 (Diplopoda, Julidae). – Abhandlungen und Berichte des Naturkundemuseums Görlitz **60**(10): 1–116.

Weber, F. (1968): Circadian- Regel und Laufaktivität der Caraben (Ins. Coleoptera). – Oecologia **1**: 155–170.

Waage, B. E. (1985): Trapping efficiency of carabid beetles in glass and plastic pitfall traps containing different solutions. – Norwegian Journal of Entomology Series B **32**: 33–36.

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