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Dynamics of Abundance of Ground Beetles (Coleoptera, Carabidae) in Fenced Areas in the Cis-Altai Plain (Western Siberia)

A. N. Bespalov and I. I. Lyubechanskii

Institute of Animal Systematics and Ecology, Siberian Division, Russian Academy of Sciences, Novosibirsk, 630091 Russia
e-mail: a.bespalov@bk.ru

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Abstract—The density of ground beetle populations were estimated by means of fenced Barber traps in 2004–2008, in the environs of Biisk (Altai Territory) and Karasuk (Novosibirsk Province). In all, 64 species of ground beetles were revealed. The capture rates were usually higher in open than in fenced plots. No correlation was observed between the time of trap exposure and the captures. By the end of the 3rd–6th week of exposure, the fraction of juvenile and immature adults increased. The beetles captured within a fenced area 1 m^2 usually fell into the traps in 2–3 days. The absolute density of ground beetles in the fenced areas was estimated at 55–60 ind./m^2.

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The quantitative surveys of epigeic invertebrates are carried out using two methods: excavation and trap sampling. The excavation method allows one to characterize the species composition, dominance structure, and density of organisms per unit area, and is widely used by soil zoologists. However, this method is very labor consuming and tends to underestimate the abundance of large, mobile, and rare herpetobionts (Gilyarov, 1975).

The Barber traps have some advantages over the excavation method. Trap sampling eliminates the subjective bias and allows one to carry out prolonged surveys which are required to characterize the daily and seasonal dynamics of activity, the direction of migrations (combined with marking techniques), and a number of other parameters.

An essential drawback of the trapping method is that it cannot estimate the actual density of animals, or their number per unit area. Therefore the abundance is measured in arbitrary units of “trap yield,” i.e., the number of specimens captured related to the number of traps and the duration of trap exposure (usually expressed per 10 or 100 trap-days). This characteristic depends on the activity of animals in the biotope, which is determined by many factors. For ground beetles, such factors are the weather conditions, the season, microrelief, vegetation, the life form and mobility of a particular species, etc. (Gryuntal, 1981; Desender and Maelfait, 1986). When applied simultaneously in the same area, the two methods reveal quite different assemblages of species (Striganova and Poryadina, 2005; Lyubechanskii, 2009).

The aim of this work was to study the possibility of using Barber traps in fenced areas to determine the density of ground beetles.

The following tasks were set:

(1) To characterize the differences in the structure of ground beetle assemblages in open and fenced areas.

(2) To characterize the differences in the trap yield depending on the size of fenced areas and details of their layout.

(3) To study the effect of the temperature on the trap yield in different sample areas.

MATERIALS AND METHODS

The studies were carried out during four seasons: in 2004–2006 in the environs of Biisk (Altai Territory) and in 2008, in the environs of Karasuk (Novosibirsk Province).

The Biisk sampling site was located on the fifth terrace of the right bank of the Biya, within the Biya-Chumysh Upland. The territory in question belongs to the middle forest-steppe zone, its macrorelief consisting of valleys and ravines. The climate is characterized by distinct continental aspects: cold, long, snowy win-

Table 1. The species diversity and abundance of ground beetles in open and fenced areas in the different seasons of study

Parameters	30.06–19.07.2004	19.06–10.07.2005	22.05–6.07.2006	03.06–22.07.2008
Number of species in fenced plots	31	21	22	16
Number of species in open plots	26	28	34	32
Total number of species	36	31	37	36
Number of ind. in fenced plots	1669	100	140	27
Number of ind. in open plots	1423	254	347	76
Total number of ind.	3092	354	487	103
The dominant species	*Poecilus fortipes*, *Harpalus rufipes*, *Anisodactylus signatus*	*Poecilus sericeus*, *Calosoma denticolle*, *Poecilus fortipes*	*Poecilus fortipes*, *Poecilus versicolor*, *Amara aenea*, *Poecilus sericeus*	*Syntomus truncatellus*, *Badister bullatus*, *Ophonus puncticollis*

Note: 2004: 3 fenced plots of different size: 1 m^2 (4 traps), 9 m^2 (9 traps), and 25 m^2 (25 traps), and the same total number of traps in unfenced areas; 2005 and 2006: 5 plots of 1 m^2 (4 traps in each), 3 plots of 4 m^2 (8 traps in each), and the same number of traps in unfenced areas; 2008: 10 plots of 1 m^2 (4 traps in each) and the same number of traps in unfenced areas.

ter and short, warm, sometimes hot summer. The mean annual precipitation is 474 mm, the mean duration of the frostless season is 120 days (Ostroumov, 1961). The sampling area is occupied by grass and forb vegetation, with a pronounced sod layer. The average height of vegetation was 30–40 cm, the projective cover, 70–80%. In terms of mesorelief, the sampling area was a level surface gradually continuing into a gentle slope.

The surveys were carried out in meadow plots of approximately 100 × 300 m. The Barber traps (200-ml plastic cups with the upper diameter 6.5 cm) were installed inside fenced plots of 1, 4, 9, and 25 m^2, and the same number of traps was installed in the unfenced territory nearby. Both the fences and the traps were removed after the survey period and installed again in about the same places in the following year; their positions changed from year to year by no more than several meters. The number of fenced plots and traps used during each season is characterized in the comments to Table 1. The arrangement of fences and traps in 2005–2006 is shown in Fig. 1.

The Karasuk sampling site was located in the Baraba forest-steppe. The duration of the frostless season in the region is 80 days, and the mean annual precipitation is 260 mm (*The West Siberia*, 1963). The

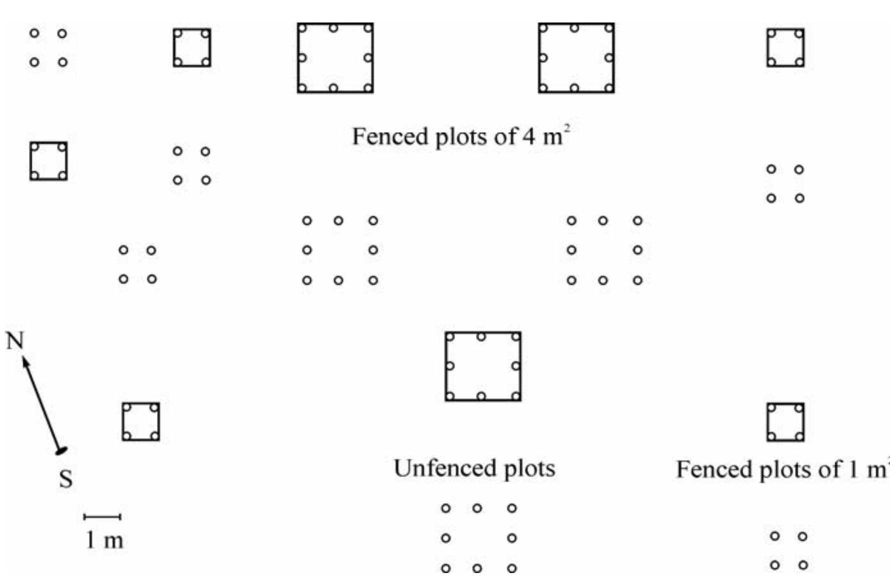

Fig 1. The arrangement of fenced and unfenced traps in 2005–2006 at the sample site in the environs of Biisk.

work was carried out in a patch of feathergrass meadow steppe near the shore of Krotova Lyaga Lake. The soil is common chernozem; the average height of vegetation was about 30 cm, the projective cover was 80–90%, the dominant plant species were the feathergrass, meadow grass, and yarrow.

In 2008 the surveys were carried out at the Karasuk sampling site, within an area of 50 × 150 m. The fences were installed in two rows in staggered order, following the scheme shown in Fig. 1.

In 2004 the sample plots were enclosed with fences of polyethylene film 30 cm high. In the subsequent years the fences were made of thick cardboard or fiberboard (30 cm high in 2005–2006 and 60 cm high in 2008); the plots were covered with mosquito net (mesh size 2 × 2 mm). The fences penetrated 5 cm deep into the ground (20 cm in 2008). The traps inside the fenced plots were installed with 1-m intervals along the inner perimeter, so as to preserve vegetation and make inspection more convenient. In 2005–2008, the traps were checked daily through rectangular openings in the fences, which were otherwise kept covered.

In 2008 some ground beetles were examined to determine the phase of development of their reproductive systems (juvenile, immature, generative, or postgenerative), the state of the mandibles, and the hardness of the integument (Wallin, 1987; Makarov, 1989; Khobrakova and Sharova, 2005). In all, about 200 ground beetles were dissected, mostly from the genera *Amara*, *Poecilus*, and *Harpalus*. The specimens were collected near the sampling site, and 32 ind., inside the sampling area.

The recapture experiments were carried out from July 21 to August 1, 2004, using a fenced plot 3 × 3 m with the same layout as in the main experiment. The ground beetles were marked and released into the plot. Marking was performed by cutting off small parts of the elytra (the left elytron after the first capture, the right one after the second capture, etc.). This procedure is relatively harmless, since in the nature ground beetles can break off up to 50% of their elytra without any visible impediment of their activity (*Quantitative Methods…*, 1987).

The experiments with ground beetles in artificial habitats were carried out from June 15 to June 24, 2008 in two replicates, using 20 or 30 beetles of different species from the genera *Amara*, *Poecilus*, and *Harpalus*. A specially fenced plot (arena) measuring 1 × 1 m was established at the sample site. The grass was mown down and the arena was filled with sand to make a layer 2–3 cm thick. The sand was isolated from the underlying soil by two layers of polyethylene film. Four Barber traps and two water dishes were installed in the arena. The sand was moistened every two days. The ground beetles were marked with quick-drying red nail polish applied to the elytra, which did no harm to the insects (*Quantitative Methods…*, 1987). The goal of the experiment was to determine the time interval during which all the beetles present in a 1-m^2 arena would be captured, and to estimate the mobility of ground beetles. The total number of captured living beetles and dead ones found in the arena was equal to the number of beetles originally released into the arena.

The air temperature was measured simultaneously with the surveys of the ground beetles. In 2005 and 2006, three shaded outdoor alcohol thermometers were installed 30 m apart at the sample site. The measuring elements of the thermometers were positioned 10 cm above the ground.

RESULTS

During the entire period of observation, ground beetles of 64 species from 22 genera and 14 tribes were collected; the total material comprised over 10 thousand trap-days (Table 2).

The ground beetle assemblage of forest-steppe biotopes in the environs of Biisk is mostly composed of representatives of the genera *Poecilus* (52.7% of the total number of specimens collected), *Harpalus* (18.7%), and *Calathus* (9.8%). The most diverse genera were *Harpalus* (17 species), *Amara* (9), and *Poecilus* (5). Each of the genera *Agonum*, *Broscus*, *Masoreus*, *Microlestes*, *Pseudotaphoxenus*, *Pterostichus*, and *Syntomus* was represented by a single species. The composition of the fauna was typical of steppe and forest-steppe landscapes of South Siberia (Dudko and Lyubechanskii, 2002).

The most abundant species were *Poecilus fortipes* Chaud. (27.5%), *Poecilus cupreus* L. (11.5%), *Dolichus halensis* Schall. (9.6%), *Harpalus rufipes* Deg. (9.2%), *Poecilus versicolor* Sturm (8.2%), and *Anisodactylus signatus* Pz. (7.1%). The group of common species included *Poecilus sericeus* F.-W., *Agonum gracilipes* Duft., and *Harpalus anxius* Duft. All the remaining species, each comprising less than 1% of the total abundance, can be regarded as rare and occasional forms.

Table 2. The ground beetle population of the model areas (ind. per 100 trap-days)

Species	Environs of Biisk (meadow steppe)	Environs of Karasuk (feathergrass meadow steppe)	Species	Environs of Biisk (meadow steppe)	Environs of Karasuk (feathergrass meadow steppe)
Agonum gracilipes (Duft.)	2.95	0	*H. akinini* Tschit.	0	0.08
A. aenea (Deg.)	0.95	0.05	*H. calathoides* Motsch.	0.19	0
A. apricaria (Pk.)	0.03	0.08	*H. calceatus* (Duft.)	0.84	0.05
A. bamidunyae H. Bat.	0.03	0.03	*H. distinguendus* (Duft.)	0.04	0.03
A. communis (Pz.)	0.01	0	*H. griseus* (Pz.)	0.16	0
A. consularis (Duft.)	0.01	0	*H. lumbaris* Mnnh.	0.40	0
A. equestris (Duft.)	0.35	0.03	*H. oodioides* Dej.	0	0.03
A. eurynota (Pz.)	0.05	0	*H. politus* Dej.	0.15	0.05
A. lunicollis Schiodte	0.03	0	*H. pumilus* (Strum)	0.29	0
A. tibialis (Pk.)	0.16	0.05	*H. rufiscapus* Gebl.	0	0.03
A. bifrons (Gyll.)	0	0.03	*H. rubripes* (Duft.)	1.75	0.08
A. infima (Duft.)	0	0.05	*H. rufipes* (Deg.)	7.83	0
Anisodactilus signatus (Pz.)	4.85	0	*H. kirgisicus* Motsch.	0	0.28
Badister bullatus (Schrank)	0	0.15	*H. signaticornis* (Duft.)	0.01	0
B. lacertosus Strum	0	0.03	*H. smaragdinus* (Duft.)	0.83	0.03
Bembidion sp.	0	0.13	*H. subcylindricus* Dej.	0.08	0.03
B. properans (Steph.)	0.29	0	*H. tardus* (Pz.)	0.04	0.03
Broscus cephalotes (L.)	0	0.03	*H. zabroides* Dej.	0.01	0
B. semistriatus (Dej.)	0.03	0.03	*Masoreus wetterhalli* (Gyll.)	0.03	0.03
Calathus erratus (C.R. Sahlb.)	0.03	0.05	*Microlestes minutulus* (Gz.)	0.07	0.10
Dolychus halensis (Schall.)	3.73	0	*M. fissuralis* Rtt. (? *maurus* Strum)	0	0.75
Calosoma denticolle Gebl.	0.85	0	*Notiophilus germinyi* Fauv.	0	0.03
C. investigator (Ill.)	0.15	0	*Ophonus stictus* (Steph.)	0.01	0
Carabus clathratus L.	0	0.03	*O. puncticollis* (Pk.)	0.04	0.15
C. regalis Fisch.	0.09	0	*Poecilus cupreus* L.	3.89	0
C. tuberculosus Dej.	0.01	0	*P. fortipes* Chaud.	14.45	0.10
Curtonotus castaneus (Putz.)	0	0.08	*P. punctulatus* (Schall.)	0.11	0
Cymindis angularis (Gyll.)	0	0.03	*P. sericeus* (Fisch.)	1.97	0.08
Dyschiriodes sp.	0	0.05	*P. versicolor* (Strum)	3.01	0
D. salinus (Schaum.)	0	0.03	*Pseudotaphoxenus tillesii* (Fisch.)	0.11	0
Harpalus affinis (Schrank)	0.29	0	*Pterostichus magus* Mnnh.	0.01	0
H. anxius (Duft.)	1.12	0.18	*Syntomus truncatellus* (L.)	0.09	0.28

In the steppe biotopes of the environs of Karasuk the most abundant were representatives of the genera *Harpalus*, *Amara*, and *Syntomus*, which comprised 33.0, 11.65, and 10.68% of the total number of specimens collected, respectively. The most abundant species was *Syntomus truncatellus* L. (10.68% of the total number). The most diverse genera were *Harpalus* (11 species) and *Amara* (7); several genera were represented by two species each: *Poecilus*, *Microlestes*, *Broscus*, and *Badister* (Table 2).

Table 3. Pearson's coefficient of linear correlation between the trap yields in fenced and unfenced plots in different years of study

Type of biotope and year of study	Linear correlation coefficient *r*
2004	
Unfenced vs. fenced plots of 1 m^2	0.44*
Unfenced vs. fenced plots of 9 m^2	0.55*
Unfenced vs. fenced plots of 25 m^2	0.55
Fenced plots of 1 m^2 vs. fenced plots of 9 m^2	0.68**
Fenced plots of 1 m^2 vs. fenced plots of 25 m^2	0.42
Fenced plots of 9 m^2 vs. fenced plots of 25 m^2	0.49*
2005	
Unfenced vs. fenced plots of 1 m^2	–0.17
Unfenced vs. fenced plots of 4 m^2	–0.08
Fenced plots of 1 m^2 vs. fenced plots of 4 m^2	0.30
2006	
Unfenced vs. fenced plots of 1 m^2	0.41*
Unfenced vs. fenced plots of 4 m^2	0.36*
Fenced plots of 1 m^2 vs. fenced plots of 4 m^2	0.65**
2008	
Unfenced vs. fenced plots of 1 m^2	0.57**

Notes: The differences are significant: * at $p < 0.05$, ** at $p < 0.01$.

The relative abundance of species in fenced and open areas was only insignificantly different. The total number of species was smaller in fenced plots, usually due to the absence of some rare and occasional species (see Table 1).

In general, the daily trap yields in open and fenced areas were positively correlated. The Pearson's coefficient of linear correlation was positive in different years except 2005 and for sample plots of different size (Table 3). Therefore we can conclude that the presence of fencing does not affect the activity of ground beetles.

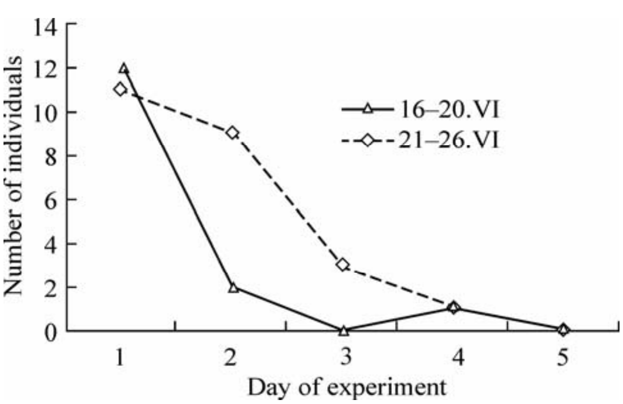

Fig. 2. Captures of ground beetles in a test arena installed in the environs of Biisk.

The trap yields were usually higher in unfenced plots, probably due to migration from adjacent territories. However, in 2004, when the survey was carried out in large plots (9 and 25 m^2), the total number of beetles in fenced plots was slightly greater than that in unfenced areas. These data may serve as an indirect estimate of the individual activity radius of ground beetles. For example, the highly mobile, alate beetle *Calosoma denticolle* Gebl. was found only in large fenced plots but was never encountered in fenced plots of 1 and 4 m^2, even though it was captured in the nearby unfenced traps.

The highest mean trap yield in 2004 was observed in fenced 9-m^2 plots (2.52 ± 0.39 ind./trap-day). Lower values were observed for larger fenced plots (2.20 ± 0.22 ind./trap-day in 25-m^2 plots) and for unfenced areas (1.87 ± 0.25 ind./trap-day). However, the lowest yield was recorded in fenced 1-m^2 plots (1.43 ± 0.21 ind./trap-day), which differed significantly ($p < 0.01$) from all other fenced and unfenced plots. Other variants of test plots revealed no significant differences.

The fenced plots of 1 m^2 showed the highest trap yield per unit area (for fenced traps in 2004): 5.70 ± 0.83 ind. per 1 m^2 per day, as compared to

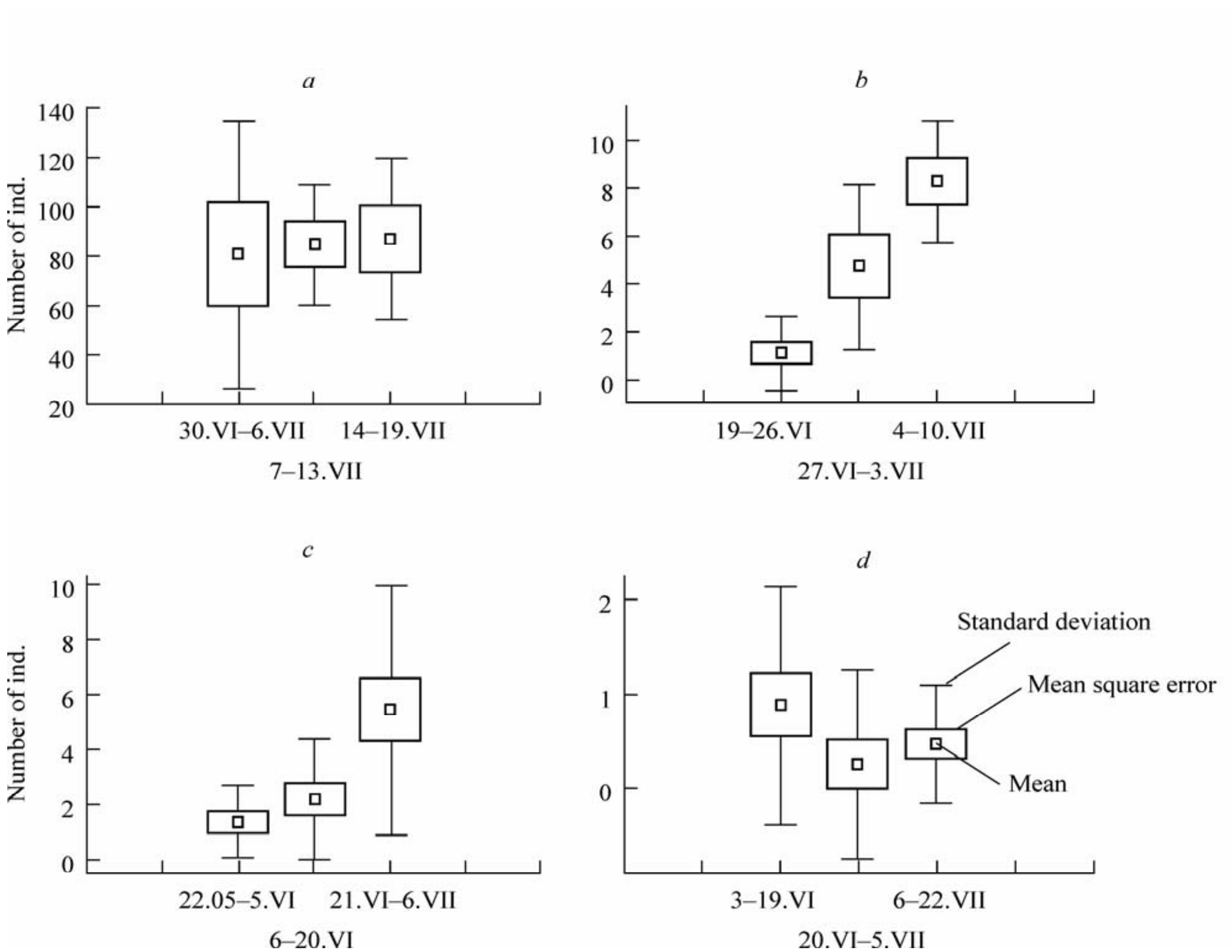

Fig. 3. Average daily trap yield in fenced plots in 2004 (*a*), 2005 (*b*), 2006 (*c*), and 2008 (*d*).

2.52 ± 0.39 or smaller for all other variants of fenced plots.

In the artificial habitat with an area of 1 m^2, it usually took 1–4 days for a beetle to be captured. On the 5th day of the experiment all the beetles were captured (Fig. 2).

The trap yield in fenced plots was significantly and positively correlated with temperature in 2004–2006 (Pearson's coefficient of linear correlation: r = 0.38–0.74, p < 0.05). The total trap yield was correlated with temperature (r = 0.59, p < 0.001) only in 2005. The trap yield in unfenced plots did not show a significant correlation with temperature.

In the mark-recapture experiment, 86 beetles of 3 genera: *Amara*, *Harpalus*, and *Poecilus*, were marked. Of these, 14 beetles were captured again. The total number of captured individuals of these genera was 105. Thus, the abundance of these ground beetles within the fenced area can be estimated at 500 ind., or 55–60 ind./m^2.

DISCUSSION

Pitfall trapping within enclosed areas has been used since the 1970s (Kudrin, 1971; Gryuntal, 1981; Desender and Maelfait, 1986; Holland and Smith, 1991); the results obtained by this method are controversial. For example, Kudrin (1971) noted a decrease in the number of ground beetles within a fenced area but did not confirm this observation statistically. If we assume that a certain number of ground beetles gets trapped inside the enclosure, then in the absence of immigration the abundance of beetles will decrease at a more or less uniform rate; the more mobile individuals will be the first to be captured. This assumption is confirmed by the result of our experiment with a limited number of beetles in an artificial arena (see Fig. 2), but not by the trapping data for the fenced plots of a natural biotope.

The most interesting result is the absence of correlation between the duration of trap exposure inside fenced plots and the trap yield (Fig. 3). No depletion or even a significant decrease in the abundance of ground beetles was observed during three-week surveys in 2004 and 2005 and a six-week survey in 2006, even in the smallest sample plots of 1 m^2. The abundance of beetles even increased during the last week of the surveys in 2005 and 2006.

We assume that the steppe-dwelling ground beetles interrupt their activity during the season, entering aestivation diapause. The existence of this diapause can be confirmed by the presence of numerous diapausing beetles (mostly of the genus *Amara*) in soil samples taken from nearby biotopes (Lyubechanskii, 2009). Because of this feature, individuals in generative and postgenerative phases can appear in the captures. During the entire survey period some ground beetles emerge from the pupae, and some get reactivated after aestivation. The emerging insects fall into the traps in 1–2 days. The results of the experiment in the artificial habitat, described above, also demonstrate the high rates of captures.

If we assume that the ground beetles can enter the enclosed area from above, then the number of immigrating insects will be proportional to the perimeter of the enclosure (the perimeter-to-area ratio decreases as the area increases). However, in this case the beetles should be able to leave the enclosed area in the same way. A fence 30 cm high, even open from the above, appears to be a serious obstacle for most species of ground beetles. The daily activity radius of the dominant species *Poecilus fortipes* Chaud., *Poecilus cupreus* L., *Dolichus halensis* Schall., and *Harpalus rufipes* Deg. lies within the range of several meters; all these beetles seldom fly. During one day, a beetle will have twice as many chances to get into the trap installed within an area of 0.25 m^2 than into the trap located within an area of 1 m^2.

Analysis of our survey data shows that the activity of ground beetles depends on the weather. The activity is higher in warm (25–35°C) and fair weather, and lower in hot (over 35°C) and cool (less than 20°C) weather. Thus, weather conditions should be also taken into account during analysis of the beetle activity.

The correlation between the trap yield in fenced areas and air temperature (and the absence of such correlation in unfenced areas) may suggest that the temperature positively affects the ability of the beetles to enter and terminate summer diapause or stimulates emergence from pupae, rather than merely increases their activity.

According to the data of a 12-day mark-recapture experiment, the abundance of ground beetles in a fenced plot of 9 m^2 can be estimated at 500 ind. This estimation agrees with the results of a survey carried out in the same season, when 454 ind. were collected from a fenced area of 9 m^2 during 20 days. The absolute density of ground beetles was 55–60 ind./m^2. These experimental data differ from the results of manual collection of beetles in soil samples from a similar biotope, which revealed 21–26 ind./m^2 (Lyubechanskii, 2009). The difference between these results may be accounted for by a longer duration of the recapture experiment, allowing both mature adults and freshly emerged ones to be recorded, whereas examination of soil samples reveals only the adults present at the moment of sampling.

Thus, the ground beetle assemblage of the forest-steppe zone is a dynamic system including both adults and preimaginal stages, which gradually complete metamorphosis and supplement the population of adult beetles during the entire summer season. The functioning of the assemblage cannot be completely characterized if only the adults are taken into account.

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