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Preliminary investigations on the spatial distribution of the harvestmen (Opiliones, Arachnida) from Vitosha Mt. (SW Bulgaria)

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ABSTRACT

The spatial distribution of 13 species of Opiliones from the Vitosha Mt. (Bulgaria) is analysed by means of Lexis' (λ) index of dispersion. *Carinostoma ornatum* (Hadži), *Paranemastoma radewi* (Roewer), *Leiobunum rumelicum* Šilhavý, *Rilaena balcanica* Šilhavý, *Rilaena triangularis* (Herbst), *Phalangium opilio* L., *Zacheus crista* (Brullé), *Lacinius horridus* (Panzer), *Lacinius dentiger* (C. L. K.), *Mitopus morio* (Fabricius) show a nearly random spatial distribution of the individuals in the population. *Carinostoma ornatum* (Hadži), *Mitostoma chrysomelas* (Hermann), *Paranemastoma aurigerum ryla* (Roewer), *Leiobunum rumelicum* Šilhavý, *Opilio dinaricus* Šilhavý, *Lacinius horridus* (Panzer), *Mitopus morio* (Fabricius) tend to form contagious spatial patterns. A very rare case of regular spatial distribution was observed for *Lacinius horridus* (Panzer). The dual characteristics of the spatial distribution of the species *Carinostoma ornatum* (Hadži), *Leiobunum rumelicum* Šilhavý, *Lacinius horridus* (Panzer) and *Mitopus morio* (Fabricius) is established to be corresponding with some phenological peculiarities.

INTRODUCTION

The spatial distribution of the individuals is a very important ecological character for each species, varying even within a population or a particular habitat. The knowledge of the spatial distribution is important to understand the structure of the population and for a reliable estimation of the number of individuals and the biomass of an investigated species. It also may help us to improve the methods for both quantitative and qualitative samplings.

The only data concerning this problem for harvestmen occuring in Bulgaria are provided by Mikityuk (1976) (the random distribution of *Phalangium opilio* L.), by Macfadyen (1965) (the density of Phalangiidae on a meadow, 2 - 38 ind./m^2) and by Sechterova (1989) ((stating that *Lacinius* *ephippiatus* (C. L. K.) is regularly distributed, whereas *Nemastoma lugubre* (Müller) and *Mitopus morio* (Fabricius) are contagiously distributed)).

MATERIAL AND METHODS

The material was collected from three meadows and three wooded areas situated in the northern part of the Vitosha Mountain, at altitudes between 900 and 1850 m above the see level:

1) above Dragalevtsi, 900 m:

a) meadow: *Deschampsia caespitosa* + *D. flexuosa* + *Urtica dioica-Rubus idaeus* association - (M1),

b) wood: *Carpinus betulus* + *Fagus sylvatica-Poa nemoralis* + *Galium odoratum* association - (W1).

2) the range of Bay Krustyo, 1350 m:

a) meadow: *Agrostis capillaris* + *Festuca rubra* + *Briza media* association - (M2),

b) wood: *Fagus sylvatica* + *Carpinus betulus-Hordeum europaeus* + *Luzula sylvatica* - (W2a) and *Fagus sylvatica* + *Carpinus betulus-Hordeum europaeus* + *Carex sylvatica* + *Millium effusum* associations - (W2b).

3) the range of Goli Vruh, 1820 m:

a) meadow: *Juniperus sibirica* + *Vaccinium myrtillus* + *Vaccinium vitis-idaea-Festuca valida* and *Carex nigra* + *Deschampsia caespitosa* associations - (M3),

b) wood - *Pinus peuce* Griseb. with an undergrowth of *Vaccinium myrtillus* L. - (W3).

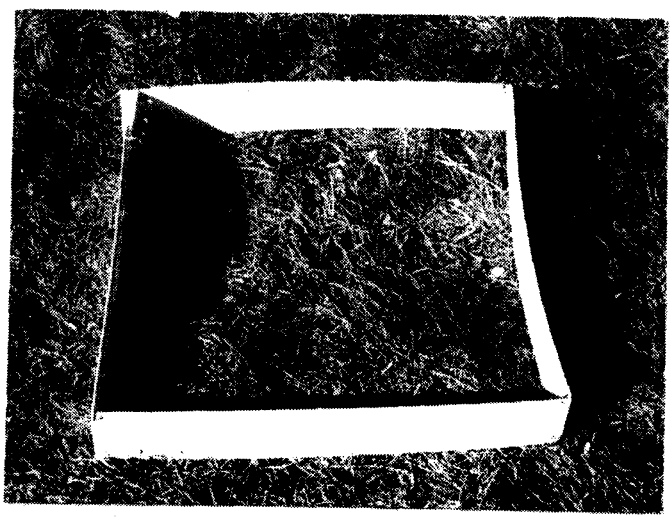

Fig. 1. Plastic frame used to determine the surface of the samples.

The main work method was the hand sorting of the fenced (by means of a plastic frame (Fig. 1) (0.5 x 0.5x 0.07 m)) parcels (samples) of soil surface and litter. Totally, 351 epigeic samples (= 88 m^2, each with a surface of 0.25 m^2)[1], 1.5 to 2.0 metres distant each other and in series of 20 to 37[2], were taken. The data were statistically processed and analysed by means of the following formulae (Elliott 1977):

Lexis' index was computed after the formula: $\lambda = \frac{s}{\sqrt{\bar{x}}}$, where: s - standard deviation of sample, $\bar{x}$ - arithmetic mean of sample. The index equals one for a random distribution, is greater than one for a contagious distribution, and equals zero for a regular distribution.

Because the values of this index are a rather abstract measure of the contagiousity of a population and are difficult to be interpreted because of the lack of such prior investigations on Opiliones, the estimations of the distributional types, in accordance with the values of (, were based upon the works of Chernova and Chugunova (1967), Dubrovskaya (1975), Eskov (1981) and Mikhailov (1983). The adopted classification is as follows:

(≤ 0.7 - for regular distribution
(>0.71 and (≤ 1.2 - for random distribution
(>1.2 - contagious distribution
(>1.2 and (< 1.5 - low aggregation ability
(>1.5 and (= 2.1 - medium aggregation ability
(>2.1 - high aggregation ability.

The distribution was estimated also by means of the χ^2 -test and nomographic chart (after Elliott 1977), at 95 % probability level (p > 0.05) and calculated after the formula:

a) for $n < 31$: $\chi^2 = \frac{s^2(n-1)}{\bar{x}}$, where: s^2 - variance of sample, n - number of sampling units, n - 1 - degrees of freedom, $\bar{x}$ - arithmetic mean of the samples.

b) for $n > 31$: $d = \sqrt{2\chi^2} - \sqrt{2\nu - 1}$, where: d is a normal variable with zero mean and unit standard deviation, (- number of degrees of freedom (after Elliott 1977). As this value of d is greater than 1.96, agreement with a Poisson series is rejected at the 95 % probability level (p > 0.05); as d is less than 1.96 agreement with Poisson series is accepted.

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[1] These are the optimal sample dimensions for use in this kind of investigtions on epigeic invertebrates (see Tikhomirova 1975; Mikityuk 1978).

[2] According to Tikhomirova (1975), this number of samples per habitat is quite enough for such investigations.

The suitable number of sampling units $n = \frac{s^2}{D^2 \bar{x}^2} = \frac{25 s^2}{\bar{x}}$, where: $\bar{x}$ - arithmetic mean of sample; s^2 - variance of sample, $D = \frac{1}{\bar{x}} \cdot \sqrt{\frac{s^2}{n}}$ - index of precision (= 20 % or 0.2), n - number of sampling units.

If the distribution is random, then $n = \frac{\bar{x}}{D^2 \bar{x}^2} = \frac{25}{\bar{x}}$, whereas if the distribution is negative binomial, then $n = \frac{1}{D^2} \cdot (\frac{1}{\bar{x}} + \frac{1}{k}) = 25 \cdot (\frac{1}{\bar{x}} + \frac{1}{k})$, where: k is the binomial exponent $\frac{1}{k} = \frac{s^2 - \bar{x}}{\bar{x}^2 - \frac{s^2}{n}}$.

To find the type of distribution, the values of s^2 and $\bar{x}$ were used as indicators as follows:

If $s^2 < \bar{x}$ (s^2 must be 2 to 3 times less than $\bar{x}$ - see Dubrovskaya 1975), the distribution is positive binomial.

If $s^2 > \bar{x}$, the distribution is negative binomial.

If $s^2 = \bar{x}$, the Poisson series is a suitable model for the distribution (see Elliott, 1977).

The presented analysis is also based on the phenological data for Opiliones from the Vitosha Mountain, obtained from the material, collected during a period of 26 months by means of 653 pitfall-traps situated in 21 sites at an elevation between 800 and 2,290 m.

RESULTS

The results of the presented investigation are summarised in Tab. 1.

DISCUSSION

1. ***Mitostoma chrysomelas*** (Hermann). - The index of Lexis shows that the individuals have a medium aggregation ability. The chi squared-test confirms the contagious distribution of the individuals of the population. Most probably this is a result of the phenological peculiarities - the individuals are most common under stones and come together for copulation during the period July - August. The density is nearly two individuals per square metre.

2. ***Carinostoma ornatum*** (Hadži). - This species occurs often under stones and in open grassy habitats. The relatively high density and the weakly expressed aggregation ability in October may be explained with the biological peculiarities of this species - during this month one may find many

mature females with eggs and males ready for copulation. The chi squared-test shows that the spatial distribution varies from random to contagious.

3. ***Paranemastoma radewi*** (Roewer). - The spatial distribution depends upon he humidity and therefore must be contagious. The established random distribution might be a result of the low density of the investigated population at this time.

4. ***Paranemastoma aurigerum ryla*** (Roewer). - Lexis' index shows that the individual representatives of this species posses a low aggregation ability. This contagiousity may be a result of the phenological peculiarities - at this elevation (i. e. 1850 m) in July the number of individuals tends towards its maximum and they prefer to hide at day under stones and rotten tree pieces. The chi squared-test shows that the distribution is intermediate between the random and the contagious one, a fact that may be explained with the relatively low density of the investigated population.

5. ***Phalangium opilio*** L. - The medium density (approximately 1.5 individuals per square metre), the high mobility and the high ecological plasticity of this species, combined with the relative homogenous habitat explains the random distribution, a fact confirmed by the chi squared-test.

6. ***Opilio dinaricus*** Šilhavý. - During the period April - June a great amount of only juveniles (newly hatched) was found. In April the established population density (1.6 ind./m^2) and the value of Lexis' index (1.88) expresses the medium aggregation ability. This is also confirmed by the chi squared-test. The contagious distribution may be explained by the fact that the eggs are laid in aggregates and the relatively low mobility of the newly hatched juveniles.

7. ***Rilaena balcanica*** Šilhavý. - The low number of individuals in October impacts on the density (0.19 ind./m^2) and the distribution, for which the Poisson series is a suitable model. This distribution may be explained also with the relatively homogenous living conditions in the litter where this species occurs.

8. ***Rilaena triangularis*** (Herbst). - During the months July and October generally the number of specimens is relatively low or they are almost missing. The established random spatial distribution (arithmetic mean of Lexis' index = 0.995 ± 0.005) is probably a result of the low density (d (average) = 0.245 ± 0.045 ind./m^2), the homogenity of the habitat conditions, good migratory ability and partenogenetic development (the periodic aggregation of the individuals for copulation is not necessary). The chi squared-test also confirmes the random distribution.

9. ***Zacheus crista*** (Brullé). - In the end of April and July at 900 m and in the end of July at 1350 m the number of individuals is very low. The observed random distribution of the individuals is most probably due to the relatively low density of the populations (the average is lower than one per m^2 = 0.325 ± 0.08) and also due to the relative homogenity of the living

conditions at the meadows. This is also confirmed by the chi squared-test ((value (arithmetic mean) of chi squared = 19.95 ± 0.71)).

10. ***Lacinius horridus*** (Panzer). - During the period of copulation followed by the eggs laying and the strong increase of the number of juveniles (July), a contagious distribution was established. This is a condition confirmed also by the chi squared-test. This contagiousity is connected with a low aggregational ability of individuals with density of 0.38 and a medium aggregation ability in populations with a density from 1.56 to 4.57 ind./m^2. The distribution of individuals from very small and low density (mean = 0.26 ± 0.06 ind./m^2) populations is random. A very rare case of regular spatial distribution, proven by the chi squared-test, was observed in this species (Lexis' index = 0.67, d = 1.8 ind./m^2). Because the number of juveniles is maximal in July, this distributional pattern is probably/ a result of an active avoid of intraspecific competition.

11. ***Lacinius dentiger*** (C. L. K.). - The Poisson series is a suitable model for their distribution on the meadows, a fact probably consistent with the generally low number of individuals found in July and in the grassy habitats. In the woody habitats, where this species occurs more commonly, a low aggregation ability is observed. The latter is probably related to the heterogenity of the environment and to the biological peculiarities of the species, e. g. the increase of the number of juveniles during the period April - June or the forming of sexual aggregations for copulation during the months September - October. The chi squared-test yet indicates that the distribution is random.

12. ***Mitopus morio*** (Fabricius). - Random distribution was established in populations with density between 0.2 and 0.33 ind./m^2. This fact is correlated with the phenological peculiarities of the species. Medium aggregation abilities (Lexis' index = 1.53 to 2.05) posses the individuals in populations with density from 1.81 to 3.6 ind./m^2, which are situated mainly in the woody habitats. This may be explained with phenological peculiarities too - as from June to July the number, mainly of the juveniles, increases. These two types of spatial distribution are confirmed by the chi squared-test.

13. ***Leiobunum rumelicum*** Šilhavý. - Lexis' index shows, that the type of spatial distribution is random or contagious in relation with the seasonal increase of the number of animals in the populations (the density being 0.2 to 1.8 ind./m^2) in the woody habitats, where the living conditions are strongly heterogenous and the individuals prefer to hide themselves under stones, rotten wood *etc.* The chi squared-test shows that the individuals in low-density populations (density < 1) are randomly scattered, whereas these are contagiously distributed in the high-density population (density > 1).

Using the formula of Elliott (1977) it was calculated that the suitable number of sampling units in each sample must be between 73 and 1,550 (mean = 492).

Tab. 1. Spatial distribution of Opiliones from Vitosha Mountain (Bulgaria): Basic statistical indexes and criteria.

Species	Locality Date	Specimens m = male f = female	Degrees of freedom $\nu = n-1$	Arithmetic mean $\overline{x}$	Variance s^2	Lexis' index λ	Type of spatial distribution based on Lexis' index	chi squared (p>0.05) χ^2	Type of distribution based on χ^2-test	Density ind./m^2
Mitostoma chrysomelas	W2b /08.VII.1988	2m, 8f	20	0.476 ± 0.10	1.262	1.63	contagious (medium aggregation = m. a.)	53.00	contagious	1.90
Carinostoma ornatum	M1 /28.IV.1989	2m, 2f	21	0.182 ± 0.11	0.251	1.17	random contagious	29.00	random	0.73
	M1 /20.X.1988	12m, 7f	36	0.513 ± 0.15	0.812	1.26	(low aggregation = l. a.)	56.95	contagious	2.48
Paranemastoma radewi	W2b /08.VII.1988	1f, 1juv.	20	0.095 ± 0.06	0.090	0.97	random	19.00	random	0.38
Paranemastoma aurigerum ryla	W3 /10.VII.1988	2m, 1f	19	0.150 ± 0.11	0.239	1.26	contagious (l. a.)	30.33	random	0.60
Phalangium opilio	M2 /08.VII.1988	11juv.	19	0.550 ± 0.15	0.471	0.925	random	16.27	random	2.20
	M3 /10.VII.1988	9juv.	20	0.428 ± 0.15	0.457	1.03	random	21.33	random	1.71
	M1 /31.VII.1988	1m (subad.), 2juv.	22	0.130 ± 0.07	0.118	0.95	random	20.01	random	0.52
Opilio dinaricus	W1 /28.IV.1989	8juv.	19	0.400 ± 0.26	1.410	1.88	contagious (m. a.)	67.00	contagious	1.60
Rilaena balcanica	W1 /20.X.1988	1juv.	20	0.047 ± 0.047	0.047	1.00	random	20.00	random	0.19
Rilaena triangularis	M2 /08.VII.1988	1f	19	0.05 ± 0.049	0.049	1.00	random	18.96	random	0.20
	W3 /10.VII.1988	1f	19	0.05 ± 0.049	0.049	1.00	random	18.96	random	0.20
	M3 /24.X.1988	1juv.	19	0.05 ± 0.049	0.049	1.00	random	18.96	random	0.20
	M3 /10.VII.1988	2f	20	0.095 ± 0.06	0.090	0.98	random	18.20	random	0.38
Zacheus crista	M2 /08.VII.1988	1m	19	0.05 ± 0.049	0.049	1.00	random	18.96	random	0.20
	M1 /23.VII.1988	2f	20	0.10 ± 0.068	0.095	0.97	random	19.88	random	0.38
	M1 /28.IV.1989	3juv.	21	0.136 ± 0.075	0.123	0.95	random	19.00	random	0.545
	M1 /31.VII.1988	1f	22	0.043 ± 0.043	0.043	0.999	random	21.98	random	0.174

Tab. 1 cont.

Species	Locality / Date	Specimens m = male f = female	Degrees of freedom $v = n-1$	Arithmetic mean $\overline{x}$	Variance s^2	Lexis' index λ	Type of spatial distribution based on Lexis' index	chi squared (p>0.05) χ^2	Type of distribution based on χ^2-test	Density ind./m^2
Lacinius horridus	M2 /08.VII.1988	9juv.	19	0.45 ± 0.45	0.202	0.67	regular	8.55	regular	1.80
	M1 /23.VII.1988	1juv.	20	0.047 ± 0.047	0.047	1.00	random	20.00	random	0.19
	W1 /20.X.1988	1m	20	0.047 ± 0.047	0.047	1.00	random	20.00	random	0.19
	W2b /08.VII.1988	2juv.	20	0.095 ± 0.095	0.190	1.41	contagious (l. a.)	40.01	contagious	0.38
	M3 /10.VII.1988	24juv.	20	1.143 ± 0.38	3.128	1.65	contagious (m. a.)	54.75	contagious	4.57
	M1 /28.IV.1988	1juv.	21	0.045 ± 0.045	0.045	0.999	random	21.00	random	0.18
	M1 /31.VII.1988	9juv.	22	0.391 ± 0.206	0.962	1.58	contagious (m. a.)	54.11	contagious	1.56
	W1 /23.VII.1988	2juv.	30	0.064 ± 0.045	0.062	0.98	random	29.00	random	0.258
	M1 /20.X.1988	4m	36	0.108 ± 0.064	0.154	1.20	random	51.51	random	0.43
Lacinius dentiger	W1 /28.IV.1989	4juv.	19	0.200 ± 0.117	0.273	1.17	random	25.99	random	0.80
	M1 /23.VII.1988	1juv.	20	0.047 ± 0.047	0.047	1.00	random	20.96	random	0.19
	W1 /20.X.1988	3m	20	0.143 ± 0.104	0.228	1.26	contagious (l. a.)	31.98	random	0.57
	M1 /31.VII.1988	1juv.	22	0.043 ± 0.043	0.043	0.999	random	21.98	random	0.174
	W2a /08.VII.1988	12juv.	31	0.375 ± 0.125	0.500	1.154	random	41.33	random	1.55
Mitopus morio	M3 /24.X.1988	1m	19	0.05 ± 0.049	0.049	1.00	random	18.96	random	0.20
	W3 /10.VII.1988	18juv.	19	0.900 ± 0.435	3.779	2.05	contagious (m. a.)	79.78	contagious	3.60
	W2b /08.VII.1988	7juv.	20	0.333 ± 0.126	0.333	1.00	random	20.00	random	1.33
	W2a /08.VII.1988	12juv.	31	0.375 ± 0.125	0.500	1.53	contagious (m. a.)	72.86	contagious	1.81
Leiobunum rumelicum	W3 /24.X.1988	4juv.	19	0,200 ± 0.117	0.273	1.17	random	25.93	random	0.20
	W3 /10.VII.1988	1m, 3f, 5juv.	19	0.450 ± 0.285	1.628	1.90	contagious (m. a.)	68.77	contagious	1.8
	W2a /08.VII.1988	4juv.	31	0.125 ± 0.074	0.177	1.19	random	43.99	random	0.52

CONCLUSIONS

1) The aggregation index of Lexis (λ) is a convenient and clear criterion for the analysis of the degree of aggregation, especially in cases when the density of the population is not too high. This fact is confirmed by the research of other authors (Chernova & Chugunova 1967).

2) There are no regular changes in the value of (when the number of samples increases (for example see *Phalangium opilio* and *Lacinius horridus*), but the preliminary nature of this research does not allow to make definitive conclusions.

3) The values of χ^2 show that *Mitostoma chrysomelas*, *Carinostoma ornatum**, *Paranemastoma aurigerum ryla*, *Opilio dinaricus*, *Lacinius horridus**, *Mitopus morio**, *Leiobunum rumelicum** have distinctive aggregation abilities. For the species signed with an asterisk a random distribution is also characteristic. This dual type of spatial distribution of the above marked species is established to be corresponding with some phenological peculiarities. For *Paranemastoma radewi*, *Phalangium opilio*, *Rilaena balcanica*, *Rilaena triangularis*, *Zacheus crista* and *Lacinius dentiger* only the random type of spatial distribution is characteristic. A very rare case of regular spatial distribution was observed for *Lacinius horridus*. This distributional pattern is probably a result of an active avoidance of intraspecific competition.

4) Similar to the observations of Chernova and Chugunova (1967) on other invertebrates, for the majority of harvestmen-species with low density populations a random distribution was established ($\lambda \leq 1.2$). In all this cases the population density is between 0.19 and 2.20 ind./m^2 ($\bar{x}$ = 0.586 ± 0.105 ind./m^2). The low population densities are not always correlated with a random distribution (see Chernova & Chugunova, 1967). For example the representatives of *Lacinius horridus* tend to form distinct aggregations even when the population density equals 0.38 ind./m^2. Another interesting fact represented by the case of *Phalangium opilio*, which is randomly distributed even when the population density is 2.20 ind./m^2, a value very close to the average density at which the other harvestmen tend to form aggregations ($\bar{x}$ = 2.188 ± 0.729 ind./m^2 (0.38-4.57 ind./m^2)).

5) The results of the presented investigation confirm the statement of Chernova and Chugunova (1967), that the random distribution of invertebrates does not occur as rarely as pointed out by Andrewartha (1961) (after Chernova & Chugunova, 1967) and Macfadyen (1965).

6). The distributional type is determined by the intraspecific relations, the degree of sensitivity and selectivity of the environmental factors, the way of egg laying, the migratory abilities, the homogenity of the environment, the population density, the developmental phase, the physiological state of the individuals, the collecting method etc. In view of these determinants, a certain conformity of the modifications of the distributional type of Opiliones under the influence of diverse factors with a law may be revealed only after analysing a sufficient number of observations (Chernova & Chugunova 1967; Dubrovskaya 1975).

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REFERENCES

Chernova N. M. & Chugunova M. N. 1967. Analyse der räumlichen Verteilung von bodenbewohnenden Mikroarthropoden innerhalb einer Pflanzenassoziation. Pedobiologia, **7**: 67-87.

Dubrovskaya N. A. 1975. On the types of spatial distribution of some mass insects in agrocoenoses. Ecology, Sverdlovsk, **6**: 54-60. (In Russian).

Elliott J. M. 1977. Some methods for the statistical analysis of samples of benthic invertebrates. Freshwater Biolog. Assoc., Scientific publication N°25, pp. 156.

Eskov K. Yu. 1981. Analysis of spatial distribution of spiders in the Enisei taiga. Zool. Zhurnal, **60**, 3: 353-362. (In Russian, English summary).

Macfadyen A. 1965. Animal ecology. Aims and methods. Mir, Moscow, 375 pp. (In Russian).

Mikhailov K. G. 1983. Pauki (Arachnida, Aranei) lesnoy podstilki Zvenigorodskoy biostantsii MGU. In: Fauna i ekologiya pochvennyh bespozvonochnyh Moskovskoy oblasti. Nauka, Moscow, pp. 52-67. (In Russian).

Mikityuk V. F. 1978. Analiz prostranstvennogo raspredeleniya hishtnyh bespozvonochnyh v lesnoy podstilke. In: Problemy pochvennoy zoologii. Nauka i tehnika, Minsk, pp. 152-153. (In Russian).

Sechterova E. 1989. The spatial horizontal distribution of epigeic spiders and harvestmen populations living in a spruce forest in the Beskydy mountains (Araneae: Opiliones). Stud. oecol. (Ostrava), **2**: 17-27.

Tikhomirova A. L. 1975. Taking censuses of soil surface dwelling invertebrates. In: Gilyarov M. S. (ed.), Metoduy pochveno-zoologicheskih issledovaniy. Nauka, Moscow, pp. 73-85. (In Russian, English summary).