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THE FAUNA OF SOIL BEETLES (EDAPHIC COLEOPTERA) AS A SENSITIVE INDICATOR OF EVOLUTION AND CONSERVATION OF ECOSYSTEMS. A STUDY ON THE ALTITUDINAL GRADIENT IN THE RODNEI MOUNTAINS BIOSPHERE RESERVE (THE CARPATHIANS)

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Abstract — Study of the soil beetle fauna as an ecological indicator could be relevant considering that it is very well-represented in all types of terrestrial ecosystems, with species belonging to all trophic categories (predators, scavengers/decomposers, phytophagous) and methods of sampling the soil fauna are very accurate. The present studies were carried out in the largest standard protected area of the Carpathians – the Pietrosul Rodnei Biosphere Reserve. Species diversity was estimated using the jackknife technique and the S* method, the latter of which is based on a log-normal fitting curve (Ludwig and Reynolds, 1988). A total of 103 soil beetle species (belonging to 21 families) were collected in habitats from alpine, subalpine, and montane zones. The estimated species richness is given for each sampled zone. The observed number of species exceeds 60% of the estimated number of species for all investigated areas. The species richness and structure of the soil beetle fauna exhibit evident differences (statistically tested) in forests in different phases of development. The cluster and correspondence analyses performed for alpine, subalpine, and montane forested habitats showed an altitudinal gradient in the distribution of species and faunal differences between forests in different development phases. Up to now, a large number of studies on the fauna of ground beetles (Carabidae), most of them predators, have been used worldwide for biodiversity monitoring. Our study confirms that structural changes in the soil beetle fauna (as an ensemble) are profound and reflect the reaction of different trophic categories to ecological changes. The response of the soil beetle fauna to habitat changes (as manifested in species richness and faunal structure) observed in this particular case (in which five different types of habitats are compared), indicates its relevance for ecological studies on a larger scale.

Key words: soil (edaphic) Coleoptera, Rodnei Mountains Biosphere Reserve, Northern Carpathians, ecological relevance, primeval forests, Romania

INTRODUCTION

Situated in the northern part of the Eastern Carpathians, between 47°25'54" – 47°37'28" N latitude and 24°31'30" – 25°01'30" E longitude, the Rodnei Mountains Biosphere Reservation has a total area of 47,000 ha. A series of *scientific reserves*

(Pietrosul Mare – 3,300 ha; Piatra Rea – 309 ha; Bila-Lala – 1,646.9 ha; Corongis – 592.4 ha) and *natural reserves* are delimited within the park. Of the area surrounding the Pietrosul Mare Peak, 53% is covered by forests and 47% by alpine meadows. The Pietrosul Rodnei Biosphere Reserve is the largest standard protected area of the Carpathians.

The vegetation along an altitudinal gradient can be divided into four biotic zones, considerably different from those presented by Mani (1968).

1. the lower forest zone – premontane beech forests;

2. the upper forest zone, including mixed forests (spruce, fir, and beech) and extending from the lower forest zone to the forest line (spruce);

3. the subalpine zone, from the upper limit of the forest to the upper limit of juniper associations with *Rhododendron* and *Pinus mugo*;

4. the alpine zone – alpine meadows with *Nardus*, lacking shrub vegetation formation.

The coleopteran fauna of the Rodnei Mountains has been studied since the 19th century, but only fragmentarily. The first catalog including data on Coleoptera from the Rodnei Mountains was published by K. Petri (1912). Csiki's studies (1946, 1951) contributed greatly to knowledge of the coleopteran fauna of this area. The genus *Duvalius* was studied by R. Jeannel (1927). Other studies were carried out by Maican (2004) (some data on the Crysomelidae) and by Serafim (1997) (Coccinelidae and Cerambycidae).

In this paper, we present the first quantitative study on the soil fauna of Coleoptera of the Rodnei Mountains Biosphere Reserve. The research was carried out along an altitudinal gradient and was conceived in order to clarify differences in the faunal and zoogeographic composition of this area.

MATERIAL AND METHODS

The studies were carried out in June 2006 (when most ground beetle species are active as imagoes). The sampling campaign started after 10 consecutive days with diurnal temperatures over 10°C, according to meteorological data provided by the NOOA Air Resources Laboratory (Fig. 1).

Seven sampling areas of 100 m^2 each were placed at elevations (in m) of 2,047, 2,005, 1,795, 1,413-1,390 (one site specially selected as a riparian-sylvan microhabitat), 1,353, and 1,269, each sample consisting of nine sampling units (pitfall traps). For each sample, the values of relative humidity, temperature, and dwelling points were taken at the moment of placement of the sampling units. The pitfall (Barber) traps were checked and emptied five days after their placement in field.

The species were sorted, prepared, and identified using an Olympus SZ60 stereomicroscope and an Olympus CH2 microscope.

Species richness was estimated using the jackknife technique and the S* method, the latter of which is based on a log-normal fitting curve (Table 1).

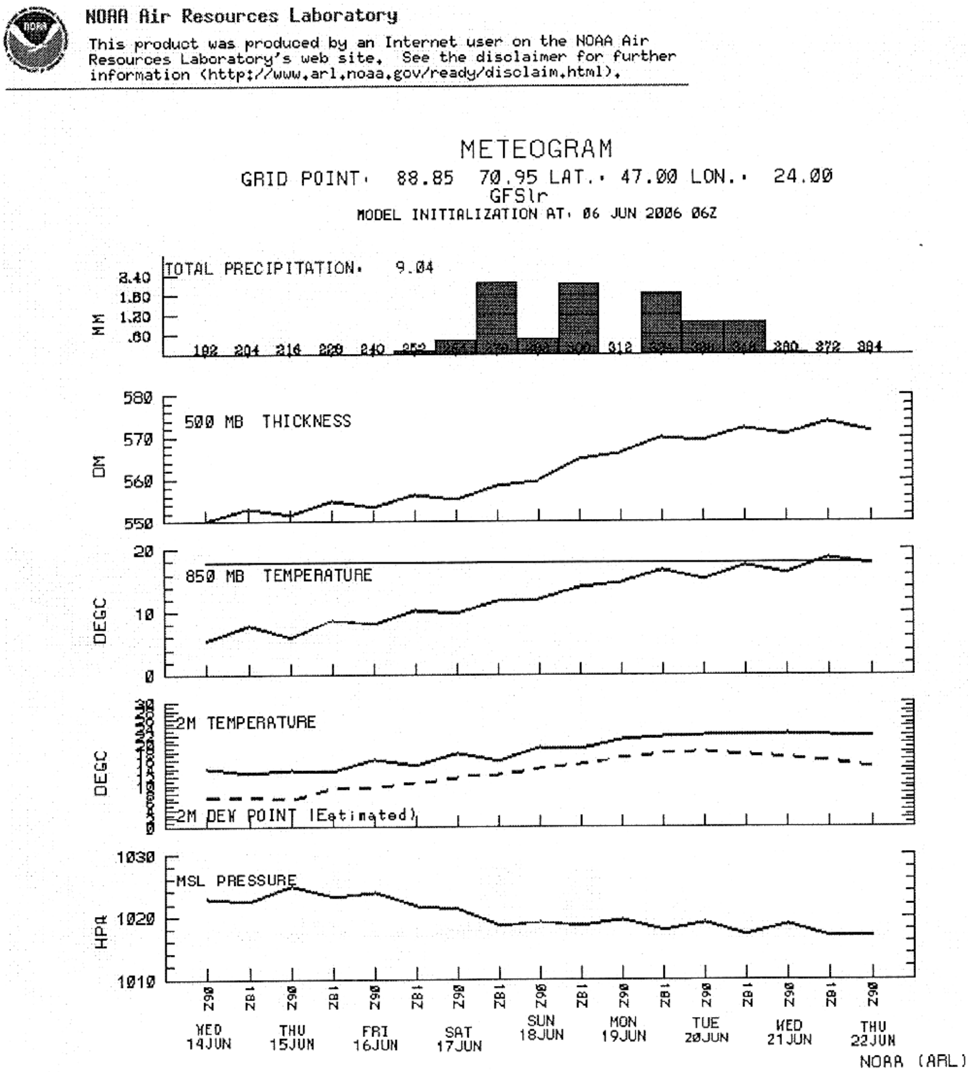


Fig. 1. Precipitation and temperature diagram for the sampling period in the "Pietrosul Mare" Scientific Reserve.

For the method based on fitting a log-normal distribution using estimates of S_0 and a, the expected log-normal frequencies are computed using the equation:

$$S(R)=S_0 e^{\left(-a^2R^2\right)}$$

where S(R) is the number of species in the *R*th octave from the mode, S_0 is the estimated number of species in the modal octave (the octave with most species), and a is an inverse measure of width of the distribution (i.e., $a = 1/2\sigma$, where σ is the standard deviation). For details of procedures, see Ludwig and Reynold (1988).

Table 1. Statistical methods for species richness estimation.

Based on the unique species/sample	Based on fitting a log-normal distribution
Jackknife estimator	Species richness (S*)
$\hat{S} = s + k\left(\frac{n-1}{n}\right)$	$S^* = 1.77(S_0 / a)$ $a = \sqrt{\frac{\ln[S(0)/S(R\max)]}{R^2 \max}}$ $S_0 = e^{(\overline{\ln S(R)} + a^2 \overline{R}^2)}$
s= observed total number of species present in n sample units n= total number of sample units k= number of unique species (spp. occurs only in one S.U.)	S(0) = observed no. of species in the modale octave $_0$ = estimated no. of species in the modal octave S(Rmax) = obs. no. of spp. in the octave *most distant* from the modal ln S(R) = mean of the logarithms of the obs. no. of spp./ octave

The quality of the model's fit to the observed frequencies was "tested" with a chi-square statistic. As the cited authors stated, "*since we are only attempting to obtain an approximate fit, this chi-square statistic should be used as a guide for selection of parameters rather than a formal statistical test*". The LOGNORM program was used to perform the statistical test.

For cluster analysis, we used the group average link method and Euclidean distance. The species responsible for site clustering were established using correspondence analysis. The MVSP and BIODIVERSITY PROFESSIONAL programs were used for computing.

RESULTS AND DISCUSSION

We identified 103 species of soil Coleoptera belonging to 21 families. The identified species and the number of specimens per sample are presented in Appendix 1.

A short characterization of each site, its altitude, and the recorded values of temperature, relative humidity, and dwelling point are presented in the heading of Table 2.

The observed number of species and species richness estimates are presented in Table 2. From the zoogeographic viewpoint, we found the greatest number of endemic species in the alpine steppe at 2,047-2,005 m. Faunal and zoogeographic analyses were presented by us in a recent paper (Nitzu et al., 2008).

As can be seen from Table 2, the greatest species richness is recorded in the area of a montane old spruce forest (the sample located at an elevation of 1,413 m). The riparian-sylvan microhabitat should be regarded as a subsample of the spruce forest as far as it is included in it. It was only counted separately by us because it is characterized by typical riparian species (hygrophilic species). The old spruce forest of the Pietrosul Rodnei Reserve at elevation of 1,400-1,450 m is characterized by thick

Table 2. Observed and estimated number of species per altitudinal samples. 1- Alpine steppe (2047 m elevation) RH 52.2%, temp. 18.1^{0}C, DP=7.8; 2 - Rocky habitat in alpine steppe (2005 m) RH 41.5%, temp. 26.5°C, DP=12; 3 - *Pinus mugo+Vaccinium myrtilus* subalpine assoc. (1795 m) R.H 21.7%, temp. 32.4^{0}C, DP=7.9; 4 - Montane old spruce forest with low productivity (1,413 m) RH 80%, temp. 16°C, DP=12; 5 - Riparian-sylvan microhabitat in spruce forest (1,390 m) R.H. 85%, temp. 16^{0}C; 6 - Montane spruce forest with high productivity (1353 m) R.H. 83.3%, temp. 15.1^{0}C, DP=12.3; 7 - Montane mixed forest (1,269 m) R.H. 67.2%, temp. 17.6°C, DP=11.5.

Sampled habitat	1	2	3	4	5	6	7
No. observed species	***30***	***20***	***36***	***40***	***19***	***21***	***29***
No. of unique species	18	7	26	28	9	12	13
Estimated no. of species (S*)	**44**	**23**	**50**	**61**	**26**	**33**	**31**
Estimated no. of species (Jackknife)	**46**	**26.2**	**59.1**	**64.9**	**27**	**31**	**40**
Standard deviation	2.98	3.47	7.36	8.05	1.89	4.39	4.14
95% confidence limits	39.1-52.9	18.2-34.2	42.1-76.1	48.2-81.6	22.7-31.3	21.1-41.9	30.5-50.2
Fraction of observed vs. total estimated	65-77%	77-99%	61-85%	61.5-83%	74-80%	68-100%	72.5-95%

litter with abundant vegetable debris (including a large quantity of dead wood) and scarce herbaceous vegetation consisting preponderantly of pteridophytes (this is a so-called *forest with low productivity*). In contrast, the montane spruce forest at lower altitude (1,300-1,350) has litter covered by dense herbaceous vegetation (preponderantly *Oxalys* and bryophytes) with a smaller amount of dead wood (this habitat is a *forest with high productivity*). The estimated species richness for the spruce forest with litter consisting of a large quantity of dead wood is 61 (S*) to 65 (Ŝ) (for 48.2-81 confidence limits), *versus* 33 (S*) to 31 (Ŝ) (for 21.1-41.9 confidence limits) for the forest with high productivity. Analyzing the ranks of species abundances, we note that the spruce forest with lower values of species richness exhibits the greatest number of species with higher abundance ranks (in reference to the forested areas): 51-*Pterostichus unctulatus* (eudominant species), 30 – *Pt. jurinei,* and 21 – *Pt. foveolatus*. For the spruce forests with higher species richness, only one species shows a high abundance (47 – *Tachinus pallipes*), while abundance ranks in montane mixed forests at 1,269 meters of altitude are more 'balanced' (Fig. 2).

The degree of resemblance between altitudinal biotic zones based on the soil coleopteran fauna was evaluated using *cluster analysis*. Similarities of the investigated habitats are illustrated in the dendrogram (Fig.3).

As can be seen from Fig. 3, the subalpine zone shows great faunal differences in comparison with the montane forests and alpine zones, being more similar to the forested habitats. The investigated subalpine area is characterized by shrub vegetation consisting of an association of *Pinus mugo* and *Vaccinium myrtilus*, the most

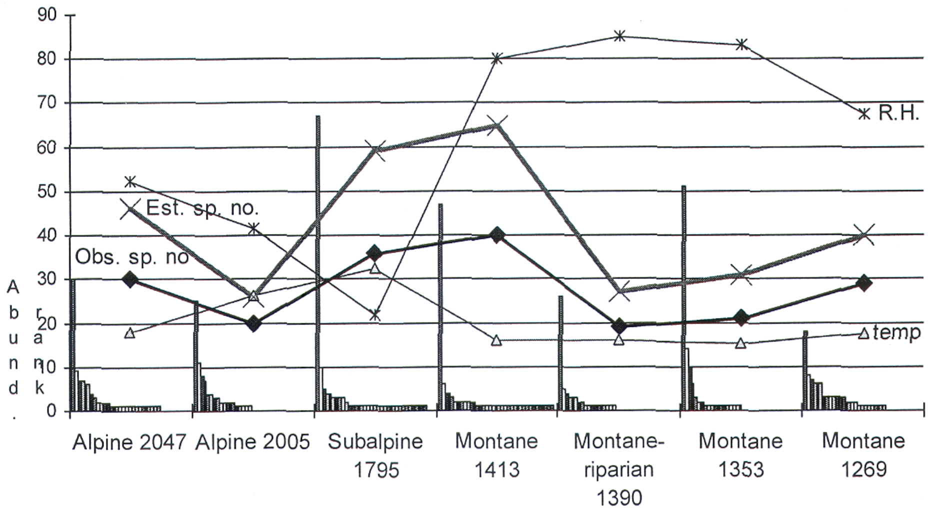


Fig. 2. Species abundance ranks (columns) versus species richness (thick lines). R.H.– relative humidity, temp.– temperature.

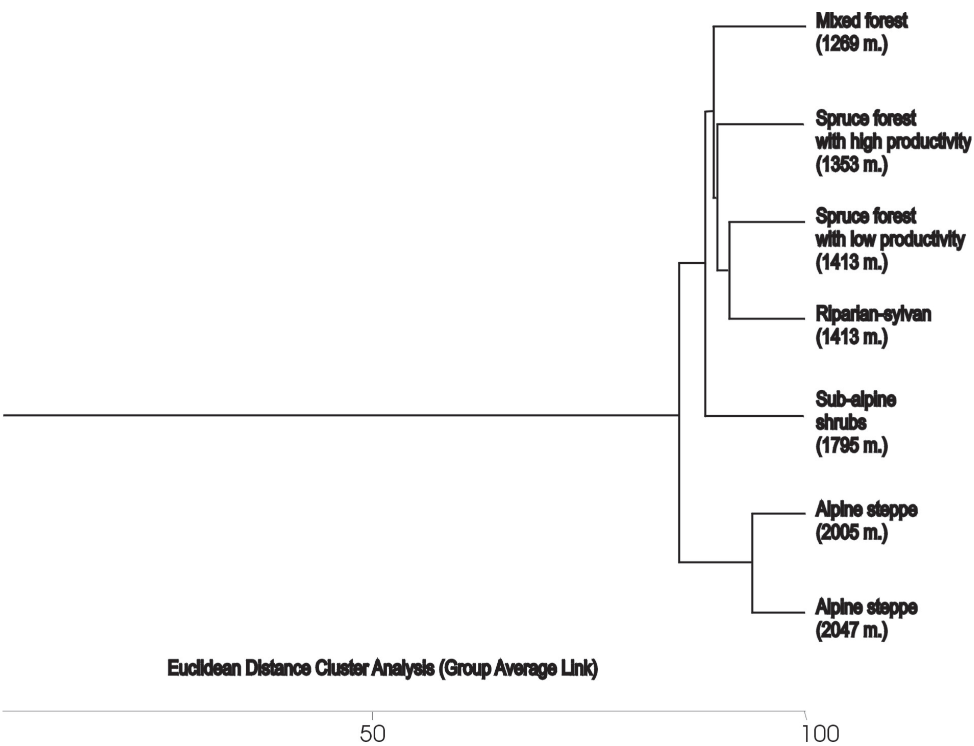


Fig. 3. Dendrogram of clustering of altitudinal samples in the Pietrosul Mare Mountain Reserve.

typical edaphic species for this zone being *Carabus arcensis carpathus*. The montane forested areas are clustered together. Great similarity exists between the fauna of the old spruce forest with low productivity and that of the riparian-sylvan habitat. On the one hand, this similarity was expected, since the riparian habitat is situated in the old spruce forest; on the other hand, it shows that the characteristic riparian species (hygrophilic species that inhabit only wet river banks) are unable to induce drastic faunal differences as compared to the surrounding spruce forest. On the whole, a faunal gradient is evident from alpine areas (clustered together) to subalpine areas with shrub associations, and further to forested montane areas.

The soil beetle species responsible for this clustering were clarified by correspondence analysis. Whereas cluster analysis as a classification technique *forces* certain entities (in our case samples) to form artificial groups (clusters) based on their faunal similarities, correspondence analysis is an ordination technique in which the species are arranged in relation to one or more coordinate axes, so that their positions relative to the axes and to each other provide maximum information about their ecological similarities (Ludwig and Reynolds, 1988). The species ordination in *hyperspace of the sites* (axe I and II) is presented in Fig. 4.

Inasmuch as the X axis represents 32.5% of eigenvalue and the Y axis only 19%, the most significant differences between sites are given by the species ordered at great distances from another, especially on the X axis. A concentration of species is evident in the "+ +" dial, grouping the alpine and subalpine characteristic and dominant species (*Carabus arcensis, Carabus fabricii, Nebria transsylvanica, Choleva oresitropha*, etc.). On the other hand, the "- -" and "- +" dials group species such as *Carabus linnei*, *C. violaceus, Trechus latus, Tr. pulchellus, Tachinus pallipes, Catops tristis*, etc., which are dominant or characteristic of the different forested habitats. Other species such as *Pterostichus foveolatus, Carabus auronitens,* and *Otiorrhynchus scaber* are less characteristic of a specific zone and less responsible for the soil beetle faunal dissimilarities between samples.

CONCLUSIONS

1) 103 species of soil Coleoptera belonging to 21 families were identified in seven samples (63 sample units) placed in alpine, subalpine, and montane biotic zones, at different altitudes and in different microhabitats.

2) The observed number of species exceeds 60% (for minimum confidence interval values) of the estimated number of species for all sampled areas. The estimated number of edaphic species of Coleoptera for the Pietrosul Mare Scientific Reserve is 152 (103 observed – 67.76% of the estimated species richness).

3) The riparian species characteristic of the riparian-sylvan microhabitat are unable to induce noticeable differences in comparison with the soil fauna of the surrounding spruce forest.

4) The ground beetles (Carabidae) give the greatest number of dominant (D) and characteristic (C) species for all types of habitats, followed by Staphylinidae

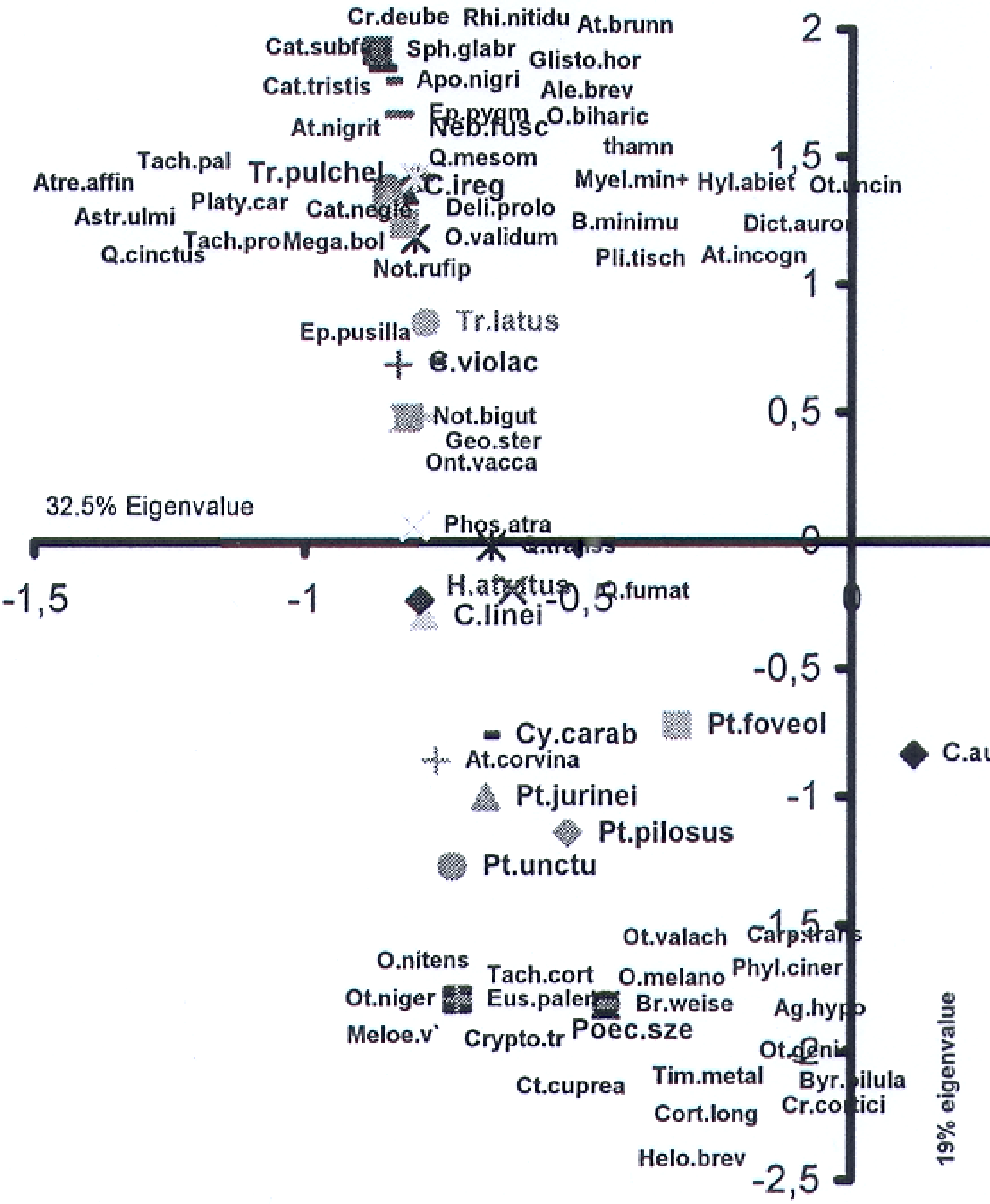
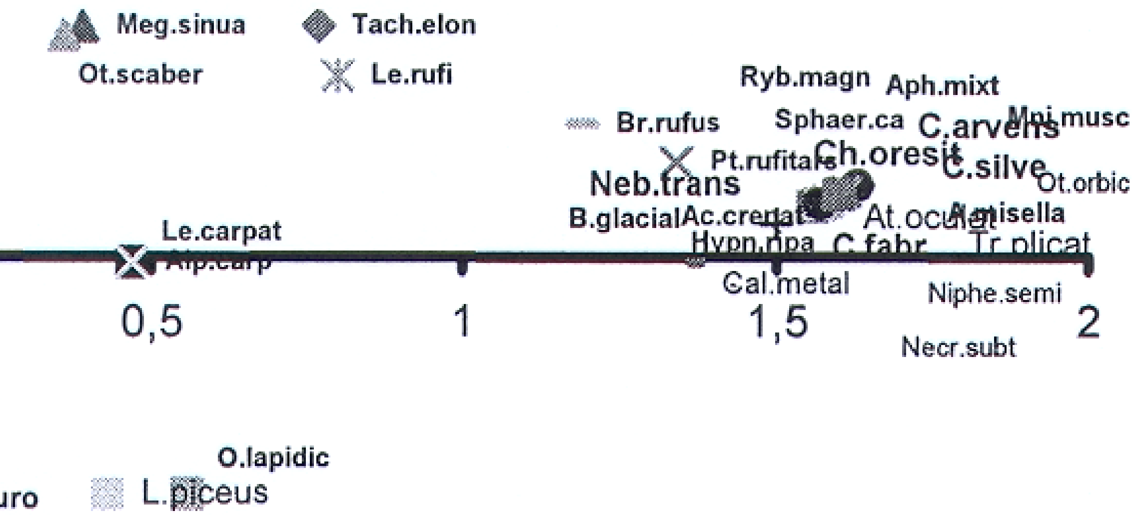


Fig. 4. Correspondence analysis for 103 edaphic Coleoptera in the hyperspace of seven montane-alpine sites.


Meg.sinua
Tach.elon
Ot.scaber
Le.rufi
Ryb.magn
Aph.mixt
Br.rufus
Sphaer.ca
C.arvens
Mni.musc
Pt.rufitars
Ch.oresit
C.silve
Ot.orbic
Neb.trans
B.glacial
Ac.crenat
At.oculat
A.misella
Le.carpat
Alp.carp
Hypn.ripa
C.fabr
Tr.plicat
Cal.metal
Niphe.semi
0,5
1
1,5
2
Necr.subt
O.lapidic
L.piceus

and Leiodidae:

– *Carabus sylvestris transsylvanicus* (D); and *C. fabricii malachiticus* and *Nebria transsylvanica* (C) in the alpine zone;

– *Pterostichus pilosus* and *Carabus arcensis carpathus* (D*)* in the subalpine zone; and

– *Pterostichus unctulatus* and *Pterostichus jurinei* (D), together with *C. linnei* (C) in the spruce montane forest area.

5) The species richness/species abundances exhibit significant variances for the montane forests in different stages of evolution: 61 (S*) to 65 (Ŝ) (for 48.2-81 confidence limits) for the primeval spruce forest with low productivity, *versus* 33 (S*) to 31 (Ŝ) (for 21.1-41.9 confidence limits) for the spruce forests with high productivity. Analyzing the ranks of species abundances, we note that the spruce forest with lower values of species richness has the greatest number of species with higher abundance ranks (in reference to the forested areas).

6) Among the characteristic species of each altitudinal biotic zone, some relative large species of Carabidae, easy to identify by the Park's ranger-biologists, are suitable for monitoring studies in the management of protected areas.

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Appendix 1. List of edaphic species of Coleoptera identified in the Pietrosul Mare al Rodnei Scientific Reservation. 1 - Alpine, 2047 m; 2 - Alpine rocky, 2005 m; 3 - Sub-alpine, 1795 m; 4 - Montanespruce forest, 1413 m; 5 - Montane-riparian-sylvan, 1390 m; 6 - Montane spruce forest, 1353 m; 7 - Montane mixed forest, 1269 m.

Species / abundance per sample in altitudinal biotic zone	1	2	3	4	5	6	7
• **Fam. Carabidae**							
1. Carabus auronitens escherii Palliardi, 1825	1	4	10	1	1		
2. Carabus silvestris transsylvanicus Dejean 1826	30	25	1				
3. Carabus linnei Panzer, 1812					1	10	6
4. Carabus fabricii malachiticus Thomson, 1875	3	8					
5. Carabus irregularis Fabricius, 1792				1			
6. Carabus arvensis carpathus Born, 1902	1		33				
7. Carabus violaceus wolffi Dejean, 1826				2		1	1
8. Cychrus caraboides Linnaeus, 1758			1	1		1	
9. Nebria (Alpaeus) transsylvanica Germar, 1824	9	2					
10. Nebria (Alpaeus) fuscipes Fuss, 1849					3		
11. Leistus piceus Frölich, 1799	1					1	
12. Notiophilus rufipes Curtis, 1829				1			
13. Notiophilus biguttatus Fabricius, 1779				1		1	1
14. Trechus plicatulus L. Miller, 1868	6	2					
15. Trechus latus Putzeys, 1847			1	4	4	1	1
16. Trechus pulchellus Putzeys, 1846 1845				1			
17. Bembidion (Emphanes) minimum Fabricius, 1792					1		
18. Bembidion (Testediolum) glaciale Heer, 1837	1						
19. Pterostichus (Calopterus) pilosus wellensii Drapiez, 1819		2	67	6	7	14	6
20. Pterostichus (Pertrophilus) foveolatus Duftschmid, 1812	6	4	21	2	5	21	8
21. Pterostichus (Oreophilus) jurinei Panzer, 1803	1		5	7	3	30	1
22. Pterostichus (Eosteropus) rufitarsis Dejean, 1828	7	2			1		
23. Pterostichus unctulatus Duftschmid, 1812			3	6	1	51	3
24. Poecilus szepligetii Csiki, 1908			1				
25. Agonum hypocrita Apfelbeck, 1904			1				
26. Calathus metallicus Dejean, 1828	26	15	3			2	
27. Amara (Celia) misella L. Miller, 1868		1					
28. Harpalus atratus Latreille, 1804				1		1	
• **Fam. Sphaeritidae**							
29. Sphaerites glabratus (Fabricius, 1792)							2
• **Fam. Staphylinidae**							
30. Megarthrus sinuaticollis (Boisduval Lacordaire, 1835)		1		1			
31. Eusphalerum pallens Heer, 1841						1	
32. Omalium validum Kraatz, 1857			1	2	2		3
33. Deliphrosoma prolongatum Rottenberg, 1873				2	1		
34. Niphetodes semicarinatus Zerche, 1990	1						
35. Atrecus affinis Paykull, 1789 (*Baptolinus)*				1			
36. Astrapeus ulmi Rossi, 1790				1			
37. Othius melanocephalus (Gravenhorst, 1806)			1				
38. Othius lapidicola Märkel & Kiesenwetter, 1848	1		1	1			
39. Quedius (Quedionuchus) cinctus Paykull, 1790					1		
40. Quedius (Raphirus) fumatus Stephens, 1833			3		3		
41. Quedius (Raphirus) transsilvanicus Weise, 1875			4	1			3
42. Quedius mesomelinus Marsham, 1802				2		1	6
43. Ocypus (Goerius) biharicus J. Müller, 1926							2
44. Ocypus (Goerius) nitens Schrank, 1781 (=*similis* Fabricius, 1792)			1				
45. Bryophacis rufus Erichson, 1839	2	3					1
46. Tachinus elongatus Gyllenhal, 1810	1	1					
47. Tachinus pallipes Gravenhorst, 1806			4	47	26	3	18
48. Tachinus proximus Kraatz, 1855					1		
49. Tachinus corticinus Gravenhorst, 1802						1	

Appendix 1. Continued.

Species / abundance per sample in altitudinal biotic zone	1	2	3	4	5	6	7
50. Carphacis striatus Olivier, 1795		3					
51. Atheta incognita Sharp, 1869					12		
52. Atheta (Bessobia) oculata (Erichson, 1837)	1						
53. Atheta (Anopleta) corvina Thomson, 1856,						6	2
54. Atheta brunneipennis Thomson, 1852							3
55. Atheta nigritula Gravenhorst, 1802							3
56. Acidota crenata Fabricius, 1793	1	2					
57. Alpinia carpathica Miller, 1868	1	1					
58. Aleochara brevipennis Gravenhorst, 1806							2
59. Leptusa carpathica Weise, 1877	1	1	1			1	
60. Leptusa ruficollis Erichson, 1839	1		1	1			
• **Pselaphinae**							
61. Bryaxis weisei Saulcy, 1875			1				
• **Fam. Leiodidae** (Cholevini, Catopini)							
62. Choleva oresitropha Ganglbauer, 1896	7	11	1				
63. Apocatops nigrita nigrita Erichson, 1837.					1		3
64. Catops tristis Panzer, 1794					2		12
65. Catops subfuscus Kellner, 1846							7
66. Catops neglectus Kraatz, 1852				1			
67. Rybinskiella magnifica Rybinski, 1902	2						
• **Fam. Silphidae**							
68. Phosphuga atrata Linnaeus, 1758				1			1
69. Necrophilus subterraneus Dahl, 1807	2						
• **Fam. Hydrophilidae**							
* *70. Helophorus brevipalpis* Bedel, 1881			1				
71. Megasternum boletophagum Marsham, 1802 [Cercyon]				2			
• **Fam. Geotrupidae**							
72. Geotrupes stercorosus Scriba, 1791			1	3		2	3
• **Fam. Lucanidae**							
73. Platycerus caraboides (Linnaeus, 1758)				1			
• **Fam. Scarabeidae**							
74. Aphodius (Agolius) mixtus Villa 1833	9	14					
75. Onthophagus vacca Linnaeus, 1767				1		1	1
• **Fam. Byrrhidae**							
76. Carpathobyrrhulus transsilvanicus Suffrian, 1848.			1				
*77. Byrrhus pilula*Linnaeus, 1758			2				
• **Fam. Elateridae**							
78. Hypnodius riparius (Fabricius, 1782)	4	7					
79. Ctenicera cuprea (Fabricius, 1775)			1				
• **Fam. Lyctidae**							
80. Dictyopterus aurora (Herbst, 1789)				1			
• **Fam. Nitidulidae**							
81. Epuraea pusilla (Illiger, 1798)			1	4			
82. Epuraea pygmaea (Gyllenhal, 1808)					1		1
83. Glischrochilus hortensis (Fourcroy, 1775)							11
• **Fam. Cryptophagidae**							
84. Cryptophagus transsilvanicus Ganglbauer 1897				1			
85. Cryptophagus corticinus Thomson, 1863			1				
86. Cryptophagus deubeli Ganglbauer, 1897							1
• **Fam. Rhizophagidae**							
87. Rhizophagus nitidulus (Fabricius, 1798)							1
• **Fam. Alexiidae**							
88. Sphaerosoma carpathicum Reitter, 1883	2						
• **Fam. Lathridiidae**							

Appendix 1. Continued.

Species / abundance per sample in altitudinal biotic zone	1	2	3	4	5	6	7
89. Corticaria longicollis (Zetterstedt, 1838)			1				
• **Fam. Meloidae**							
90. Meloe violaceus Marsham, 1802						1	
• **Fam. Chrysomelidae**							
91. Mniophila muscorum (Koch, 1803)	1						
92. Timarcha metallica (Laicharting, 1781)			1				
• **Fam. Curculionidae**							
93. Otiorrhynchus orbicularis (Herbst, 1795)	1		1				
94. Otiorrhynchus scaber (Linnaeus, 1758) [*ambigener*]*	1			1			
95. Otiorrhynchus valachiae kelecsenyii Frivaldsky			1				
96. Otiorrhynchus uncinatus Germar, 1824				1			
97. Otiorrhynchus (Dodecastichus) geniculatus (Germar, 1817)				1			
98 Otiorrhynchus niger (Fabricius, 1775)						1	
99. Hylobius abietis (Linnaeus, 1758)				2			
100. Phyllobius cinerascens (Fabricius, 1792)							
101. Plinthus tischeri Germar, 1824				1			
• **Fam. Scolytidae**							
102. Myelophilus minor (Hartig, 1834)				1			
103. Thamnurgus kaltenbachi (Bach, 1849)				1			