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INVERTEBRATE FAUNA AS INDICATOR OF THE CONSERVATION STATUS IN HABITATS INCLUDED IN ECOLOGICAL RESTORATION PROGRAMS IN THE FĂGĂRAȘ MOUNTAINS AREA (ROMANIA)

Marius SKOLKA[1,5], Rodica PLĂIAȘU[2,5], Raluca Ioana BĂNCILĂ[2,5], Daniyar MEMEDEMIN[1,5], Cristina PREDA[1,5], Constantin CIUBUC[3], Oliviu Grigore POP[4], Ovidiu DRAGAN[1,5], Carla GAVRILESCU[1,5], Ștefan Cătălin BABA[2]

[1]"Ovidius" University of Constanța, Faculty of Natural and Agricultural Sciences, Aleea Universității Nr. 1, corp B, 900470, Constanța, mskolka@gmail.com, daniyar.memedemin@univ-ovidius.ro, cristina.preda@univ-ovidius.ro, carlaflaviagavrilescu@gmail.com, ovidiu.draganbio@gmail.com
[2]"Emil Racoviță" Institute of Speleology, Calea 13 Septembrie Nr. 13, 050711, Bucharest, Romania, e-mail: rodica_plaiasu@yahoo.com, bancilaralucaioana@gmail.com, catalinstefanbaba@gmail.com
[3]University of Bucharest, Faculty of Biology, Splaiul Independenței Nr. 91-95, 050095, Bucharest, Romania, e-mail: ciubuc1206@gmail.com
[4]Foundation Conservation Carpathia, Calea Feldioarei nr. 27A, Brașov 500450, Romania, e-mail: o.pop@carpathia.org
[5]NGO Association Chelonia Romania


Study area


Spruce monoculture – Ursului valley


Clear cut area – Groapele Mountain


Riparian habitat – Tamas Valley


Alpine habitat – Furfulescu area

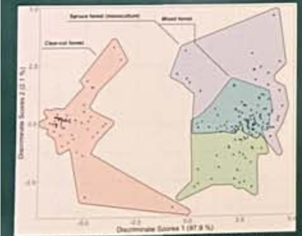

Fig. 1 Ordination of the linear discriminant analysis among the three types of forest habitats based on vegetation parameters (Wilks' lambda = 0.051, chi-square = 162.58, df = 190, p < 0.001). (Closed circle in red) clear-cut forest (n = 62); (Closed square in blue) spruce forest (monoculture) (n = 62); and (Closed triangle in green) mixed forest (n = 69). For full list of parameters that affected each discriminant axis see Table 1.

Table 1 The correlation between the habitat structure parameters and the standardized canonical discriminant functions. TRC – tree species cover (%); VPS – vascular plant cover (%); BRC – Bryophyte cover (%); SSC – low vegetation cover (%) and TSC – tall shrub cover (%).

	Function	
	1	2
TRC	0.0443	0.0009
VPC	-0.0744	-0.1136
BRC	0.0134	-0.0144
SSC	0.0091	0.1213
TSC	0.0245	-0.0929

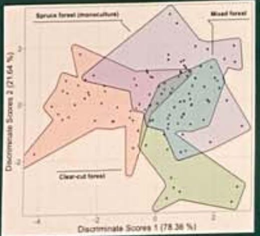

Fig. 2 Ordination of the linear discriminant analysis among the three types of forest habitats based on invertebrate community (Wilks' lambda = 0.25, chi-square = 1.736, df = 109, p = 0 0.002). (Closed circle in red) clear-cut forest (n = 35); (Closed square in blue) spruce forest (monoculture) (n = 57); and (Closed triangle in green) mixed forest (n = 20).

Table 2 The results of the MNDS ordination analysis of arthropod communities in relation to habitat structure (Fig. 2). TRC – tree species cover (%); VPS – vascular plant cover (%); BRC - Bryophyte cover (%); SSC – low vegetation cover (%) and TSC – tall shrub cover (%).

	NMDS1	NMDS2	r^2	P
TRC	-0.64503	0.76414	0.1408	0.0082
VPC	0.75501	-0.65803	0.1347	[illegible]
BRC	0.16188	0.98150	0.0346	0.3134
SSC	0.77752	-0.62880	0.1204	[illegible]
TSC	0.06493	0.99639	0.0274	0.4134

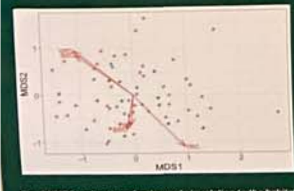

Fig. 3 NMDS ordination of arthropods in relation to the habitat structure parameters in three types of forest habitats: clear-cut forest (red), spruce forest (monoculture) (blue) and mixed forest (green). The Arthropod taxa are marked are marked by circles and arrows represent vectors of the factors that contributed to the ordination.

Table 3 The results of the GLMM of invertebrate diversity patterns in relation to habitat structure (Fig. 2). TRC – tree species cover (%); VPS – vascular plant cover (%); BRC - Bryophyte cover (%); SSC – low vegetation cover (%) and TSC – tall shrub cover (%).

	Abundance		Rarefied richness		Shannon diversity index	
	Chisq	P	Chisq	P	Chisq	P
TRC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
VPC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
BRC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SSC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TSC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Invertebrate fauna monitoring activities were carried out in the southern part of the Făgăraș Mountains and in the Iezer - Păpușa Mountains within two projects, carried out in the period 2019 – 2020 (Baseline survey in monitoring the changes and abundance of terrestrial arthropod) and 2021 – 2023, (Services for monitoring the impact of ecological reconstruction activities on the diversity and abundance of terrestrial arthropods). The study area, of approximately 1200 km².

The habitats selected for monitoring were spruce forests in monoculture, clear-cut areas, riparian type habitats and subalpine-alpine meadow habitats. The invertebrate fauna was analysed using pit-fall traps for the epigean fauna, the Winkler method, herbaceous vegetation sweeping with the entomological net, and monitoring on transects. The monitoring program of the invertebrate groups from the epigean fauna and from the grassy vegetation was carried out from April to October each year.

The selection of suitable monitoring sites was performed between 2021 and 2023. After investigating more than 100 plots, 88 plots were selected as study sites for the invertebrate fauna. At least 20 of these plots were in each of the main types of habitats studied i.e. spruce forests (20), clear-cut areas (20), riparian habitats (28) and alpine meadows (20). Additionally, half of the plots were in areas subject to ecological reconstruction activities.

The monitoring program was part of the frame the LIFE project "Creation of a wildlife reserve in the Southern Carpathians, Romania" (LIFE18NAT/RO001082)implemented by the Conservation Carpathia Foundation, with the co-financing of the Arcadia Foundation, a charitable fund created by Lisbet Rausing and Peter Baldwin, and with the management program provided by the Cambridge Conservation Initiative (CCI).

Objectives

- identify the most relevant habitats for establishing the sampling plots for monitoring program and establish a sampling protocol (2019-2020);
- examine community composition of ground-dwelling arthropods in different habitats and land use types (spruce monoculture versus mixed forest; degraded riparian habitats, alpine habitats and clear-cut areas) (2019 – 2023);
- inventory of the taxonomic groups and target species present in the studied areas (2019 – 2023);
- assess the diversity of the terrestrial arthropod communities through different methods (2019 – 2023);
- identify the structure of arthropod communities and the number of functional groups, the abundance and density of each group (2019 – 2023);
- identification of indicator species (2020 – 2023);
- assess how the land use affect species richness and functional diversity of certain taxa (2020 – 2023).

Results

- The major taxonomic groups identified were Oligochaeta, Gastropoda, Isopoda, Pseudoscorpiones, Opilionida, Araneae, Acarina, Chilopoda, Diplopoda and Insecta.
- From the point of view of abundance, the most numerous numbers for the epigean fauna were recorded in monoculture spruce forests, both in ecological reconstruction areas and in control areas.
- The taxonomic structure of the fauna was relatively constant, with 2-4 eudominant groups and 1-5 dominant groups and the analysis of diversity indices was performed for all four habitat types.
- The eudominant and dominant groups in the entire study area were represented by the epigean fauna of mites, collembola, isopods, ants, opilionids to which carabid beetles were occasionally added. For the fauna in the grassy layer, the dominant groups were represented by aphids and cycads, phytophagous coleoptera, diptera, thysanoptera, parasitoid wasps, heteroptera, to which chilopods were occasionally added.
- Indicator species. For monoculture spruce forests, the carabid coleoptera *Carabus auronitens*, *Carabus linnaei*, *Carabus coriaceus*, *Carabus violaceus*, the cerambycid coleoptera *Morimus funereus*, and the endemic limacid gastropod *Bielzia caerulans* were selected as indicator species. The previously mentioned carabid species can be used as indicator species for clear-cut habitats as well. Having a high degree of dispersion, these species are the first to settle in a habitat that evolves towards a dense forest, their presence being linked to this type of habitat. For riparian type habitats, the most indicated are the species that depend on specific microhabitat conditions such as the gastropod *Drobacia (Helicigona) banatica* and the carabid coleopter *Carabus variolosus*, to which the limacid gastropod *Bielzia caerulans* can be added. For alpine-subalpine habitats, the most suitable species is the butterfly *Erebia epiphron transsylvanica*, easily recognizable and characteristic of this type of altitude habitat.
- Several species of harvestmen (Arachnida, Opiliones) were identified in the study area: *Paranemastoma silli*, *Platybunus bucephalus*, *Platybunus pinetorum*, *Trogulus banaticus*, *Trogulus tingiformis*, *Mitopus morio*, *Nemastoma lugubre*, *Nemastoma transsylvanicum*, *Mitostoma chrysomelas*, *Ishyropsalis manicata*, *Oligolophus tridens*, *Holoscotolemon jaqueti* and *Lophopilio palpinalis*. Some of these species may be used as indicators, however, expert knowledge is required for the identification at species level.
- Species of community interest that were identified in the study area: *Drobacia (Helicigona) banatica* (Mollusca, Gastropoda), *Vertigo angustior* (Gastropoda), *Carabus variolosus*, *Carabus (Morphocarabus) rothi hampei*, *Morimus funereus*, *Rosalia alpina* (Coleoptera) (Coleoptera), *Parnassius Mnemosyne*, *Everes alcetas*, *Panaxia quadripunctaria* (Lepidoptera), *Pholidoptera transsylvanica* (Orthoptera). The endemic taxa identified in the area were *Bielzia coerulans* (Gastropoda), *Somatochlora alpestris* (Odonata), *Boloria pales carpathomeridionalis*, *Erebia epiphron transsylvanica*, *Pieris bryoniae* (Lepidoptera), *Pterostichus pilosus wellensii* (Coleoptera), *Paranemastoma sillii*, *Ishyropsalis manicata*, *Trogulus banaticus*, *Nemastoma transsylvanicum* (Arachnida, Opiliones).
- In the area of Făgăraș and Iezer Păpușa Mountains, 135 species of butterflies were recorded, of which two are considered endangered (*Erebia sudetica radnaensis* and *Nymphalis vau album*) and 8 species are considered vulnerable. We identified 63 species of diurnal lepidoptera, including 3 species listed on the Annexes of the Habitats Directive (one on Annex 4A – *Parnassius mnemosyne* and two on Annex 4B – *Neptis hylas* and *Everes alcetas*) and 7 species and subspecies endemic to the Carpathian Mountains..
- In the study area, we recorded 4 alien species, two of them having the status of invasive species - *Arion lusitanicus* (Gastropoda), *Corytucha arcuata* (Heteroptera), *Sceliphron curvatum* (Hymenoptera), *Harmonia axyridis* (Coleoptera).
- 48 impact factors were identified in the studied area. Among them, those in the forestry sector (10 factors), in climate change (7 factors) and in the development, construction and use of infrastructure and residential, commercial, industrial, and recreational areas (6 factors), stand out.

Data analysis for spruce monoculture, mixed forests and clear cut areas

Linear discriminate analysis (LDA) was used to determine if the three types of forest habitat were different in the structure of vegetation and invertebrate communities. We used non-metric multidimensional scaling (NMDS) ordination to estimate the effect of vegetation characteristics on arthropod community composition in the tree types of forest habitats and the Monte Carlo method to test the significance of the results. LDA and NMDS were conducted in in the "vegan" R package and for Monte Carlo method we used the ade4 package. We performed Generalized Linear Mixed Models (GLMM) to estimate the effect of vegetation characteristics on invertebrate diversity. To this end, we calculated the abundance, the rarefied richness and Shannon - Weiner diversity (H') index, using the vegan R package. When abundance was used as a response variable, we specified a Poisson error distribution and a logarithmic link function and a Gaussian distribution and identity link function when rarefied richness and Shannon-Wiener diversity index were the response variables. Site was included in all models as a random factor. For this analysis we used the "lme4" package and lmerTest package.

LDA significantly showed that based on vegetation attributes cut-clear forest habitat was distinctive from the other two types of forest but spruce forest (monoculture) habitat and mixed forest habitat partially overlapped (Fig. 1, Table 1). The LDA of invertebrate community in relation to differences in the forest habitat types illustrates that there is a lot of overlap in invertebrate community composition among the forest habitats (Fig. 2). The NMDS ordination demonstrated that the vascular plant cover, small species cover and the tree species cover were significantly associated with arthropod community composition (Fig 3. Table 2). The GLMM showed that none of the vegetation characteristics had a significant effect on either invertebrate abundance, rarified richness or (H') index (Table 3).

The tendencies in the structure of invertebrate communities following the implementation of ecological reconstruction measures is difficult to highlight after only three years of observations. The only place where this trend is clearly visible is the alder plantation at Richita, and, to a much lesser extent, in the ecological reconstruction area at Cuca. This change takes shape in a first stage in the polarization of the percent of the eudominant groups compared to all other groups. A definitive conclusion, however, can only be drawn after the implementation of a monitoring program that extends on 10 – 15 years, throughout the main stages of ecological reconstruction.

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