

Original Research

**RIFFLE BEETLE *Elmis maugetii* Latreille, 1802 (COLEOPTERA: ELMIDAE):
NOTES ON THE SPECIES' MORPHOLOGICAL PLASTICITY IN THE BALKAN
PENINSULA**

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**Boris Novaković^{1,a*}, Jelena Đuknić^{2,b}, Nikola Paskaš¹, Marko Raković^{3,c},
Vidak Lakušić^{4,d}, Ivana Živić^{4,e}**

¹ Department of National Laboratory, Serbian Environmental Protection Agency, Ministry of Environmental Protection of the Republic of Serbia, Žabljačka 10A, 11160 Belgrade, SERBIA

² Department for Hydroecology and Water Protection, Institute for Biological Research “Siniša Stanković”, National Institute of the Republic of Serbia, University of Belgrade, Despota Stefana Blvd. 142, 11060 Belgrade, SERBIA

³ Department of Biodiversity and Environmental Research, University of Belgrade-Institute for Multidisciplinary Research, Despota Stefana Blvd. 142, 11060 Belgrade, SERBIA

⁴ Department of Invertebrate Zoology and Entomology, University of Belgrade, Faculty of Biology, Studentski trg 16, 11000 Belgrade, SERBIA

^a <https://orcid.org/0000-0003-4846-6371> ^b <https://orcid.org/0000-0003-3635-5463>

^c <https://orcid.org/0000-0002-3658-3362> ^d <https://orcid.org/0000-0002-0768-0382>

^e <https://orcid.org/0000-0002-4397-9904>

Abstract

The study present data on morphological plasticity of the riffle beetle species, *Elmis maugetii* (Coleoptera: Elmidae) in the Balkan Peninsula. In general, morphological plasticity of the riffle beetles explains that identification of imagoes is difficult due to many species expressed high morphological variability influenced by environmental conditions. For the purposes of this study, riffle beetle samples were sampled in 2014-2017 period from four Balkans' countries: Serbia, Bosnia and Herzegovina, North Macedonia and Greece. Species morphological variability are related to body shape, pronotum structure, abdomen length/width and size, and it can vary considerably among beetle populations. Determining morphological plasticity, shaped by genetically-based species characters as well as ability of organism to alter its physical structure in response to environmental conditions, is inherently complex. Such complexity stems from distinguishing species' ecological responses from genetic variation in the light of spatio-temporal and environmental context. The present study specifically discussed ecophenotypic and morphometric plasticity of *Elmis maugetii* among investigated localities (different population ecophenotypes) assuming that water discharge, water temperature, dissolved oxygen concentration in water, HYMO (hydromorphological) characteristics, are strongly associated with the riffle beetle species morphological plasticity.

Keywords: aquatic beetle, ecophenotype, morphological plasticity, abiotic factors, the Balkans.

* boris.novakovic@sepa.gov.rs

INTRODUCTION

Morphological plasticity in aquatic beetles arises through complex interactions among ontogenetic processes, genetic and ecological factors. Altogether, these factors shape variation in body size, coloration, appendage structure, respiration-related adaptations, dispersal ability, and reproductive traits among aquatic beetle populations. Though each factor might be minor on its own, their cumulative effects often could result in a considerably higher, disproportionate impact on organisms. Aquatic beetles are excellent model organisms for studying ecophenotypic variability due to species occurred in diverse freshwater habitats and respond strongly to environmental gradients.

Among aquatic macroinvertebrates, morphological plasticity is known from caddisfly study from lakes and streams. Caddisflies like *Limnephilus externus* display remarkable phenotypic plasticity when inhabiting both lakes (lentic) and streams (lotic) [1].

Morphological plasticity in Ephemeroptera (mayflies) refers to the remarkable ability of their aquatic nymphs to alter physical traits-such as gill size, ionocyte cell counts, and body size at metamorphosis-in response to environmental stressors like poor water quality, predation pressure, and temperature fluctuations, such as *Baetis rhodani* species [2]. Also, a single study regarding stress and response: a systematic review of epigenetic pathways underlying gene expression and phenotypic plasticity in aquatic invertebrates is recently published [3].

Evidence of phenotypic plasticity along an altitudinal gradient is known from a single study the dung beetle *Onthophagus proteus* [4], but there are no studies related to morphological plasticity of aquatic beetles in general. Morphological plasticity of aquatic beetles is poorly known in general. A single, related study of influence on hydraulic pressure on morphometric variability of same species from the present study (*Elmis maugetii*) is known [5].

The main objective of the study is to predict factors affect morphological plasticity of the riffle beetle species (*Elmis maugetii*) in the Balkans as well as to estimate which factors predominantly triggered this species morphological plasticity.

MATERIALS AND METHODS

Riffle beetle specimens of *Elmis maugetii* (only imagoes, not larval individuals) were collected using Surber net (300 cm², 250 µm mesh size) and hand net (25x25 cm, 500 µm mesh size), and manually by tweezer. Samples were preserved using 70% ethanol solution, and further analysed in the laboratory with selecting characteristic riffle beetle specimens for the purposes of this study. Riffle beetle samples were taken in the 2014–2017 period covering four Balkans' countries: Serbia, Bosnia and Herzegovina, North Macedonia and Greece. Identification of the organisms was performed on Leica MS5 and Carl Zeiss SteREO Discovery.V8 stereomicroscopes by using appropriate taxonomic keys.

RESULTS AND DISCUSSION

The riffle beetle *Elmis maugetii* showed morphological plasticity mainly in response to abiotic conditions associated with running-water habitats. As a rheophilic representative of the elmids, we assumed its morphology is strongly influenced by hydrodynamics, water flow-driven factors, oxygen availability, temperature, riverbed substrate size and composition, and the amount of available food (resource). Our prediction is the most important abiotic factor for riffle beetle morphological variability is current discharge, which is corroborated by the data from previous study of same riffle beetle species [5]. According to this study, a larger riffle beetle specimens were found in streams characterized by higher flow velocity, and on other hand, water level and sampling depth is not significant in terms of the species' body size. Populations inhabiting fast-flowing streams and torrents often develop more flattened and streamlined body forms, stronger claws, and more compact appendages that improve resistance against hydraulic stress and help maintain attachment to stones or submerged wood. In slower running waters, specimens may appear slightly broader or less dorsoventrally flattened (one of possible “scenarios” is the existence of different species' ecophenotypes as adaptive forms, provided in Figure 1).

Elmis maugetii ecophenotypical variability is primarily related to body shape, pronotum structure, pronotum/abdomen length/width and size, and it could vary considerably among different populations.

Morphological plasticity in riffle beetles is strongly linked to current flow velocity because these insects live in fast-flowing stream habitats where hydrodynamic stress shapes survival, attachment, respiration, and feeding behavior. Also, water temperature is important factor for morphological plasticity. In cold, highly oxygenated mountain streams, cuticular microstructures and body surface features associated with gas exchange may differ from those in warmer or less oxygen-rich waters. Temperature itself can influence body size and developmental timing; cooler habitats often produce slower development and sometimes larger, more heavily sclerotized adults, whereas warmer streams may favor smaller body size and faster life cycles. Dissolved oxygen concentration in water and HYMO (hydromorphological) characteristics, are important in terms of aquatic beetle morphological plasticity. Oxygen concentration is important factor because elmids rely heavily on plastron respiration. We assumed that food amount and its availability (resource) could also affect the species' morphological variability.

In the light of evolutionary processes, morphological plasticity of riffle beetles is also closely related to reproductive isolation in geographically fragmented freshwater habitats such as canyons, gorges, and isolated mountain streams. Because riffle beetles are highly dependent on fast-flowing, oxygen-rich lotic environments and generally possess limited dispersal ability, populations separated by deep valleys, waterfalls, gorges, or canyon systems may experience reduced gene flow over time. In terms of the species' dispersal ability, it is important that two riffle beetle *Elmis maugetii* species forms exist, brachypterous (non-flying) and macropterous (ability to fly), and potentially, could be occurred in a same population. Differences in current discharge, substrate composition, water chemistry, and microhabitat structure among isolated stream systems can drive local morphological adaptations, including variation in body shape, attachment structures, and size. As these populations remain isolated,

ecological specialization and hydrodynamic adaptation may gradually contribute to genetic divergence and reproductive isolation through allopatric speciation. In canyon and gorge systems, physical barriers and habitat discontinuity can prevent interbreeding between populations, allowing independent evolutionary trajectories shaped by local hydraulic conditions. Consequently, morphological plasticity associated with flow velocity may not only reflect short-term ecological responses but may also play an important role in long-term diversification and speciation processes in riffle beetles, particularly for species inhabiting fragmented freshwater habitats.

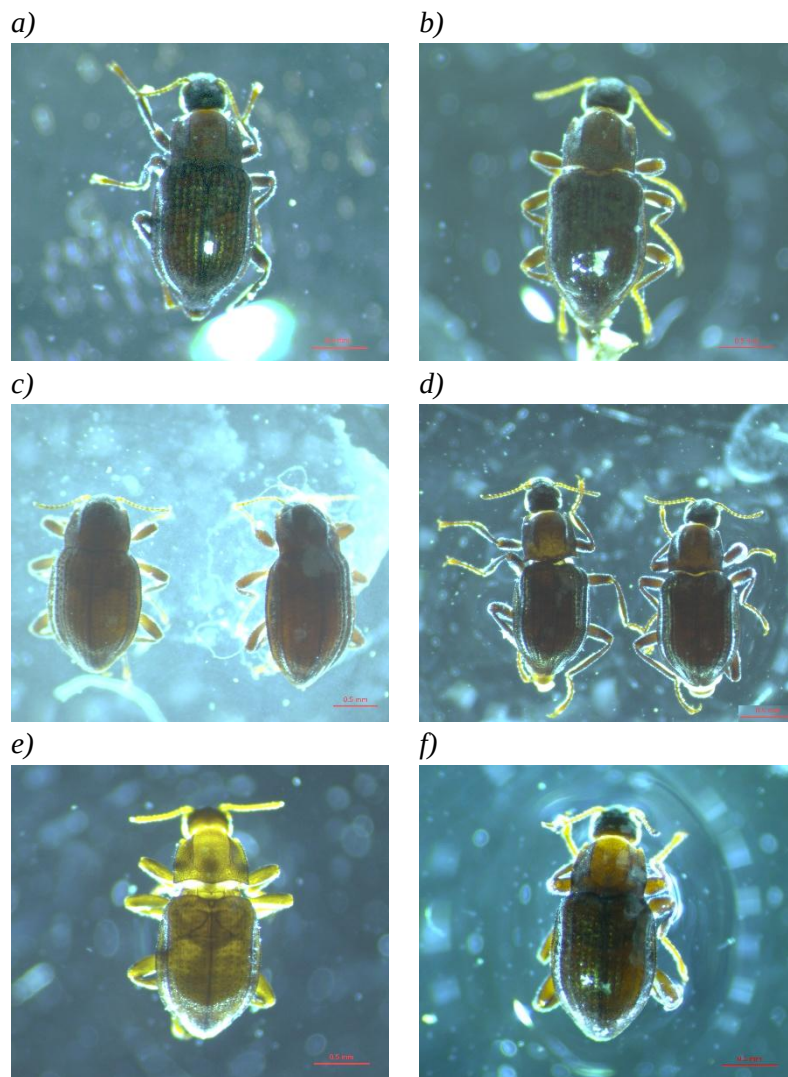


Figure 1 Different ecophenotypes of the riffle beetle *Elmis maugetii* Latreille, 1802 from the Balkan Peninsula, localities of findings: a) Boturići-Rasina (central Serbia); b) Niš-Kutinska Reka (SE Serbia); c) Krepoljinska Reka (E Serbia); d) Čapljina/Buna River (Bosnia and Herzegovina); e) Pčinja River upstream the Kumanovo (North Macedonia); f) Ano Kefalari/Zygaktes (Greece)

CONCLUSION

Hydraulic stress strongly influenced riffle beetle (*Elmis maugetii*) body shape, flattening, claw development, and attachment structures needed for survival in fast-flowing streams.

Specimens from torrential habitats are usually more streamlined and dorsoventrally flattened than those from slower running waters reducing drag and help them remain attached to stones and submerged wood improving adhesion in turbulent water.

Besides hydrodynamic conditions, morphological plasticity of the riffle beetle (*Elmis maugetii*) is closely associated with water temperature, and consequently, dissolved oxygen concentration in water (due to its plastron respiration), and HYMO (hydromorphological) characteristics, primarily riverbed substrate type and composition, and food amount (resource) and its availability.

Overall, genetic variation, phylogeographic patterns, phenotypic plasticity, and inter- and intrapopulation variability in riffle beetle describe how geography and environmental conditions influence the genetic and physical differences of these aquatic insects. Phylogeography examines how populations from different streams or regions are genetically related and how historical isolation or dispersal shaped their distribution. Ecophenotypes (visually distinguishable types exclusively linked to phenotypic plasticity) refer to variations in morphology affected by environmental factors such as water flow, water temperature, dissolved oxygen concentration in water, HYMO (hydromorphological) characteristics of stream/river, and not associated with the species' genetic variability.

Our assumptions are there are two major riffle *Elmis maugetii* ecophenotypes: rheophilic (slim and long occurred in fast current) and rheophobic (wide and round-shaped occurred in slower current), with many “intermediate“ ecophenotypes varied depend on triggering morphological plasticity factors, predominantly water discharge and its intensity (an ecophenotype is a form or an organism that developed due to environmental influences rather than genetic differences). In fact, ecophenotype is regarded as some kind of adaptive form to local water conditions, i.e. species adaptation.

Also, the present study pointed out that phenotypic plasticity complicates riffle beetle classical taxonomy problems underlining the need for combining morphological (with identification based on species *aedeagus* characteristics) and molecular (DNA-compliant) approach such as DNA barcoding for precise species identification. Determining morphological plasticity, shaped by genetically-based species characters as well as ability of organism to alter its physical structure in response to environmental conditions, is inherently complex. Such complexity stems from distinguishing species' ecological responses from genetic variation in the light of spatio-temporal and environmental context.

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