Influence of Hydraulic pressure on Morphometric Variability of Riffle Beetle *Elmis maugetii* Latreille, 1802 (Coleoptera: Elmidae)

BORIS B. NOVAKOVIĆ, Ministry of Environmental Protection,
Department of National Laboratory,
The Serbian Environmental Protection Agency, Belgrade

Original sceintific paper
UDC: 595.782.3
DOI: 10.5937/tehnika2001105N

The paper presents the results of morphometric study of the riffle beetle Elmis maugetii Latreille, 1802 in response to hydraulic pressure. The following species morphometric characters were analyzed: head length, prothoracic width and total body length with respect to measured hydrological parameters (water level, sampling depth and current discharge). A total of 155 E. maugetii adult specimens from six typical riffle beetle streams in Serbia were examined during investigated period (2014-2015). Among measured hydrological parameters, it was found that only current discharge affects specimen size-a larger specimens were found in streams characterized by higher flow velocity. The main goal of the study is to assess the influence of current discharge on species morphometric variability.

Key words: *riffle beetle, Elmis maugetii, flow, velocity, stream, morphometrics*

1. INTRODUCTION

Riffle beetles in the family Elmidae are frequent members of the invertebrate community of running water. Most elmid species occur in well-aerated streams and rivers, but some also occur on wave-washed lake shores. Adults of a few species are terrestrial, but most are aquatic with plastron respiration [1].

Hydraulic conditions can play a key role in the distribution of organisms in streams and rivers, through direct effects, i.e. flooding and drag forces [2, 3], or indirect effects, such as those of stream discharge on the substrate particles [4] and food availability [5, 6]. Changes in hydraulic conditions, particularly current discharge, could also disturb the fauna by remving or killing organisms [7] and affecting reproduction rates, thus creating new opportunities for individuals to settle [8, 9]. The vulnerability of orgnisms to intense current discharge can be reduced by morphological adaptations of the body or behavioural mechanisms such as the use of refugia [9, 10, 11, 12]. Reduced body size is favoured in adverse hydraulic conditions because smaller larvae can penetrate sub strates of low porosity, in small interstitial spaces that serve as refugia against current displacement [13]. In adverse conditions, organisms in these shelters are more likely to survive and later recolonise the affected areas. The active search by macroinvertebrates for shelter during high-flow events was confirmed in observations made during simulated floods in tanks [14].

Phylogenetic relationships might also influence the body shape of beetles. However, all other ecological and behavioral factors have relationship with phylogeny so it is difficult to take them into account separately. Moreover, contribution of diet, flying ability and other behavioral factors should be considered to explain the underlying evolutionary processes of this shape variation [15]. On the other hand, some studies explain geographical variation considering shape differences [16].

Elmis maugetii was selected as a model for this study due to it is the most common riffle beetle species in the investigated area. The main goal of the study is to assess impact of hydrological regime parameters to morphometric characters of this riffle beetle species.

2. MATERIAL AND METHODS

Aquatic beetle samples were taken using a hand net (25x25 cm, 500 μm mesh size) or specimens were manually collected during the Annual Water Quality Monitoring Programme conducted by the Serbian Environmental Protection Agency (SEPA) in 2014 and

Author's address: Boris Novaković, Ministry of Environmental Protection, Department of National Laboratory, The Serbian Environmental Protection Agency, Belgrade, Ruže Jovanović 27a

e-mail: boris.novakovic@sepa.gov.rs

Paper received: 05.12.2019.

Paper accepted: 15.12.2019.

2015. The multi-habitat sampling procedure [17] and the AQEM protocol [18] were applied. The samples were preserved using 70% ethanol and further processed in the laboratory. Species determination was carried out by using the stereomicroscopes Leica MS 5 and Carl Zeiss StereoDiscovery V8 with AxioCam ICc5 and riffle beetle taxonomic key [19]. Ecoregion delineation was given according to [20].

The adult *E. maugetii* riffle beetle specimens were collected from six streams in Serbia. The sampling sites are numerically coded: 1 (Tulare/Tularska Reka), 2 (Trnski Odorovci/Jerma), 3 (Mrtvine/Gaberska Reka), 4 (Krivi Do/Visočica), 5 (Crnajka/Crnajka) and 6 (Manasija/Resava). The selected streams are typical for riffle beetles, mainly situated in the submountain regions, predominantly with riffle microhabitats.

General data on sampling sites are provided in Table 1.

Table 1. General data on sampling sites

Sampling Site	1	2	3	4	5	6
Sampling date	25-Aug-15	29-Aug-14	26-Oct-15	27-Oct-15	10-Aug-15	13-Oct-14
Coordinates (N, E)	42.80165 21.57303	42.92862 22.62611	42.99738 22.77266	43.10118 22.93536	44.30592 22.13795	44.10047 21.47077
Elevation (m a.s.l.)	412	573	464.8	813.4	152	211.5
Ecoregion (Illies, 1978)	6	7/6 border	7	7	7/10 border	7/5 border
Dominant river bed substrate	mesolithal	megalithal and mesolithal	megalithal and mesolithal	mesolithal	mesolithal	megalithal and mesolithal
No. of measured adult specimens	16	22	40	18	17	42

A total of 155 adult specimens were examined in this study. Additionally, some of physico-chemical parameters relevant to the riffle beetle community occurrence [water temperature (ºC) and oxygen saturation (%)] are given (Table 2).

Table 2. Water temperature (ºC) and oxygen saturation (%) at sampling sites

Sampling Site	1	2	3	4	5	6
Water temperature (ºC)	16.7	15.2	9.9	7.2	22.4	14.4
Oxygen saturation (%)	96	99	83	92	105	94

The following linear morphometric characters were selected (dorsally): head length, prothoracic width and total body length (Figure 1).

The following hydrological regime parameters were measured in situ: water level, sampling depth and current discharge during Annual Hydrological Programme conducted by the Hydrometeorological Service of Serbia (HMSS). A water depth is measured on sampling date for each sampling sites. A discharge was measured using different types of rotating-element current-meters depending on flow gradient.

Figure 1 - Elmis maugetii Latreille, 1802; adult specimen: selected morphometric characters

In order to estimate correlation between investigated morphometric characters and measured hydrological parameters, a linear regression analysis with 95% confidence interval for regression slope was used [21].

3. RESULTS AND DISCUSSION

Morphometric characters of adult *E. maugetii* specimens with respect to hydrological regime parameters (water level, sampling depth and current discharge) and their significance in terms of species morphometric variability were analyzed.

A one-way ANOVA showed significant differences ($p<0.05$; Table 3) in specimen body length between different populations.

Table 3. Differences in E. maugetii body length (single factor ANOVA)

Body length	SS	df	MS	F	p	F crit
Between sampling sites	2.522	5	0.504	27.67	0.001	2.275
Total	5.239	154				

Among hydrological parameters it was obtained that only current discharge is correlated with each riffle beetle morphometric character ($P<0.05$) as shown in Table 4.

Table 4. Discharge and E. maugetii morphometric characters

discharge /morphometric character	average head length	average prothoracic width	average total body length
F	18.3	22.89	42.3
DFn, DFd	1.4	1.4	1.4
P	**0.013**	**0.009**	**0.003**

The water level as well as the sampling depth are found to be insignificant with respect to analyzed morphometric characters (Table 5 and Table 6).

Table 5. Water level and E. maugetii morphometric characters

water level /morphometric character	average head length	average prothoracic width	average body length
F	1.139	0.964	1.038
DFn, DFd	1.4	1.4	1.4
P	0.346	0.382	0.366

Table 6. Sampling depth and E. maugetii morphometric characters

sampling depth /morphometric character	average head length	average prothoracic width	average body length
F	2.431	2.982	3.675
DFn, DFd	1.4	1.4	1.4
P	0.194	0.159	0.128

The results of this study are in accordance with the [22]. In this study streams in southern France were covered and larger body sizes were found predominantly under extreme hydraulic stress. They argued that morphological and behavioural characteristics such as the ability to cling to the substrate may be enhanced, according to the size of the individual thus, overcoming the disadvantage due to larger size [22].

On the other hand, the opposite results to [22] as well as to this study were provided by [9]. They investigated patterns of body size of *Phanocerus clavicornis* Sharp, 1882 (Elmidae: Larainae) larvae along a gradient of change of stream discharge in the Atlantic Rainforest. The effects of such disturbance can vary in relation to the body size of each organism: smaller individuals are more able to resist being washed away and/or survive under conditions associated with increased discharge. Their results suggest that in third-order streams may be a balance between a better use of refugia by smaller larvae and greater ability to settle on the substrate by larger larvae.

Besides they assumed a direct relationship between the velocity of stream discharge and seasonality, the discharge being slower during the dry season than the rainy. This study stated the hypothesis that *P. clavicornis* larvae have different body sizes in response to various current discharge in streams of low order in the Atlantic Rainforest. Specifically, in the period of faster discharge-the rainy season-the larvae of *P. clavicornis* would have a smaller body than in the period of slower discharge - the dry season. Similar results were also reported in a previous study in a river in Australia, where, after a major flood, the invertebrates were smaller [23].

Avariety of biological processes produce differences in shape between individuals or their parts, such as disease or injury, ontogenetic development, adaptation to local geographic factors, or longterm evolutionary diversification. Differences in shape may signal different functional roles played by the same parts, different responses to the same selective pressures (or differences in the selective pressures themselves), as well as differences in processes of growth and morphogenesis. Shape analysis is one approach to understanding those diverse causes of variation and morphological transformation [24]. Size analysis plays an important role in many kinds of biological studies. Avariety of biological processes produce differences in size between individuals, amount of food resource, physico-chemical factors, adaptation to local geographic factors. But also, ecological factors is very important. The assumption of the present study is also that differences in ontogenic development of riffle beetle larva are varied with respect to flow disturbance.

4. CONCLUSIONS

Hydraulic disturbance in water is one of a key factor for aquatic invertebrate community composition and structure. Extreme weather conditions, such as heavy rainfalls and torrents influence on aquatic taxa richness and their spatial patterns of habitat distribution.

The major morphological adaptation of riffle beetle species to rapid discharge are long legs with prominent tarsal claws allowing them to hardly cling the substrate. Furthermore riffle beetle body shape is not so hydrodynamic.

Besides, extreme weather conditions can also change the riffle beetle species microhabitat preference; riffle beetles retreat in well-aerated stretches of watercourses (provided by the oxygen saturation measured) with optimal microhabitat conditions. Hydromorphological changes influence on microhabitat structure, predominantly by devastation of perennial microhabitats, relevant as refugia for some riffle beetle species, particularly those limited to inhabit upper stretches of watercourse with specific physico-chemical and hydrological conditions (trout zone).

In streams, the irregular surface of inorganic substrates [14], leaves and wood debris [25] often provide refuges from the current discharge and enable survival during a disturbance [26]. In adverse conditions, refuges can protect organisms that will later reoccupy the areas affected [27]. Research on the influence of current discharge and the search for refugia and how they affect the functional attributes of invertebrates has recently become more prominent [11, 28, 29, 30, 31]. These studies suggest that the use of refugia plays a key role in determining the species composition and functional characteristics of benthic communities. The event of high discharge in streams is known as the main disturbance affecting the structure of macroinvertebrate communities [32].

This study provides hydraulic stress, predominantly discharge intensity influences on morphometric parameters of the *E. maugetii.* Future research should provide more precise data on impact of parameters investigated as well as other hydrological parameters to aquatic beetle size and shape including both larval and imago specimens.

5. ACKNOWLEDGEMENT

The author is grateful to colleagues from the Serbian Environmental Protection Agency (SEPA) and the Hydrometeorological Service of Serbia (HMSS).

REFERENCES

[1] Elliot J. M, The ecology of riffle beetles (Coleoptera: Elmidae). *Freshwater Reviews*, pp. 189-203, 2008.

[2] Weissenberger J, Spatz H. C, Emans A, Schoerbel J, Measurement of lift and drag forces in the range experienced by benthic arthropods at velocities beow 1.2 m/s. *Freshwater Biology* 25: 21-31, 1991.

[3] Collier K. J, Croker G. F, Hickey C. W, Quinn J. M, Smith B. S, Effects of hydraulic conditions and larval size on the microdistribution of Hydrobiosidae (Trichoptera) in two New Zealand rivers. *New Zealand Journal of Marine and Freshwater Research* 29: 439-451, 1995. doi:10.1080/00288330.1995.9516678.

[4] Jowett I. G, Richardso J, Biggs B. J. F, Hickey C. W, Quinn, J. M, Microhabitat preferences of benthic invertebrates and the development of generalized Deleatidium spp. Habitat suitability curves, applied to four New Zealand rivers. *New Zealand Journal of Marine and Freshwater Research* 25: 187-200, 1991.

[5] Biggs B. F, Hickey C. W, Periphyton response to hydraulic gradient in a regulated river in New Zealand. *Freshwater Biology* 32: 49-59, 1994. doi: 10.1111/j.1365- 2427.1994.tb00865.

[6] Hart D. D, Finelli C. M, *Physical-biological coupling in streams*. The pervasive effects of flow on benthic organisms. *Annual Reviews of Ecology and Systematics* 30: 363-395, doi: 10.1146/annurev.ecolsys.30.1.363. 1999.

[7] Townsend C. R, Hildrew A. G. Species traits in relation to a habitat templet for river systems. *Freshwater Biology* 31: 265-275, doi:10.1111/j.1365-2427.1994.tb01740.x, 1994.

[8] Sousa W. P. The role of disturbance in natural communities. *Annual Review of Ecology, Evolution and Systematics* 15: 353-391, doi: 10.1146/annurev.es.-15.110184.002033, 1984.

[9] Segura M. O, Siqueira T, Fonseca-Gessner A. A, Variation in body size of Phanocerus clavicornis Sharp, 1882 (Coleoptera : Elmidae: Larainae) in Atlantic Rainforest streams in response to hydraulic disturbance. *Brazilian Journal of Biology* 73: 747-752, doi:10.1590/S1519-69842013000400010, 2013.

[10] Statzner B, Holm T. F Morphological adaptation of shape to flow: microcurrents around lotic macroinvertebrates with known Reynolds numbers at quasinatural flow conditions. *Oecologia* 78: 145-157, doi:10.1007/BF00377150, 1989.

[11] Sedell J. R, Reeves G. H, Hauer F. R, Stanford J. A, Hawkins C. P, Role of refugi in recovery from disturbances: Modern fragmented and disconnected river systems. *Environmental Management* 14: 711-724, 1990.

[12] Sagnes P, Merigoux S, Peru N, Hydraulic habitat use with respect to body size of aquatic insect larvae: Case of six species from a French Mediterranean type stream. *Limnologica* 38: 23-33, doi:j.limno.2007.-09.002, 2008.

[13] Townsend C. R, Thompson .M, Body size in streams: macroinvertebrate community size composition along natural and human-induced environmental gradients. pp. 78-97, In: Hildrew, A.G., Raffaelli, D.G., Edmonds-Brown, R. (eds.). Body size: the structure and function of aquatic ecosystems. Cambridge: Cambridge University Press, 2007.

[14] Holomuzki J. R, Biggs B. J. F. Sediment texture mediates high-flow effects on lotic macroinvertebrates. *Journal of the North American Benthological Society* 22: 542-553, 2003.

[15] Yonehara Y, Konuma J, Klingenberg C.P, The use of geometric morphometrics in a study of shape diversity of ground beetles (Coleoptera: Carabidae). *The Second International Symposium of Biological Shape Analysis*. Okinawa, Japan: 1–15 pp, 2011.

[16] Alibert P, Moureau B, Dommergues JLB, David B. Differentiation at a microgeographical scale within two species of ground beetle, Carabus auronitens and C. nemoralis (Coleoptera, Carabidae): a geometrical morphometric approach. *Zoologica Scripta*, 30 (4): 299-311, 2001.

[17] Hering D, Verdonschot P. F. M, Moog O, Sandin L. Overview and application of the AQEM assessment system. *Hydrobiologia* 516: 1-20, 2004.

[18] AQEM Consortium. Manual for the application of the AQEM system. A comprehensive method to as-

sess European streams using benthic macroinvertebrates developed for the purpose of the Water Framework Directive, 2002.

[19]Olmi M, *Coleoptera, Dryopidae, Elminthidae*. *Fauna d'Italia*. 12. Edizioni Caldcrini, Bologna, 1976.

[20]Illies J. (ed.). *Limnofauna Europaea*. Gustav Fischer Verlag, 1978.

[21]Kenney J. F, Keeping ES. *Linear Regression and Correlation*. Ch. 15. pp. 252-285. In: *Mathematics of Statistics*, Pt. 1, 3rd ed. Princeton, NJ: Van Nostrand, 1962.

[22]Merigoux S, Dolodec S, Hydraulic requirements of stream communities: a case study on invertebrates. *Freshwater Biology* 49: 600-613, doi:10.1111/j.-1365-2427.2004.01214, 2004.

[23]Thomson J. R, The effects of hydrological disturbance on the densities of macroinvertebrate predators and their prey in a coastal stream. *Freshwater Biology* 47: 1333-1351, doi:10.1890/0012-9658, 2002.

[24]Kendall D, *The diffusion of shape*. Advances in Applied Probability 9: 428-430, doi:10.1017/S0001-867800000999, 1977.

[25]Palmer M. A, Arensburger A. P, Martin A. P, Denmnan D. W, Disturbance and patch-specific responses: the interactive effects of woody debris dams on lotic invertebrates. *Oecologia* 105: 247-257, doi:-10.1007/BF00328554, 1996.

[26]Lancaster J, Bélanger-Buffin T, Reid I, Rice S, *Flow and substratum-mediated movement by a stream insect. Freshwater Biology* 51: 1053-1069, doi: 10.1111/j.1365-2427.2006.01554, 2006.

[27]Rempel L. L Richardson J. S, Healey M. C, Flow refugia for benthic macroinvertebrates during flooding of a large river. *Journal of the North American Benthological Society* 18 (1): 34-48, 1999.

[28]Sibly RM, Calow P. A life-cycle theory of responses to stress. *Biological Journal of the Linnean Society* 37: 101-116, doi:10.1111/j.1095-8312.1989.tb02-007.x, 1989.

[29]Lancaster J, Hildrew A. G, Flow refugia and the microdistribution of lotic macroinvertebrates. *Journal of North American Benthological Society* 12: 385-393, doi:10.2307/1467619, 1993.

[30]Winterbottom J. H, Orton S. E, Hildrew A. G, Lancaster J, Field experiments on flow refugia in streams. *Freshwater Biology* 37: 569-580, 1997. doi:-10.1046/j.1365-2427.1997.00184.x

[31]Franken J, Gardeniers J. P, Beijer J. A. J, Peeters ETHM, Effects of interstitial refugia and current velocity on growth of the amphipod Gammarus pulex Linnaeus. *Journal of the North American Benthological Society* 25 (3): 656-663, 2006.

[32]Melo A. S, Niyogi D. K, Matthaei C. D, Townsend C. R, Resistance, resilience and patchiness of invertebrate assemblages in native tussock and pasture streams in New Zealand after a hydrological disturbance. *Canadian Journal of Fisheries an Aquatic Sciences* 60: 731-739, 2003

REZIME

UTICAJ HIDRAULIČKOG PRITISKA NA MORFOMETRIJSKU VARIJABILNOST BUBA RIĐE *ELMIS MAUGETII LATREILLE*, 1802 (COLEOPTERA: ELMIDAE)

U radu su prikazani rezultati morfometrijske studije vrste slapoljuba Elmis maugetii, 1802 kao odgovor na hidraulički pritisak. Analizirani su sledeći morfometrijski karakteri vrste: dužina glave, širina protoraksa i ukupna dužina tela, u odnosu na izmerene hidrološke parametre (vodostaj, dubina uzorkovanja i proticaj). Ukupno 155 adultnih jedinki vrste E. maugetii sa šest tipičnih potočnih staništa za slapoljube u Srbiji je analizirano tokom perioda istraživanja (2014-2015 godina). Od izmerenih hidroloških parametara, konstatovano je da jedino proticaj utiče na veličinu jedinki-krupnije jedinke nađene su u potocima koje karakteriše veći proticaj. Glavni cilj studije je da proceni uticaj proticaja na morfometrijsku varijabilnost vrste.

Ključne reči*: slapoljubi, Elmis maugetii, proticaj, brzina, potok, morfometrija*