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DIVERSITY OF AQUATIC INSECTS (HETEROPTERA: NEPOMORPHA, GERROMORPHA AND COLEOPTERA: HYDRADEPHAGA, HYDROPHILIDAE) IN THE KARST AREA OF GORSKI KOTAR, CROATIA

Nataša Turić*, Enrih Merdić, Branimir Hackenberger Kutuzović, Željka Jeličić & Tomislav Bogdanović

Department of Biology, J. J. Strossmayer University in Osijek,
Trg Ljudevita Gaja 6, HR – 31000 Osijek, Croatia

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The aim of this study was to determine aquatic insect (Heteroptera: Nepomorpha, Gerromorpha and Coleoptera: Hydradephaga, Hydrophilidae) fauna in two temporary and two permanent ponds and to relate assemblage structure, abundance and diversity with respect to hydroperiod, habitat size, shading of ponds and altitude. Field work was conducted out in four karst ponds in the municipality of Mrkopalj (Gorski kotar) from June to September 2005. Altogether, 247 specimens belonging to 24 species of water bugs and beetles were collected. A large number of species was recorded in the Sungerski lug pond (S1) while great species diversity in relation to abundance was recorded for the Sunger pond (S2).

The occurrence of *Anacena limbata* and *Anacena lutescens* from the family Hydrophilidae and *Hydroporus melanarius* from the family Dytiscidae is an important faunistic result, because they are new to the fauna of Croatia. According to the results of our study, water bugs and beetles prefer large, permanent, open ponds at a lower altitude. The proportion of species differed between temporary and permanent ponds, and temporary and small ponds (S2) had especially diverse fauna of aquatic insects.

Key words: Aquatic Heteroptera, aquatic Coleoptera, diversity, karst ponds, Gorski Kotar

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* corresponding author: nturic@biologija.unios.hr

Hydrophilidae) u krškom području Gorskog kotara, Hrvatska. Nat. Croat., Vol. 20, No. 1., 179–188, 2011, Zagreb.

Cilj ovoga rada je utvrditi faunu vodenih kukaca (Heteroptera: Nepomorpha, Gerromorpha i Coleoptera: Hydradephaga, Hydrophilidae) u stalnim i privremenim lokvama te usporediti sastav, brojnost i raznolikost u odnosu na razdoblje različite razine vode (hidroperiod), veličinu staništa, zasjenjenost svake lokve okolnom vegetacijom i nadmorsku visinu. Istraživanje je provedeno od lipnja do rujna 2005 na dvije stalne i dvije privremene lokve na području općine Mrkopalj (Gorski kotar). Uzorkovano je ukupno 247 jedinki i utvrđene su 24 vrste vodenih stjenica (Heteroptera) i vodenih kornjaša (Coleoptera). Najveći broj vrsta zabilježen je u lokvi Sungerski lug (S1), a najveća raznolikost vrsta u odnosu na brojnost jedinki je zabilježena u lokvi Sunger (S2). Vrste *Anacena limbata* i *Anacena lutescens* iz porodice Hydrophilidae i vrsta *Hydroporus melanarius* iz porodice Dytiscidae su prvi puta zabilježene za faunu Hrvatske. Utvrđeno je da su vodene stjenice i vodeni kornjaši na istraživanom području skloni velikim, stalnim, nezasjenjenim lokvama niže nadmorske visine. Udio vrsta se razlikovao između trajnih i privremenih lokvi, te je najveća raznolikost utvrđena unutar male i privremene lokve (S2).

Ključne riječi: vodene stjenice, vodeni kornjaši, raznolikost, krške lokve, Gorski Kotar

INTRODUCTION

Aquatic bugs and beetles (Heteroptera and Coleoptera, Insecta) can be found in almost every freshwater biotope. They have many morphological adaptations to their aquatic environment, making them excellent subjects for ecological and biogeographic studies (MORENO *et al.*, 1997; RIBERA, 2000; MILLÁN *et al.*, 2006). Temporary and permanent waters represent important habitats for this group. But today, these ecosystems are highly vulnerable to threats related to intensive human influences (BELLA *et al.*, 2005). Additionally, water beetles are important indicators of spatial and temporal changes in the environment. This is why some authors have used them as bio-indicators of habitat quality in terms of nutrient enrichment or the presence of potential pollutants; they are also used for selecting areas for conservation (DAVIS *et al.*, 1987; EYRE & FOSTER, 1989; GONZÁLES & VALLADARES, 1996; HUFNAGEL *et al.*, 1999; SÁNCHEZ-FERNÁNDEZ *et al.*, 2004). Assemblages of water bugs are generally poorer in species than those of water beetles, and seem to be more resilient to environmental changes (ROBACK, 1974; EYRE & FOSTER, 1989; TULY *et al.*, 1991; KARAOUZAS & GRITZALIS, 2006). The relation between water beetle assemblage and habitat features (e. g. hydroperiod, shading, size of water bodies, water chemistry, macrophytes structure) has been studied all over Europe (FAIRCHILD *et al.*, 2000; LUNDKVIST *et al.*, 2001; BELLA *et al.*, 2005; TEMUNOVIĆ *et al.*, 2007), while no such study has ever been performed in the karst area of Gorski Kotar.

Faunal research into water bugs has been less intensive than research into land-inhabiting true bugs in Croatia. Such research was carried out by STRPIĆ (1996, 1997) in the Kvarner region (islands of Krk, Prvić, Rab and Mljet) in the northern Adriatic, Turopolje and Hrvatsko Zagorje in Central Croatia. Recently, water bugs (Nepomorpha and Gerromorpha) have been researched on the wider area and flooded area of Kopački rit Nature Park (MERDIĆ *et al.*, 2005; TURIĆ *et al.*, 2010). Additionally, water beetle fauna is poorly explored in Croatia. The first published research, dating from the beginning of the 20th century, was performed by Koča Gjuro. This research was carried out in East Croatia, the Vinkovci and Papuk region (KOČA, 1900; 1906). Also, faunal research in Croatia was conducted by NOVAK

(1952) within the context of research into the beetle fauna in Dalmatia and the surrounding islands, while research into the Hydradephaga fauna of the northern Adriatic islands (Krk, Rab, Pag, Cres, Lošinj, Unije) was performed by FRANCISCOLO (1972; 1978). All known data about water beetles in Croatia published before 1971 are collected in the Catalogues Fauna Jugoslaviae (GUÉORGUIEV, 1971). Recently, water bug and beetle fauna have been investigated on the wider and the flooded areas of Kopački rit Nature Park (MERDIĆ *et al.*, 2005, TURIĆ *et al.*, 2008; 2010) and in temporary ponds of Lonjsko polje Nature Park (TEMUNOVIĆ *et al.*, 2007).

The aim of this research was to determine aquatic insect (Heteroptera: Nepomorpha, Gerromorpha and Coleoptera: Hydradephaga, Hydrophiloidea) fauna in two temporary and two permanent karst ponds located in the municipality of Mrkopalj (Gorski kotar) and to relate assemblage structure, diversity and abundance with respect to hydroperiod, habitat size, shading of ponds and altitude. According to these, we could evaluate karst ponds as different types of habitats for aquatic insects and how these environmental characteristics make an influence on them.

MATERIAL AND METHODS

For this study two temporary and two permanent karst ponds were selected which are located in the municipality of Mrkopalj, Gorski kotar (Fig. 1). Gorski kotar is a mountain region of Croatia. It is surrounded by the mountains Kapela, Klek, Risnjak, Snježnik, Bjelolasica and the rivers Kupa, Čabranka and Dobra. The area of Gorski Kotar covers ca 2000 square kilometers and this area is the rainiest area in Croatia. The researched ponds varied in size, shading by surrounding vege-

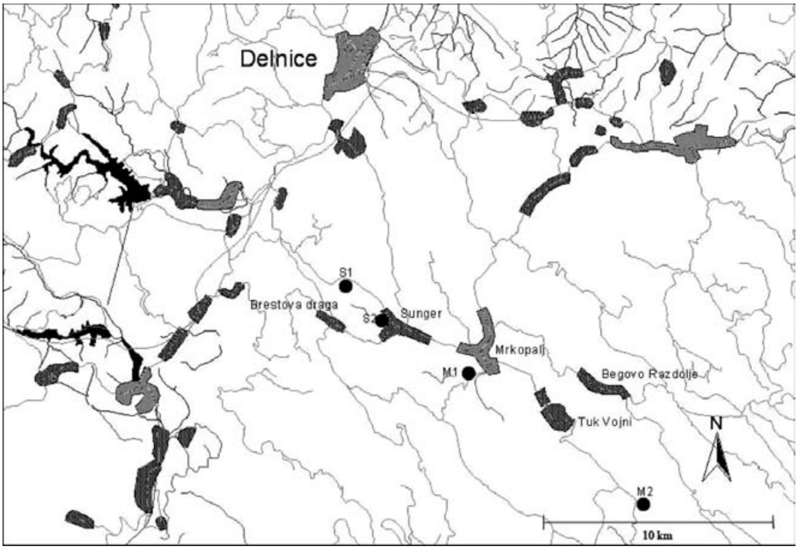

Fig. 1. Map of study site with the four research ponds in the municipality of Mrkopalj (Gorski kotar, Croatia); (ponds: S1 – Sungerski lug, S2 – Sunger, M1 – Mrkopalj and M2 – Matić poljana)

tation and water permanence (hydroperiod), which is influenced by precipitation. According to these characteristics the ponds were classified into two categories: a small and open pond, with low density of neighboring trees and a large pond shaded by trees. A brief description of ponds is given below.

Pond S1 – Sungerski lug (N 45° 20' 09'' E 14° 47' 46''); altitude 780.2 m; large pond, located on the edge of the silver fir forest (association *Blechno-Abietetum* Ht. (1938) 1950)), therefore its surface is partially shaded.

Pond S2 – Sunger (45° 19' 25'' E 14° 48' 56''); altitude 788 m; small pond and completely open surface. The bottom of pond is not muddy and the water is transparent to the bottom. In August the water level of that pond was very low.

Pond M1 – Mrkopalj (N 45° 18' 27'' E 14° 50' 53''); altitude 846 m; small pond and completely open surface, although situated near the forest. In August, the pond dries out.

Pond M2 – Matić poljana (N 45° 16' 01'' E 14° 54' 58''); altitude 1037 m; large pond, located in the forest with a completely shaded surface.

Only the large ponds S1 and M2 have a belt of aquatic plants around the shore. These ponds are small water bodies with a thin layer of organic matter on the bottom, because they are situated in a karst area of Croatia.

Field work was carried out once a month from June to September. The samples were collected using semiquantitative method of sweeping with a dip net and strainer from sturdy material (50 µm mesh). Each sampling consisted of strokes on the waterline affecting the aquatic and sub-aquatic vegetation of the littoral zone and lightly into the substratum to cover all available habitats. Sampling collection generally took 30 min per site. Samples were preserved in 70% ethanol and taken to the laboratory for identification. The following keys were used for identification: CSABAI (2000), CSABAI *et al.* (2002), HEBAUER & KLAUSNITZER (1998), NILSSON (1996), KLAUSNITZER (1996), DROST *et al.* (1992) and MACAN (1976). All specimens were labelled and stored in the insect collections of the Department of Biology at the Josip Juraj Strossmayer University in Osijek.

The Shannon (H) and Simpson (D) indices were used to test faunal diversity of Heteroptera and Coleoptera species composition between ponds (MAGURRAN, 1988). The estimation of total speciess richness in the four different ponds were calculated using non-parametric estimator one-factorial Jacknife (Jacknife-1). Quantification of cluster membership for all species was performed using hierarchical clustering procedure (MAECHLER *et al.*, 2005) and a dendogram was constructed to visualize the similarities and dissimilarities in assemblages between ponds. The analyses were made using R statistical environment package (R-Development Core Team, 2009). Additionally, the altitude of each pond was estimated by utilizing the digital contour map of Gorski kotar in ArcView.

RESULTS AND DISCUSSION

Fauna of aquatic insects in karst ponds

In the period from June to September 2005, 247 adults were collected and 24 species of aquatic insects (Heteroptera: Nepomorpha, Gerromorpha and Coleoptera:

Hydradephaga, Hydrophiloidea) were identified. Within 183 specimens collected and classified into 8 genera and 13 species, the family Dytiscidae has the highest species richness and abundance followed by the family Notonectidae with 5 species, the family Hydrophilidae with 3 species, the family Gerridae with 2 species and finally the families Haliplidae, Noteridae and Gyrinidae with one species each, *Haliplus heydeni*, *Noterus clavicornis* and *Gyrinus distinctus*. Water beetles (Coleoptera) are often amongst the most abundant insects in water habitats, making them very useful in conservation assessment. The order Heteroptera was represented by only seven species because many water bugs show distinct preferences in terms of water chemistry and habitat structure (e. g. amount of vegetation or successional stage). Although the family Corixidae is the most numerous family within the order Heteroptera, not a single specimen was sampled in this study. However, a number of publications indicate that Corixidae seem to have clearly defined habitat demands. For example, the distribution of corixids was found to correlate with the percentage of organic material in the sediment (MACAN 1976), electrical conductivity and shape of the water body (SAVAGE, 1982), water hardness (TULLY *et al.*, 1991) and vegetation (TULLY, 1991; MACAN, 1976; NOSEK *et al.*, 2007).

Among valuable faunal data are records of species *Anacaena limbata* (Fabricius, 1792) and *Anacaena lutescens* (Stephens, 1829) from the family Hydrophilidae and *Hydroporus melanarius* (Sturm, 1835) from the family Dytiscidae (Tab. 1). These are the first records of these species in Croatia. The species *Anacaena limbata* and *Anacaena lutescens* are widespread and very common in the entire Palaeartic Region and introduced to the Nearctic Region (HANSEN, 2004). They inhabit various types of standing waters but *A. lutescens* probably avoids temporary habitats (BOUKAL *et al.*, 2007). *Hydroporus melanarius* is a Euro-Siberian species distributed in northern and central Europe and western Siberia, reaching France, northern Italy, and the former Yugoslavia in southern Europe (NILSSON & HOLMEN, 1995). It occurs often in small peaty fens and in peat bogs (BOUKAL *et al.*, 2007), such as pond S1 where we sampled this species.

A systematic list of water bug (Heteroptera) and water beetle (Coleoptera) species was made according to NILSSON (1996), CSABAI (2000) and CSABAI (2002) (Tab. 1).

Diversity of aquatic assemblage in karst ponds

Differences were observed in the species composition, abundance and diversity of water bug and water beetle fauna in the four karst ponds. The highest species richness (68,18% of all species) as well as the highest abundance (41,06% of all species) were recorded for pond S1 (Tab. 2). Of 24 identified species of water bugs and beetles, four species were recorded exclusively in that pond, three species exclusively in pond M1, two in pond S2 and none in pond M2. Two species were found in all four ponds while nine species were recorded just once during the sampling period (Tab. 2). Water bugs *Gerris lacustris* and *Notonecta viridis* were the only species sampled at all ponds. These species are widely distributed, very common and abundant all over Europe (MACAN, 1976). Also, the second name for *Gerris lacustris* is »common pond skater« and Notonectidae act as pioneer species in ponds (BLOECHL *et al.*, 2010). In these ponds, which representing smaller water bodies, the genus *Hydroporus* was the most common and the most abundant of all *Hydroporus* species was *Hydroporus planus*. This species occurred in three ponds and is most abundant species in pond S1

(45,54% of all specimens). It is generally widespread, occurring across almost all of Europe, with a preference for puddles and small water bodies without a layer of organic matter on the bottom (NILSSON & HOLMEN, 1995; BOUKAL, 2007), such as the researched karst ponds. Similar results were found in TEMUNOVIĆ *et al.* (2007) wherethe genus *Hydroporus* was also common in all investigated ponds in continental Croatia, but the most abundant species was *Hydroporus palustris* with a preference for eutrophic permanent water bodies. Our results confirmed that Hydradephaga fauna assemblages are clearly different in the ponds in karst and in continental Croatia.

One of the main parameters influencing water bug and water beetle species richness and composition is the degree of water permanence or the hydroperiod (LUNDKVIST *et al.*, 2001; RUNDLE *et al.*, 2002). The highest species richness and abundance were recorded for pond S1 (Fig. 2) which is a permanent pond with constant water level throughout the year and represents a stable environment for aquatic insects. Several studies pointed out the importance of habitats with a longer hydroperiod, because they provide a longer period for colonisation and water beetles prefer more permanent ponds (RUNDLE *et al.*, 2002; TEMUNOVIĆ *et al.*, 2007). But the perma-

Tab. 1. Systematic list of aquatic insect (Heteroptera: Nepomorpha, Gerromorpha and Coleoptera: Hydradephaga) species present in ponds of Mrkopalj, Gorski kotar

HETEROPTERA	**Hydroporus (s. str.)** Clairville, 1806
Family: GERRIDAE	• *Hydroporus planus* (Fabricius, 1781)
Subfamily**: Gerrinae**	• *Hydroporus palustris* (Linnaeus, 1761)
Gerris Fabricius, 1784	• *Hydroporus erytrocephalus* (Linnaeus, 1758)
• *Gerris lacustris* (Linné, 1758)	• *Hydroporus pubescens* (Gyllenhal, 1808)
• *Gerris odontogaster* (Zettersted, 1828)	• *Hydroporus melanarius* (Sturm, 1835)
Family: NOTONECTIDAE	Subfamily: **Laccophilinae**
Subfamily: **Notonectinae**	***Laccophilus*** Leach, 1817
Notonecta Linnaeus, 1758	• *Laccophilus minutus* (Linnaeus, 1758)
• *Notonecta glauca* (Linnaeus, 1758)	Subfamily: **Colymbetinae**
• *Notonecta maculata* (Fabricius, 1794)	***Colymbetes*** Clairville, 1806
• *Notonecta lutea* (Mueller, 1776)	• *Colymbetes fuscus* (Linnaeus, 1758)
• *Notonecta oblique* (Thunberg, 1787)	**Agabus** Leach, 1817
• *Notonecta viridis* (Delcourt, 1909)	• *Agabus bipustulatus* (Linnaeus, 1767)
COLEOPTERA	• *Agabus nebulosus* (Forster, 1771)
Family: HALIPLIDAE	Subfamily: **Dytiscinae**
Haliplus Latreille, 1802	***Acilius*** Leach, 1817
• *Haliplus heydeni* (Wehncke, 1875)	• *Acilius sulcatus* (Linnaeus, 1758)
Family: NOTERIDAE	***Dytiscus*** Linnaeus, 1758
Noterus Clairville, 1806	• *Dytiscus marginalis* (Linnaeus, 1758)
• *Noterus clavicornis* (De Geer, 1774)	Family: HYDROPHILIDAE
Family: GYRINIDAE	Subfamily: **Hydrophilinae**
Subfamily: **Gyrininae**	***Anacaena*** Thomson, 1859
Gyrinus Müller, 1867	• *Anacaena limbata* (Fabricius, 1792)
• *Gyrinus distinctus* (Aubé, 1836)	• *Anacaena lutescens* (Stephens, 1829)
Family: DYTISCIDAE	***Hydrobius*** Leach, 1815
Subfamily: **Hydroporinae**	• *Hydrobius fuscipes* (Linnaeus, 1758)

Tab. 2. Abundance of aquatic insects in karst ponds of Gorski kotar

POND	**S1**	**S2**	**M1**	**M2**	**Σ**
Species					
Gerris lacustris	8	4	18	18	48
Gerris odontogaster	0	1	1	0	2
Notonecta glauca	2	1	4	0	7
Notonecta maculata	0	0	1	0	1
Notonecta lutea	0	0	1	0	1
Notonecta obliqua	0	1	0	1	2
Notonecta viridis	2	1	13	3	19
Hydroporus planus	46	5	0	2	53
Hydroporus palustris	17	0	0	0	17
Hydroporus melanarius	1	0	0	0	1
Hydroporus pubescens	1	0	0	0	1
Hydroporus erythrocephalus	2	2	0	0	4
Agabus bipustulatus	12	18	0	9	39
Agabus nebulosus	1	0	0	1	2
Hydrobius fuscipes	3	0	0	0	10
Gyrinus distinctus	0	0	0	0	0
Haliplus heydeni	2	0	0	0	2
Anacena limbata	2	1	0	0	14
Anacena lutescens	1	0	0	7	8
Acillius sulcatus	1	5	3	0	9
Laccophilus minutus	0	1	0	0	1
Dytiscus marginalis	0	8	0	0	8
Colymbetes fuscus	1	1	0	0	2
Noterus clavicornis	0	0	14	0	14
Σ specimens	**102**	**49**	**55**	**41**	**247**
Total number of species	**16**	**13**	**8**	**7**	

nent pond M2 has fewer species than pond S1 (Tab. 2 and Fig. 2). The former pond is located at the highest altitude in a dense forest and this could be a possible explanation for the smaller number of species. The experiments of WE *et al.* (2002) confirm this; they found that altitude as a geographical parameter is the major factor correlated with bug and beetle distribution. Generally, the number of species is higher in open habitats because one of the most important factors for dispersal by flying aquatic insects is the polarotactic detectability of water bodies (CSABAI *et al.*, 2006) which has a positive influence on colonization (LUNDKVIST *et al.*, 2001). The greatest diversity of species was found at pond S2 with 13 species (Tab. 2), although it is a small, temporary pond. The water beetle assemblage of that pond is characterized by very active species of Dytiscidae (*Dytiscus marginalis* and *Agabus bipustulatus*). Both commonly used indices, Shannon and Simpson's, showed greater values for this pond according to results from Tab. 3. Estimator (one-factorial Jackknife) was used to improve the index estimates (Tab. 3). However, it was found out

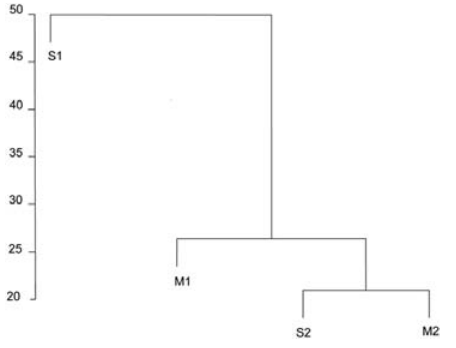

Fig. 2. Dendrogram showing the classification of ponds by the similarity of their faunal inventories. For abbreviations, see Fig. 1.

Tab. 3. Comparison of richness, abundance, diversity indices and estimator from the four ponds including total values

Ponds	Mark of pond	Richness	Abundance	Shannon	Simpson	Jack 1
Sungerski lug	S1	16	102	1,83	0,741	18
Sunger	S2	13	49	2,02	0,806	20
Mrkopalj	M1	8	55	1,62	0,763	19
Matić poljana	M2	7	41	1,52	0,721	22

that a notable difference exists between the true collected species richness in the ponds we explored (24 species), and the number of species that we can expect to collect with reasonable effort (36). A longer sampling period is necessary to investigate the whole fauna of water bugs and beetles in these ponds and factors influencing the assemblage structure. How, an important consequence for conservation has already been shown, which is that the karst ponds, as habitats for water bugs and beetles, play a crucial role in the preservation of biodiversity.

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