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LIGHT-TRAPPED CADDISFLIES (INSECTA: TRICHOPTERA) AS INDICATORS OF THE ECOLOGICAL INTEGRITY OF THE LIŠTICA RIVER, BOSNIA AND HERZEGOVINA

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A study of caddisfly biodiversity and its application for use as indicator species to assess the ecological integrity of aquatic environments was conducted in the area of the Lištica River, Bosnia and Herzegovina. A portable UV light-trap was used to collect caddisflies at two sites: the spring of Lištica - Bilo Vrilo and the middle reach of this river in a karstic depression - Mostarsko Blato. From March 2003 to March 2004 a total of 4334 individuals, representing 34 species, were caught. There were significant differences in species composition and abundance between sampling sites. The flight periods are shown for all recorded species and studied in detail for twelve abundant species. The species inventories were used for analysing the longitudinal classification of the sampling sites, composition of functional feeding guilds and the saprobic indices.

Caddisflies, Lištica River, Bosnia and Herzegovina, ecological integrity

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Istraživana je bioraznolikost tulara rijeke Lištice te primjena njihovih zajednica u procjeni ekološkog statusa vodenih ekosustava. Odrasle jedinke uzorkovane su na dvjema postajama, tj na izvoru rijeke Bilo vrilo i središnjem dijelu toka Lištice, u krškom polju Mostarskom blatu. Materijal je prikupljan godinu dana (ožujak 2003. – ožujak 2004.) metodom lova pomoću UV lampe. Istraživanjima su zabilježene 34 vrste s 4334 uzorkovanih jedinki. Utvrđene su značajne razlike u fauni tulara na dvjema istraživanim postajama, koje su se ogledale u sastavu zajednica i brojnosti uzorkovanih jedinki. U radu je prikazan period aktivnosti svih zabilježenih vrsta te je analizirana sezonska dinamika dvanaest vrsta s najvećim brojem uzorkovanih jedinki. Na temelju sastava zajednica odraslih tulara određeni su indeksi saprobnosti, rasprostranjenost hranidbenih skupina te longitudinalna klasifikacija staništa.

Tulari, Lištica, Bosna i Hercegovina, ekološki status

Introduction

The term "ecological integrity" is frequently used in surface water monitoring programs as a measure of the global condition of aquatic ecosystems (Chatzinikolaou et al., 2008; Oliviera & Cortes, 2006). This approach has been incorporated in the EU 2000/60 Water Framework Directive (WFD), which obliges member states to achieve at least "good quality status" (class II within a five class system) for all surface waters before 2015 (European Union, 2000; Irmer, 2000).

The ecological status of water bodies has to be assessed by comparing the current state of a river with its type-specific reference condition, which should be near pristine and minimally altered by man (European Union, 2000). This approach requires the recording of a variety of parameters in order to detect different types of disturbances (e.g. physicochemical degradation, hydrological fluctuations, physical habitat impairment) (Chatzinikolaou et al., 2008). Disruptions can also be seen by biotic alternations: quantitative and qualitative changes in species assemblage that can lead to either the disappearance of naturally occurring species or the appearance of atypical ones. The most important criteria for the classification of ecological integrity by using biological elements include analyses of species composition and abundance, composition of functional-feeding guilds, shifts in the longitudinal zonation patterns of biocoenotic communities and saprobic indices (Moog, 2002).

Trichoptera represent key species for assessing the ecological status of aquatic habitats (Waringer & Graf, 2006). High species diversity, various ecological and behavioural specializations and very strict environmental requirements, particularly along the longitudinal continuum, make caddisfly larvae excellent study organisms for environmental gradient studies (Bonada, 2004; Holzenthal et al., 2007; Mackay & Wiggins, 1979; Morse, 2003). Since adult caddisflies stay close to their water habitats in most species (Collier & Smith, 1998; Petersen et al., 2004; Svensson, 1972, 1974) and adult assemblages accurately reflect larval assemblages, a proven collecting technique for using caddisflies as environmental indicators is light-trapping (Chantaramongkol, 1983; Malicky & Chantaramongkol, 1993; Schmera, 2003; Smith et al., 2002; Waringer, 1989, 2003; Waringer & Graf, 2006). This method is also useful in faunistic and ecological investigations and allows various aspects such as changes in insect populations, flight patterns, life history etc to be studied (Collier et al., 1997; Crichton et al., 1978; Tsuruishi, 2003).

The present investigation used light-trapping for studying caddisflies of the Lištica River in Herzegovina. The study provides information on the species composition, phenology and use of caddisfly assemblages for analysing saprobic indices, the composition of functional feeding guilds and stream zonation patterns.

Material and Methods

The study was conducted in the area of the Lištica River, situated in southwestern Bosnia and Herzegovina. Lištica is a perennial karst river; its springs are located in the vicinity of the town of Široki Brijeg and its sinkholes are located on the eastern part of the karstic field Mostarsko Blato. Due to its geographical location, this area is characterized by a sub-Mediterranean climate, i.e. temperate warm humid climate with hot summers (Cfa), according to the Köppen's climatic classification (Miličević, 2009).

The study was carried out at two sampling sites: the spring of the Lištica, Bilo Vrilo (L1), and the middle reach of this river (L2). Bilo Vrilo is the lowest of the six springs of the Lištica River, located at an altitude of 297 m. It is rheocrene-type karst spring, which is used as a source of drinking water; the associated construction works did not significantly alter the habitat. The second site is located in the central part of the karstic depression Mostarsko Blato, at an altitude of 231 m. This area has been greatly affected by human activity, such as agriculture, water utilization and regulation. All these factors, together with the extraction of gravel and sand from the Lištica riverbed, have negatively affected the river, either directly or indirectly (Miličević, 2009; Zelenika et al., 2005). Physical and chemical parameters of the water at the sampling sites are presented in Table 1.

Adult caddisflies were collected using an ultraviolet light trap from March 2003 to March 2004. The light trap, which was placed within 1 m of the stream edge, was operated for two hours every fifteen days at both sites. The collected

Table 1. Characteristics of the two sampling sites of the Lištica River (L1 –Bilo Vrilo spring, L2 – middle reach of the river).

Site	L1	L2
Elevation (m)	297	231
Latitude	N 43°23′43,3″	N 43°21′11,8″
Longitude	E 17°35′46,2″	E 17°40′32,8″
Substrate composition	stones, gravel	stones, gravel, sand
Water temperature (°C) min/max	8,5/10,2	9,2/13,2
Dissolved O_2 (mg/l) min/max	9,70/14,09	5,14/10,83
Oxygen saturation (%) min/max	89,1/124,3	45,8/103,5
Conductivity (µS/cm) min/max	342/525	356/495
pH min/max	7,09/7,74	6,2/8,17
Dissolved CO_2 (mg/l) min/max	22,0/92,4	17,6/57,2
Alkalinity (mg$CaCO_3$/l) min/max	127,6/210,0	153,0/190,0
Total suspended solids – 105°C* (mg/l)	256,0	202,0
Total dissolved solids - 180°C* (mg/l)	142,0	194,0
Total hardness* (mg$CaCO_3$/l)	201,5	236,5
Consumption of $KMnO_4$* (mg/l)	0,62	1,18
Chemical oxygen demand* (mg/l)	3,1	7,3
Chloride* (mg/l)	5,49	5,95
Phosphate* (mg/l)	0,0	< 0,01
Ammonia* (mg/l)	0,0	0,0
Nitrite* (µg/l)	0,0	<0,05
Nitrate* (mg/l)	0,0	0,34

(Data unpublished except * Talić *et al.*, 2007)

specimens were preserved in 70 % ethanol in the field, and identified in the laboratory using a SZX 10 stereomicroscope (Olympus, Japan). Identification and the systematic review were based on Malicky (2004, 2005). The nomenclature follows Graf et al., 2008.

Species similarity between samples from both sampling sites was calculated using the Sørensen index (Krebs, 1999) and biocoenotic metrics (saprobic index, longitudinal zonation patterns, functional feeding guilds) based on species-specific indices (Graf et al., 2002, 2008) were calculated using the procedure given by Moog (2002).

Results and Discussion

From March 2003 to March 2004 a total of 4334 specimens were collected by the light trap at two sites at the Lištica River (Table 2). Among the 34 recorded species, 18 were found in the spring Bilo Vrilo (L1) and 23 species were caught in the middle reach of the Lištica (L2). The composition of the caddisfly fauna between L1 and L2 differed considerably; only 7 species were common to both sites. Thus, the Sørensen similarity index between the two sampling sites was low (34 %).

At the sampling site in the spring of the Lištica River a total of 629 specimens were collected (Table 2). Sixty-one percent of the total catch consisted of three species: *Drusus ramae* Marinković, 1970, *Glossosoma bifidum* McLachlan, 1879 and *Rhyacophila balcanica* Radovanović, 1953. The most abundant species was *D. ramae* with 149 specimens collected. This species belongs to the group of 13 endemic caddisfly taxa of Bosnia and Herzegovina (Stanić-Koštroman, 2009). The spring area of the Lištica River is the only currently known population of *D. ramae*, because the spring of the Rama River, the *locus typicus* of this species,

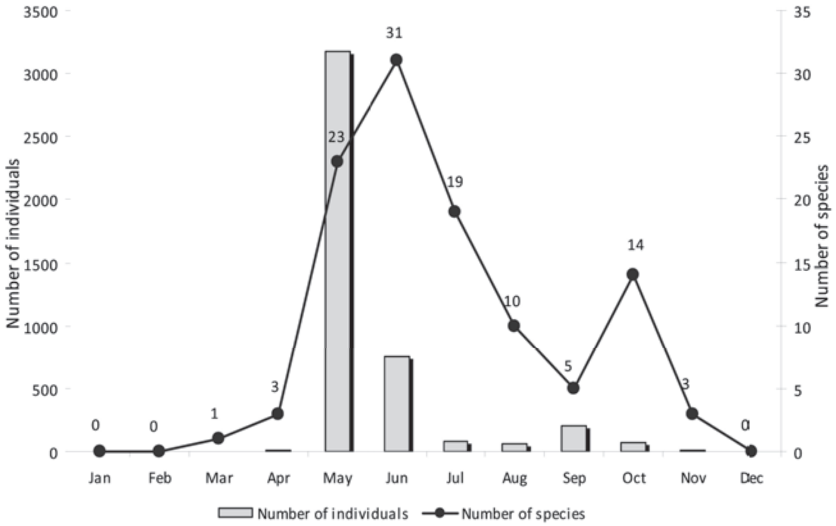


Figure 1. The total number of species and individuals caught at the two sampling sites in the Lištica River.

Table 2. Caddisfly species caught by a light trap at two sites of the Lištica River (L1 – Bilo Vrilo spring, L2 – middle reach of the river) with temporal distribution of each species.

Species	Sampling sites		Flight period
	L1	L2	
Rhyacophila balcanica Radovanović, 1953*	104		29 May – 20 Nov
Rhyacophila fasciata fasciata Hagen, 1859*	41	20	12 Apr – 20 Nov
Rhyacophila loxias Schmid, 1970	5		29 May – 15 Jul
Glossosoma bifidum McLachlan, 1879*	131		12 Apr – 25 Sep
Hydroptila forcipata (Eaton, 1873)*		196	14 May – 17 Sep
Agraylea sexmaculata Curtis, 1834*		114	27 Jun – 17 Sep
Cyrnus trimaculatus (Curtis, 1834)		1	18 Aug
Polycentropus flavomaculatus flavomaculatus (Pictet, 1834)*	7	176	14 May – 29. Aug
Plectrocnemia conspersa conspersa (Curtis, 1834)	24	2	13 Jun – 25 Sep
Lype reducta (Hagen, 1868)		3	27 Jun – 3 Oct
Psychomyia klapaleki Malicky, 1995*		302	14 May – 27 Jun
Tinodes braueri McLachlan, 1878		12	29 May – 19 Oct
Tinodes rostocki McLachlan, 1878*	69		29 May – 27 Jun
Hydropsyche instabilis (Curtis, 1834)		2	29 May – 13 Jun
Hydropsyche mostarensis Klapálek, 1898	3		13 Jun – 15 Jul
Hydropsyche saxonica McLachlan, 1884		22	14 May – 31 Jul
Hydropsyche spp. (females)		9	14 May – 18 Aug
Agrypnia varia Fabricius, 1793		12	13 Jun – 29 Aug
Micrasema minimum McLachlan, 1876	2		13 Jun
Goera pilosa (Fabricius, 1775)*		522	29 Apr – 18 Aug
Silo piceus (Brauer, 1857)*		2178	14 May – 27 Jun
Drusus ramae Marinković, 1970*	149		14 May – 27 Jun
Limnephilus lunatus Curtis, 1834		21	29 May
Limnephilus marmoratus Curtis, 1834		7	29 May
Limnephilus rhombicus rhombicus (Linnaeus, 1758)		43	29 May – 19 Oct
Halesus digitatus digitatus (Schrank, 1781)	3	5	3 Oct – 19 Oct
Micropterna nycterobia (McLachlan, 1875)	1	5	3 Oct – 19 Oct
Micropterna sequax (McLachlan, 1875)	2		13 Jun – 28 Oct
Micropterna testacea (Gmelin, 1790)	1		15 Oct
Potamophylax latipennis (Curtis, 1834)	4		14 May – 13 Jun
Sericostoma flavicorne Schneider, 1845*	50	41	14 May – 15 Jul
Odontocerum albicorne (Scopoli, 1763)	31		14 May – 15 Jul

Table 2. continued

Beraeamyia schmidi Botosaneanu, 1960		6	29 May – 13 Jul
Mystacides azurea (Linnaeus, 1761)		5	27 Jun – 29 Aug
Ceraclea dissimilis (Stephens, 1836)	2	1	15 Jul – 31 Jul
Number of specimens	**629**	**3705**	
Number of species	**18**	**23**	

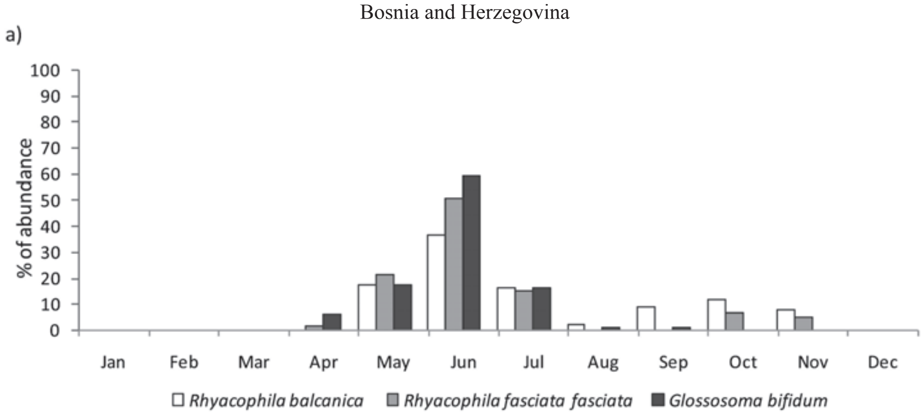
*abundant species (≥ 1% of a total catch)

was completely devastated by the construction of a reservoir during the 1970s (Kučinić et al., 2010). Beside *D. ramae*, two more species caught in the spring of the Lištica – Bilo vrilo: *R. balcanica* and *Hydropsyche mostarensis* Klapàlek, 1898 are endemic for the Balkan Peninsula (Stanić-Koštroman, 2009). The documentation of *H. mostarensis* represents the first record for the caddisfly fauna of the Lištica River spring area (Marinović-Gospodnetić, 1979).

A total of 3705 specimens belonging to 23 species were collected at the site in the middle reach of the Lištica River (Table 2). The most abundant species at this site were *Silo piceus* (Brauer, 1857) and *Goera pilosa* (Fabricius, 1775). These two species accounted for 73 % of the total catch, of which *S. piceus* alone accounted for 59 %. *Agraylea sexmaculata* Curtis, 1834 is recorded for the first time in Bosnia and Herzegovina (Stanić-Koštroman, 2009).

The flight patterns of the species collected are shown in Table 2. Adult caddisflies were caught from March to November, with flight peaks observed during the warmer spring/summer months (Fig. 1). The highest number of species was recorded in June (27 species), and the greatest numbers of individuals were light-trapped in May (73 % of the total catch). According to the classifications proposed by Crichton (in Hickin, 1967), *Halesus digitatus digitatus* (Schrank, 1781), *Micropterna nycterobia* (McLachlan, 1875) and *Micropterna testacea* (Gmelin, 1790) are autumn species, with flight periods restricted to October. All others species identified during this study had either spring or summer flight activity (Table 2).

For the most abundant species (≥ 1 % of a total catch) similar temporal flight patterns were recorded, with catches peaking in summer (Fig. 2a-d). However, in *Agraylea sexmaculata* the maximum number of specimens was caught in September. In most species, a single peak was observed, although in *A. sexmaculata* and *Hydroptila forcipata* (Eaton, 1873) there were two peaks; one in June and a later one in September. Short flying seasons of 3 months or less were recorded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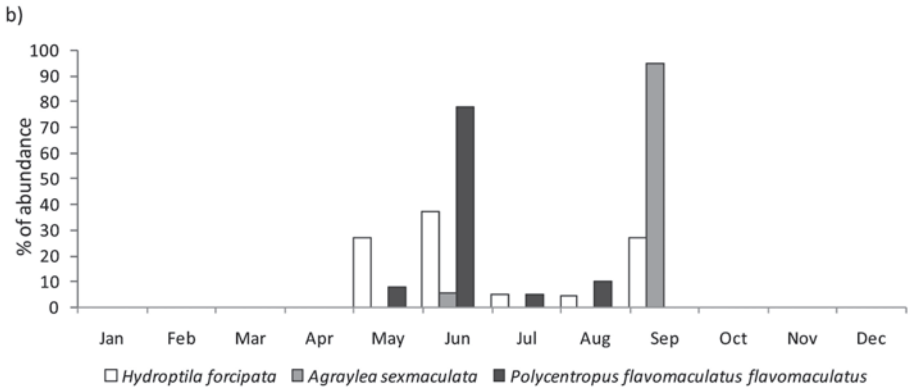
Rhyacophila balcanica
Rhyacophila fasciata fasciata
Glossosoma bifidum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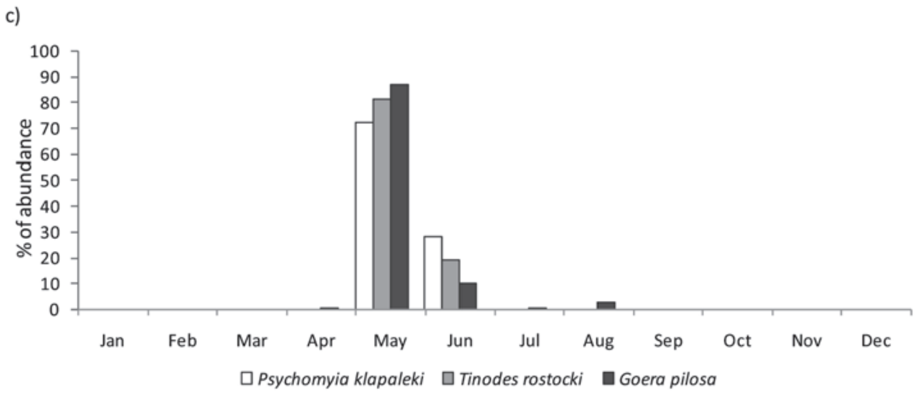
Hydroptila forcipata
Agraylea sexmaculata
Polycentropus flavomaculatus flavomaculatus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Psychomyia klapaleki
Tinodes rostocki
Goera pilosa

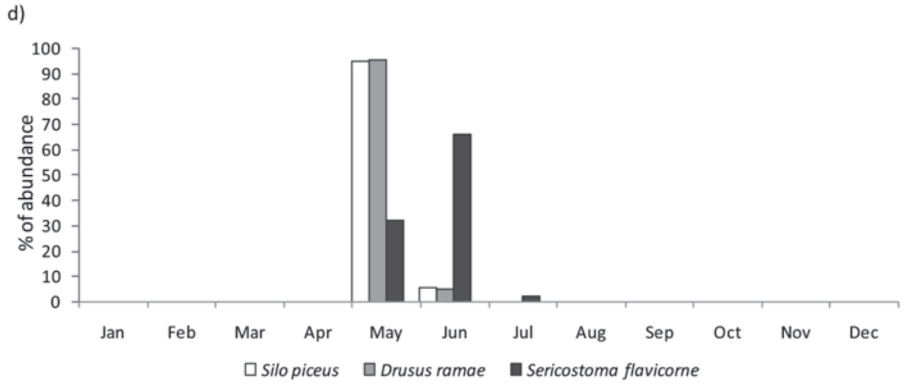
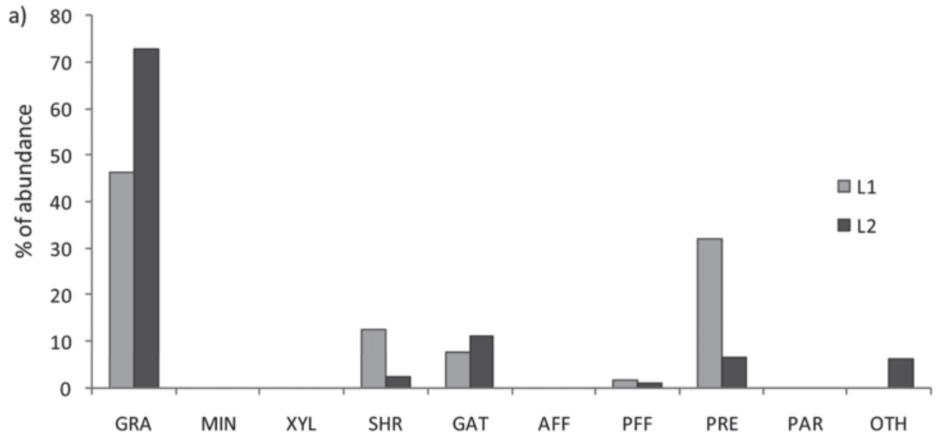


Figure 2. Flight activity of the twelve most abundant species (≥ 1% of a total catch) of Trichoptera.

for *Psychomya klapaleki* Malicky, 1995, *Tinodes rostocki*, McLachlan, 1878, *Silo piceus, Drusus ramae* and *Sericostoma flavicorne* Schneider, 1845, whereas the remaining species had flight activities of 4 months or more. The longest flight periods were observed in *Rhyacophila balcanica* and *R. fasciata fasciata* Hagen, 1859. These two species were on the wing for 7 and 8 months, respectively.

Variability in the length of flight periods may be the consequence of the sampling method, or be caused by the differences in the life cycles of species (Collier & Smith, 1998; Petersen et al., 1999; Smith et al., 2002; Waringer, 1989). Diverse life history patterns have evolved to enable species to exploit foods that are seasonably available, to use an appropriate timing for aerial existence, to evade unfavorable conditions or to avoid biotic interaction such as competition and predation (Wallace & Anderson, 1996). A relationship between duration of flight period and feeding behavior of larvae was confirmed by many authors (e.g. Otto, 1981; Previšić et al., 2007; Smith et al., 2002). In this study, caddisflies with predatory or net-spinning larvae (Rhyacophilidae, Polycentropodidae, Hydropsychidae) exhibited extended flight periods. For both these groups food availability (e.g. prey and fine particulate organic matter-FPOM) is relatively constant the whole year through (Otto, 1981). In contrast, reduced flight periods (Psychomyiidae, Goeridae, Limnephilidae, Sericostomatidae) were generally observed in grazers (feeding on algae) or shredders (feeding on fallen leaves), reflecting the seaso-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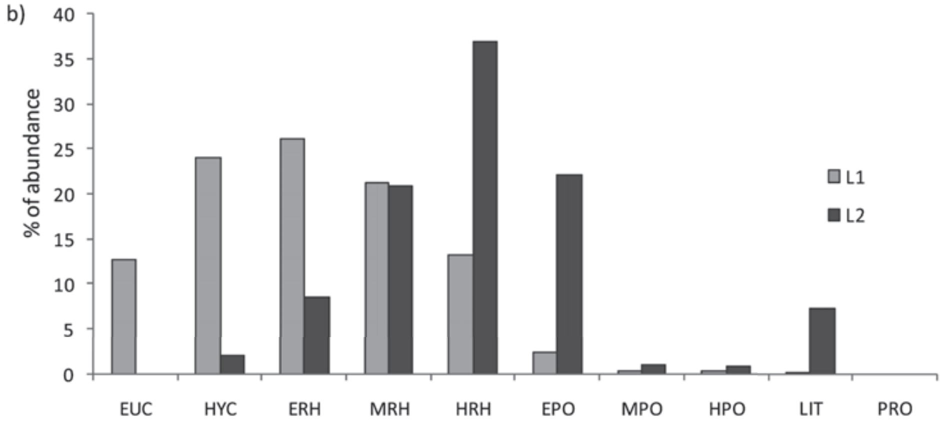
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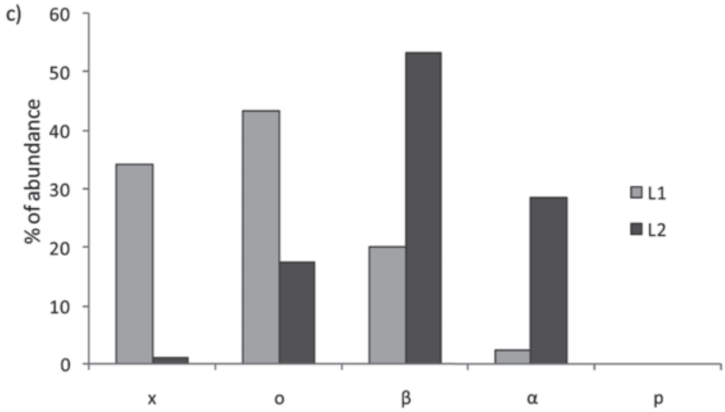

Figure 3. Composition of caddisfly assemblages at two sampling sites at the Lištica River (L1 – spring of the Lištica River; L2 – middle reach of the Lištica River) regarding: (a) Distribution of functional feeding guilds (GRA – grazers, MIN – miners, XYL – xylophagous species, SHR – shredders, GAT – gatherers, AFF – active filter feeders, PFF – passive filter feeders, PRE – predators, PAR – parasites, OTH – other feeding types); (b) Longitudinal zonation preference of caddisflies (EUC – eucrenal, HYC – hypocrenal, ERH – epirhithral, MRH – metarhithral, HRH – hyporhithral, EPO – epipotamal, MPO – metapotamal, HPO – hypopotamal, LIT – littoral, PRO – profundal) and (c) Saprobic valencies based on caddisfly species (x – xenosaprobic, o – oligosaprobic, β – beta-mesosaprobic, α – alpha-mesosaprobic, p – polysaprobic).

nal availability of food resources. According to Otto (1981), the prolonged flight periods recorded for some species of grazers and shredders (e.g. *G. bifidum*, *G. pilosa, L. rhombicus rhombicus* (Linnaeus, 1758), *M. sequax* (McLachlan, 1875)) in the current study may be caused by potentially long periods of emergence or adult longevity.

With respect to functional feeding guilds, the caddisfly assemblages at both sampling sites of the Lištica River were dominated by grazers (Fig. 3a). At the Lištica spring grazers accounted for 46 % and were represented mainly by *D. ramae* and *G. bifidum*. Predators represented by *Rhyacophila* species and shredders represented by *S. flavicorne* also accounted for a relatively large proportion of the collection (32 % and 12 %, respectively). In the middle reach of the Lištica River grazers made up to 73 % of the total catch, reflecting the high proportion of *S. piceus* and *G. pilosa*. The second and third most abundant feeding groups were gatherers (11 %) and predators (7 %).

The composition of functional feeding guilds reflects differences in habitat diversity and the shift in food availability along the river continuum (Vannote et al., 1980). According to the river continuum concept (RCC; Vannote et al., 1980) many headwater streams are strongly affected by the surrounding vegetation, resulting in communities dominated by shredders. However, in unshaded regions, such as the Bilo Vrilo spring area, primary production is not limited by riparian vegetation and grazers are the most abundant feeding group (Previšić et al., 2007; Stanić-Koštroman, 2009; Vannote et al., 1980). Patterns in the longitudinal variation of functional feeding guild composition at two sites of the Lištica River meet the predictions made by the RCC. Caddisfly assemblages at both sampling sites are dominated by grazers, with the proportion increasing downstream. The percentage of shredders declined from the spring to the middle reaches of the river; in contrast, the proportion of gatherers gradually increases, reflecting the shift from coarse to fine particulate organic matter.

The distribution of organisms, resources and biological processes depends on large-scale processes (e.g. climatic, hydrological, geomorphological) as well as local ones (e.g. biotic) (Giller & Malmqvist, 1988; Johnson et al., 2004; Ricklefs, 1987; Wagner et al., 2000). The stream zonation concept (Illies & Botosaneanu, 1963) defines a series of distinct regions along rivers: crenon, rhithron and potamon, mainly according to the distribution of animal species, but also according to temperature, discharge, water velocity and sediment particle size. The longitudinal classification of the Lištica River based on species-specific zonal distribution patterns is shown in Fig. 3b. Using the calculation procedure described by Moog (2002), both sampling sites can be classified as rhithral. At the spring Bilo Vrilo the most abundant were epirhithral species (26 %). Crenal (hypocrenal and eucrenal) species, represented mainly by *D. ramae*, also accounted for high proportions (13 % and 24 %, respectively). In the middle reach of the Lištica the benthic community was dominated by hyporhithral elements (37 %), followed by epipotamal (22 %) and metharithral (21 %) species. These results fit well with the annual range of minimum and maximum water temperatures and substrate composition (Table 1), which are the most useful abiotic indicators for longitudinal river zones (Moog, 2002).

Over the last decades, light trapping of caddisflies has also been used to monitor water quality. In this study, from among the 34 species collected, 20 species have been classified in saprobic systems (Graf et al, 2002) and were used as indicators of water quality (Fig. 3c). At the spring of the Lištica River 17 % of the species were xenosaprobic and 54 % oligosaprobic; 29 % of the species were also indicative of beta-mesosaprobic and alpha-mesosaprobic conditions (27 % and 2 %, respectively) and may have come from outside the Bilo Vrilo spring area. The calculated saprobic index of the site is 1.16. In the middle reach of the Lištica River beta-mesosaprobic and alpha mesosaprobic species (54 % and 29 %, respectively) were most abundant, with the rest (17 %) consisting of oligosaprobic and xenosaprobic elements. The saprobic index of this site is 2.12.

The results of this study showed that the water quality in the spring of the Lištica River is high, which is in agreement with physico-chemical characteristics of the water. All descriptors of the caddisfly assemblages (species inventory, abundances, longitudinal zonation and composition of functional-feeding guilds) conform to the site-specific reference state, so this site can be qualified as pristine. Since the water is used as drinking water and also because the spring itself is a tourist attraction, nature conservation and environmental protection along with landscape management are indispensable. However, measures of the biotic elements in the middle reach of the Lištica River indicated that the water at this site is moderately polluted. Since the longitudinal and functional feeding group distribution for the most part meet the reference conditions, our results indicate that the Lištica River in Mostarsko Blato can be regarded as slightly to moderately disturbed.

Based on these observations, our findings indicate that light-trapped caddisflies can be used as indicators of the ecological status of water bodies. In order to gain the best insight into community composition and proper allocation of breeding habitats, light traps should ideally be accompanied by other methods, e.g. collection of larvae.

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