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Riverine ground beetles as indicators of inundation frequency of mountain stream: a case study of the Ochotnica Stream, Southern Poland

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Effect of inundation frequency on carabid beetle assemblage structure and organization were studied in single cross-section of mountain stream. A non-metric multidimensional scaling performed on the Bray-Curtis matrix of similarity clearly divided assemblages from lower, flooded at least 1 time per year and upper elevation, flooded every two or more years. Mean species abundance, biomass and mean individual biomass were significantly lower in more frequently disturbed plots. Analyzing infrequently and frequently flooded sites jointly and separately co-occurrence pattern was clearly non-random with c-score values higher than random means, indicating segregation processes even among highly disturbed sites. Twenty nine species were significantly related to flood frequency (IndVal analysis), nine of these were indicators for frequently flooded sites with significantly lower mean body biomass. Our findings confirm the hypothesis of decreasing body size in relation to disturbance in riverine ground beetle assemblages.

Key words: Carabidae, inundation frequency, biomass, mean individual biomass, co-ocurrence, bankfull

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INTRODUCTION

Natural riverine landscapes are the most dynamic and at the same time one of the most heterogenous form of landscapes (Ward et al. 2002, Sadler et al. 2004). The riparian habitats are strongly influenced by hydrological, geomorphological and biological parameters of the channel

(Tockner et al. 2000). Especially the frequency of flood events forms the most dominant environmental characteristic of natural river systems (Robinson et al. 2002). Periodically inundated river banks create a unique environment for specifically adapted flora and fauna (Plachten & Reich 1998, Robinson et al., 2002 Lambets et al. 2008). On a global scale, river banks have specific terrestrial invertebrate fauna, especially carabid beetles (Andersen & Hansen 2005).

Since the ecology and taxonomy of ground beetle species is well-known, and as these small invertebrates have high specialization to habitat requirements and they are easy and cost-effective to survey, and moreover they respond quickly to habitat disturbance and to other species, carabid beetles are often used as bioindicators of environmental changes (Lövei & Sunderland, 1996, Rainio & Niemelä, 2003). The riparian ground beetles have been investigated by several authors (Andersen 1985, Andersen & Hanssen 2005, Van Looy et al. 2005). Bates et al. (2005) and Lambeets et al. (2009) showed that several life-history traits of riverbank carabid species are strongly affected by flood disturbance parameters.

As small invertebrates with a high number of species and diversity in floodplains, they can distinguish between different environmental habitat factors on a very small scale. The various behavioural, morphological and physiological adaptations of riparian carabid beetles are reflected in their wide range of habitat specialization (Lott 1996). Furthermore, many species have high dispersal power, and may quickly colonize pioneer habitats after inundation on river banks as well as wet meadows (Gerisch 2011). Therefore, they respond to fluctuating hydrological conditions more quickly than plants, and serve as valuable indicators of environmental conditions in riparian habitats (Bonn 2000, Bonn et al. 2002). Moreover the habitat selectivity is reflected in the species traits as the smallest, flattest, flying species are best adapted to the most dynamic riverbank habitats. Proportion of macropterous beetles differ in respect to inundation frequency on the river banks. Between 91-99% of the species close to the river edge are capable of flight and this proportion falls to about 76% in areas that are rarely inundated (Plachter 1986, Sadler & Bates 2007). Larger, slower species are restricted to the higher, less dynamic zones which are flooded once every two or more years (Van Looy et al. 2005).

The dynamic inundation process in riverine habitats can be regarded as disturbing when species co-occurrence pattern is disrupted (Gotelli & Arnett 2000, Pitzalis et al. 2010). However similar adaptations and requirements for inundation processes should create non-random distribution of assemblages with greater than expected by random co-occurrence values (Gotelli & McCabe 2002, Sanders et al. 2007), which is characteristic for habitat checkerboard in entire cross-section. If the inundation process is a filter on the pool of species inhabiting riverine habitats, distinct groups of species which are indicative for particular conditions should be expected.

In the present study we have focused on one single cross section with natural river banks development without any human impact. The aim was to answer the following main questions: (1) Does flooding changes assemblage structure of ground beetles? (2) Is inundation, potentially disturbing terrestrial habitat, responsible for random assemblage organization? (3) If not, are they structured by abiotic or biotic conditions? (4) Do we recognize inundation specialists among ground beetles?

MATERIAL AND METHODS

The study sites were located in Poland, in riverine landscape of the Ochtonica Stream. The Ochotnica Stream is situated in the Polish Carpathians (the Gorce Mountains). The Ochotnica is an alluvial and braided stream which runs through a flood plain composed of Quaternary and Holocene mudstones and coarse gravel, with occasional Tertiary Paleogenic shales, marls and sandstones (known as the Istebnianskie stratums). Typical alluvial and braided cross-sections situated approximately in the middle of the

Ochotnica Stream were chosen and observed within one calendar year. The selected cross-section exhibited a range of characteristics in terms of bank river benches (one, two or three benches), vegetation, and riverbed configuration (flat bed and/or across a river bar).

In the examined cross-section 12 localities were visually assessed based upon geomorphology of river banks and distance to the water surface. According to Woodyer (1968) three river benches were chosen: low (A), middle (B) and high (C) in terms of annual maximum series verified by vegetation cover. At each point geodesic measurements were surveyed with a classic optical level Pentax AP-241. Next, based on the location of pitfall traps, row and geometry of the channel, the potential discharge at each level in terms of volume of running water (Woloszyn et al. 1994) was calculated. For calculation of the probability of occurrence of flood in the particular point of cross section Punzet's formula was employed using the Woda 88 computer model (Radecki-Pawlik 1995) (Table 1).

At each locality within the examined cross section ten pitfall traps (plastic cups with 10% of ethylene glycol) were installed. Four samples were taken monthly throughout the whole vegetation season. Ground beetles were then sorted and preserved in 70% alcohol for further identification. Ground beetles community structure parameters such as total abundance, richness, species diversity (Berger-Parker index, Shannon-Wiener H), total biomass as a function of individual biomass B = 0:038 X (average body length)$^{2.46}$ (Ganihar 1997) and frequently used index of disturbance – Mean Individual Biomass (Schwerk & Szyszko 2007, Sklodowski 2009) were calculated for each assemblage.

Indirect ordination of the ground beetles assemblages found at the 12 sites along the cross-section was performed using non-metric multidimensional scaling (NMDS). NMDS was calculated in WinKyst 1.0 (Šmilauer 2002) on a Bray-Curtis similarity matrix, based on an initial configuration generated by principal co-ordinate analysis. The plot was subsequently orientated using Principal Component Analysis (PCA) with no transformation of data or sample weights and centering by species. The significance of multivariate differences among groups classified according to frequency of floods was tested with a one-way analysis of similarities (ANOSIM) test (Clarke 1993). The Mann-Whitney-U-Test was used to test for ground beetle assemblage structure parameters differences between frequency of flood groups. For detecting random-nonrandom pattern of distribution among and between ground beetle assemblages at frequent and infrequent flooded sites, a null model approach (Gotelli &

Table 1. Hydroecological parameters of localities in Ochotnica stream cross-section

Locality	Height of localities from stream bed [m]	Frequency of flood [years]	Average plant height [m]	Water discharge [m^3 s^{-1}] according to Woodyer index	Water discharge [m^3 s^{-1}] according to Wołoszyn index
1	5.6	100	4.3	11.3	13.9
2	4.6	50	4.2	11.2	13.7
3	3.8	40	4.1	11.1	13.6
4	1.6	1	0.2	3.4	4.1
5	0.2	1	0.1	3.2	4.1
6	0	1	0.1	3.1	4.1
7	0	1	0.2	3.2	4.1
8	0.6	1	0.3	3.3	4.1
9	0.6	1	0.5	3.5	4.1
10	3.8	1000	0.2	40.47	38.4
11	7.4	1000	10.3	40.47	38.4
12	10.4	1000	10.4	40.47	38.4

Graves 1996) was applied. We used the C-score index (Stone and Roberts 1990) using Eco-Sim program (Gotelli & Entsminger 2008) that measures the average number of checkerboard units between all possible pairs of species. We simulated 5000 random matrices testing differences between the randomized and observed assemblages. The characteristic species of the flood frequency were explored by the IndVal (Indicator Value) method (Dufrêne & Legendre 1997). The statistical significance of the species indicator values was evaluated by randomization procedure.

RESULTS

During field study 5.5 thousand of specimens belonging to 68 species were collected in the single cross-section. The most abundant species, *Pterostichus melanarius* (624 specimens) occurred on 11 localities, meanwhile the second abundant *Omophron limbatum* (377 specimens) was ascertained on 7 localities only. There was however strong correlation between abundance and frequency of distribution among sites (R_{SPEAR} = 0.85, $p<0.05$). Only five species occurred as singletons, next seven as doubletons, forty five species abundance was higher than 10 specimens.

A non-metric multidimensional scaling performed on the Bray-Curtis matrix of similarity of 12 assemblages indicated high fit of assemblages on the first two dimensions (final stress = 0.13). The two first axes of the PCA explained 100 % of the total variance of the similarity matrix. The first axis accounted for 80.5% of the total variance clearly divided assemblages from lower, flooded at least 1 time per year (squares) and upper elevation, flooded every two or more years (circles) (Fig. 1). Spatially constrained ANOSIM tests confirmed ground beetle assemblages from frequently flooded elevation differed significantly from assemblages located on higher elevations (ANOSIM R = 0.83, $p < 0.001$).

Mean number of individuals, total biomass and MIB index were found to be significantly higher on less disturbed less frequently flooded areas, meanwhile diversity and richness did not differ significantly between low and high frequently flooded areas (Fig. 2). There was no gradual elimination of species recorded but changes in species composition toward smaller animals when frequent flood appeared.

Pooling both infrequently and frequently flooding local assemblages in the same matrix and analyzing together, we can recognize highly non-random distribution of species (C-score $_{observed}$ = 34.21817, C-score $_{simulated}$ = 32.82725, P =0.000001) (Fig. 3A). Analyzing infrequently and frequently flooded sites separately, non random structure was observed in both sets (C-score $_{observed}$ = 10.17199, C-score $_{simulated}$ = 9.58824, P = 0.000001; C-score $_{observed}$ = 9.59729, C-score $_{simulated}$ = 9.42040, P = 0.02 respectively) (Fig. 3 B, C). In all cases, higher values of C-score than the means indicate aggregation processes of species with similar requirements for abiotic conditions.

In total, there were twenty nine species with an IndVal score significantly related to flood frequency (Table 2). Nine of these were indicators for frequently flooded sites, twenty for more stable sites. An example of the first group are spe-

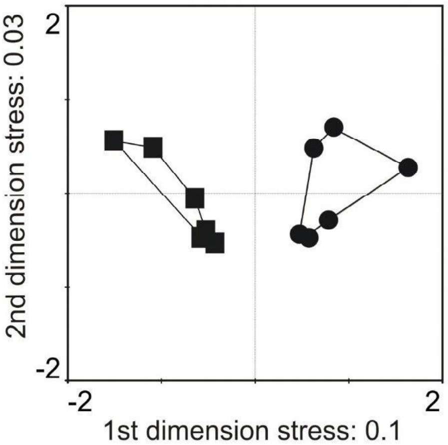

Fig. 1. Non-metric multidimensional scaling analysis (NMDS) ordination of high frequency of flood (square) and low frequency of flood (circle) ground beetle assemblages (NMDS stress = 0.03; ANOSIM: R = 0.83, p<0.001)

Table 2. Indicator values for yearly flooded and less than two years flooded sites for carabid beetles

Species	IndVal	Mean	Std	t (**p<0.01)	
yearly flooded					
Amara fulva (O.F.Muller, 1776)	77.38	40.12	15.32	2.432	**
Anisodactylus binotatus (Fabricius, 1787)	83.83	55.83	14.76	1.897	**
Bembidion atroceruleum (Duftschmid, 1812)	66.67	32.93	15.76	2.141	**
Bembidion cruciatum veselyi (Fassati, 1958)	100	40.44	16.36	3.641	**
Bembidion tricolor (Fabricius, 1801)	83.33	41.49	17.46	2.397	**
Chlaenius tibialis (Dejean, 1826)	98.47	44.35	16.45	3.291	**
Omophron limbatum (Fabricius, 1776)	99.47	44.39	16.26	3.388	**
Poecilus sericeus (Fischer von Woldheim, 1823)	100	43.06	18.52	3.074	**
Pseudophonus rufipes (DeGeer, 1774)	90.8	48.25	12.58	3.381	**
less than two years flooded					
Amara aenea (De Geer, 1774)	100	29.93	15.43	4.541	**
Amara curta (Dejean, 1828)	71.19	35.22	15.01	2.396	**
Abax carinatus (Duftschmid, 1812)	84.21	45.27	16.9	2.303	**
Abax ovalis (Duftschmid, 1812)	97.87	39.05	18.46	3.187	**
Abax parallelus (Duftschmid, 1812)	69.44	45.29	12.22	1.977	**
Abax parallelepipedus (Piller et Mitterpacher, 1783)	88.55	51.26	16.44	2.268	**
Badister bullatus (Schrank, 1798)	84.21	31.17	16.16	3.282	**
Carabus auronitens (Fabricius, 1792)	100	37.53	17.98	3.474	**
Carabus glabratus (Paykull, 1790)	97.3	43.85	18.17	2.941	**
Carabus violaceus (Linnaeus, 1758)	72.31	47.07	12.97	1.946	**
Harpalus latus (Linnaeus, 1758)	75	37.94	14.61	2.537	**
Molops piceus (Panzer, 1793)	100	34.48	17.19	3.812	**
Pterostichus aethiops (Panzer, 1797)	100	34.07	16.61	3.97	**
Pterostichus burmeisteri (Heer, 1841)	98.76	42.42	18.31	3.076	**
Pterostichus foveolatus (Duftschmid, 1812)	91.24	50.77	16.29	2.484	**
Pterostichus melanarius (Illiger, 1798)	76.2	52.14	12.34	1.95	**
Pterostichus niger (Schaller, 1783)	74.38	51.45	11.17	2.054	**
Pterostichus oblongopunctatus (Fabricius, 1787)	87.88	50.42	14.37	2.607	**
Pterostichus strenuus (Panzer, 1797)	100	30.97	15.56	4.437	**
Trichotichnus laevicollis (Duftschmid, 1812)	94.74	35.66	17.56	3.364	**

cies from small sized genus Bembidion, meanwhile in the second group, big sized forest species from the genera *Carabus* and *Pterostichus* were revealed. The average biomass for high frequency of flood indicator species was significantly lower than in the second indicating group (Fig. 4) (Mann-Whitney U test, Z = -2.308, $p<0.05$).

DISCUSSION

Natural flood regime creates a very heterogeneous habitat for specialized terrestrial invertebrate fauna. Among them carabid beetles dominate in terms of rare and endangered species (Sadler et al. 2004). Hammond (1998) estimated that 3,5 % of the total British beetle fauna are riparian specialists. Especially in the mountain region, exposed riverine sediments (ERS), frequently inundated and elevated areas of sparsely vegetated sediments, lead to variation in the physical habitat and the riparian species have a range of adaptations to deal with the dynamic nature of the environment (Sadler & Bates 2007). Andersen (1985) pointed out that carabid beetles are all capable swimmers and can survive immersion for a maximum of up to 48 hours.

Moreover, they have a high dispersal capacity and flight behavior and it seems to be of great importance for survival of carabid populations in unstable riverine habitats (Bonn 2000). Therefore, other Carabid species from habitat farthest to the river edge cannot survive in such dynamic environmental conditions, in spite of abundant food source sites (Hering & Plachter 1997).

As it was pointed out, ground beetles are a very suitable indicator for frequently changed river conditions and for river management. Ground beetle assemblages have been noticed as responding to flood regimes (Bonn et al. 2002), riparian vegetation (Greenwood et al., 1995), riparian habitat heterogeneity and distribution (Eyre et al. 2001) and bank management (Gerken et al. 1991). Responses of this group of insects to specific river conditions are useful in the evaluation of river management and flood protection (Van Looy et al. 2005). Non- metric multidimensional scaling analysis and IndVal values showed that we can clearly distinguish assemblages from different inundation frequency classes, responding consistently to habitat disturbance. It should be also noticed, that species diversity and richness didn't decreased with disturbance intensity, showing

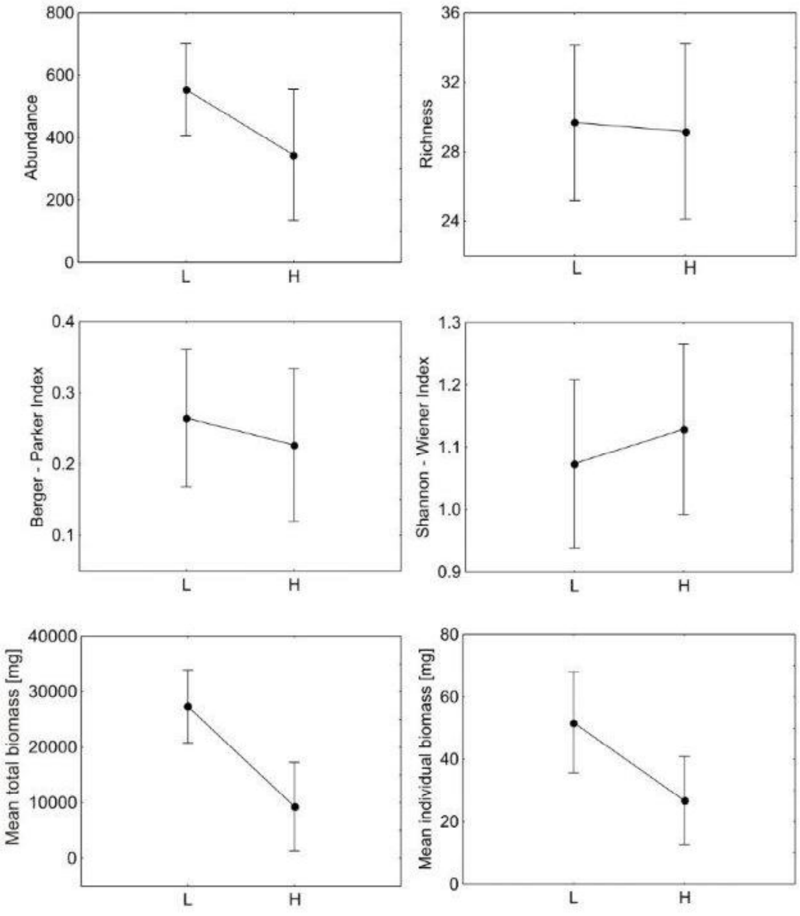

Fig. 2. Mean +SE values of ground beetle assemblages parameters with respect to high (H) and low (L) frequency of flood. Only abundance, total biomass and MIB were significantly different between two flood periods (Mann-Whitney U test, $Z_A = 2.32$, $p<0.05$, $Z_T = 2.64$, $p<0.01$, $Z_M = 2.32$, $p<0.05$ respectively).

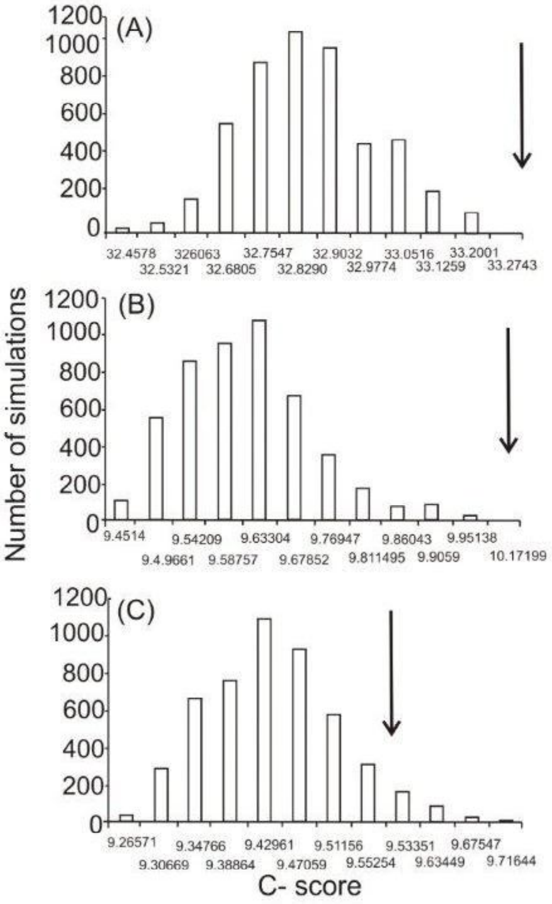

Fig. 3. Histograms of C-scores from 5000 simulated random assemblages and the placement of the observed C-score marked as arrow. (A) simulation for both infrequently and frequently flooded assemblages, (B) simulation for infrequently flooded assemblages (C) simulation for frequently flooded assemblages

that directional replacement of species between disturbance classes. For most species from frequently flooded sites, inundation is not a disturbing factor and species microhabitat selection and specialization is very well preserved (Sadler & Bates 2007).

If inundation is a disturbing factor for riverine habitats, we should have a randomized co-occurrence pattern of ground beetle assemblages (Gotelli & Arnett 2000, Sanders et al. 2003, Pitzalis et al. 2010). Significantly higher values of C-score for whole assemblages reflects an segregation of species with similar habitat requirements along a gradient of disturbance. These results suggest that biotic factors in riverine habitats can be regarded as a strong filter for riverine species. But what is more, similar patterns were shown on localities with high inundation frequency. Non-random distribution on frequently flooded sites, however, indicated that frequent inundation process is not a destructive factor for species biotic interactions or maybe it is a result of fast recovery after flooding. Sadler & Bates (2007), however, indicated that even a small ERS bar can be colonized by species with various microhabitat requirements. The habitat specialization and trait-displacements (mainly body size), reflecting sorting mechanisms (Lambeets et al. 2008), are responsible for the aggregation pattern.

Main characteristic of inundation specialists is low body size and biomass (Fig. 4). All indicator species were small. It also explains the significant decrease of biomass and MIB index on frequently flooded sites. Our findings confirm the decreasing body size hypothesis in relation to disturbance in ground beetle assemblages (Szyszko 1983, Lambeets et al 2008, Radecki-Pawlik & Skalski 2008, Gerish 2011). Nowadays river banks are exposed to a number of human alternations such as removal of sediment and fluvial woodlands, different kind of river regulations, construction of flood prevention walls, channelization and other industrial activity. A reduced frequency of bank inundation creates possibilities for a sufficient colonization by species from surrounding habitats (bigger and more competitive) and elimination of the species well adapted to the dynamic flow conditions typifying unmodified stream sections.

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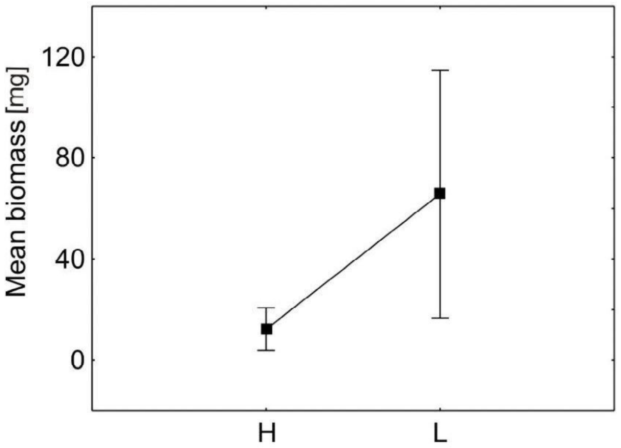

Fig. 4. Mean (±SE) biomass of indicator species in high (H) and low (L) frequency of flood revealed from IndVal analysis

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