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The application of the abundance/biomass comparison method on riverine fish assemblages: limits of use in lotic systems

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***Abstract*:**

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Fish assemblages have been widely used as ecological indicators for assessing the level of environmental degradation and ecosystem health. Environmental disturbances affect the aquatic community structure in terms of abundance and biomass. Therefore, we tested the utility of abundance/biomass comparison (ABC) method, originally developed for marine ecosystems, to detect the anthropogenic disturbance in lotic systems using fish community data. Electrofishing was conducted in the period between 2003 and 2011 at 35 sites along the Southern Morava River basin. The results indicated that species richness strongly influences the utility of ABC method to detect the anthropogenic disturbance in lotic systems. The Warwick (W) statistic showed the positive correlation and the expected direction of response with some factors defining environmental quality, applying it on the samples with greater species richness. This approach has significant power for detecting environmental quality disturbance but may be limited due to effects of habitat variability in riverine environments.

Key words: Abundance/biomass comparison method, lotic systems, fish community, PCA analysis, Southern Morava River basin

***Apstrakt*:**

Stojković Piperac, M., Milošević, Đ., Simić, V.: *Primena metode poređenja abundance i biomase na zajednicu riba tekućih voda: ograničenja prilikom upotrebe u lotičkim ekosistemima. Biologica Nyssana, 6 (1), Septembar 2015: 25-32.*

Ribe predstavljaju dobro poznate ekološke indikatore u proceni kvaliteta životne sredine. Poznato je da narušavanje sredine utiče na strukturu akvatičnih zajednica u smislu abundance i biomase. Zbog toga, u ovom radu testirana je korisnost metode poređenja abudance i biomase (ABC method, eng. abundance/biomass comparison method), inicijalno predviđene za primenu nad marinskim ekosistema, u detekciji antropogeno izazvanih promena u lotičkim ekosistemima korišćenjem podataka o zajednici riba. Procedura elektroribolova sprovedena je u periodu od 2003 do 2011 godine na 35 lokaliteta raspoređenih duž sliva Južne Morave. Rezultati ove studije ukazuju da bogatstvo vrsta u značajnoj meri utiče na korisnost ispitivane metode u proceni intenziteta antropogenog delovanja na lotičke ekosisteme. Warwick-ova (W) statistika pokazuje pozitivnu korelaciju sa faktorima koji definišu kvalitet sredine, kao i očekivani odgovor na stres, samo prilikom primene nad lokalitetima sa većim brojem vrsta. Pokazano je da ova metoda ima značajnu moć u detekciji narušenja životne sredine ali sa izvesnim ograničenjima izazvanim prirodnom varijabilnošću u lotičkim ekosistemima.

Key words: metoda poređenja abundance i biomase, lotički sistemi, zajednice riba, PCA analiza, sliv Južne Morave

Introduction

Anthropogenic modifications of natural hydrology have been altering freshwater ecosystems worldwide, threatening their ecological integrity (Rehage & Trexler, 2006). Anthropogenic alteration may change the hydrological patterns of the river basin (Ward, 1998) and modify the physical characteristics of the aquatic habitat (Karr, 1981), strongly influencing the structure and composition of the aquatic biota. The major human activities with negative impacts on aquatic communities include: human impact on habitat morphology, intensive agriculture and urbanization, construction of channels and dams, removal of snags, and pollution (Johnson et al., 1995; Sparks, 1995; Richter et al., 1997; Eitzmann & Paukert, 2010). Considering the fish fauna, it is also necessary to emphasise the possible changes caused by over-fishing by both anglers and poachers as an important factor that may dramatically diminish fish populations (Penczak & Kruk, 1999; Anticamara et al., 2010). However, the major threat to freshwater fish is modification of aquatic environment, which may cause decline in many species (Collares Pereira & Cowx, 2004).

Assessing fish community structure is one of the efficient ways of evaluating the biotic integrity in rivers in different parts of the world (Karr, 1981; Oberdorff & Hughes, 1992; Hugueny et al., 1996; Ganasan & Hughes, 1998; Breine et al., 2004; Stojković et al, 2014). Changes in fish community composition are an important factor used to characterize environmental quality, as fishes respond to changes in the aquatic environment with great sensitivity. They play an important role in aquatic ecosystems due to their dependence on both, the physical features of their environment and the other forms of aquatic life. Therefore, the health of each fish assemblage reveals conditions present in the entire aquatic community (Foltz, 1982).

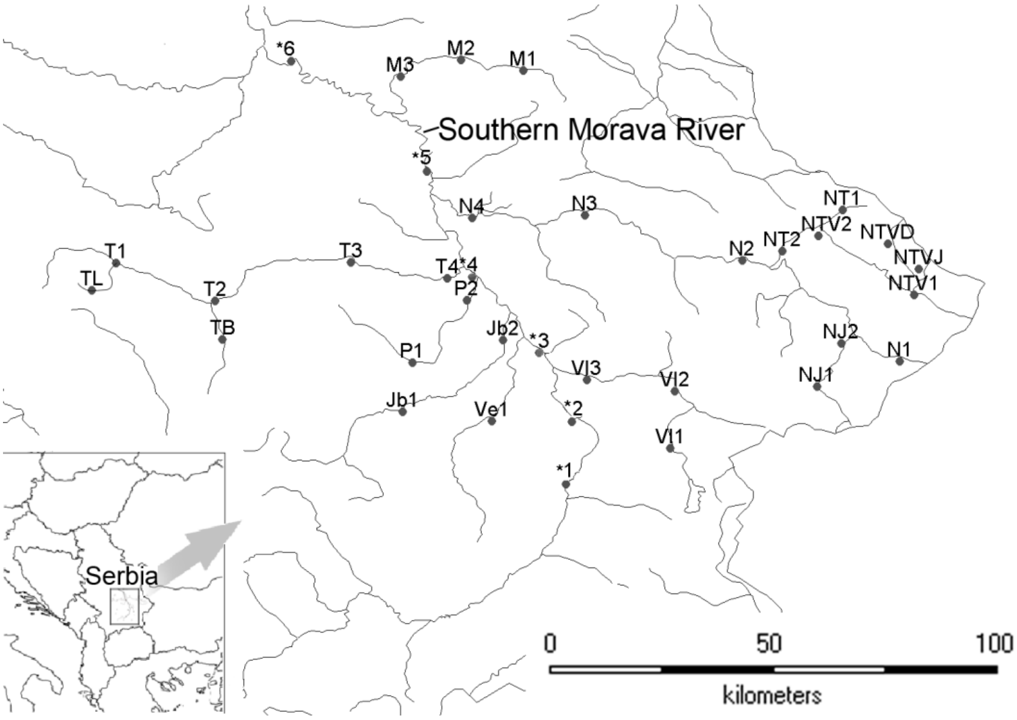

Fig. 1. Map of the sampling sites under investigation. Site codes for studied streams are the same as in Table 1.

Environmental disturbances also affect the aquatic community structure in terms of abundance and biomass, both measured by the abundance/biomass comparison (ABC) method. The ABC method was initially applied on marine macrobenthic communities to detect influence of the anthropogenic activities such as pollution (Warwick, 1986). In addition, many studies conducted by now, stressed that this method could be also applicable to detect the effect of anthropogenic changes on freshwater biota caused by pollution (Coeck et al., 1993), industrial plant impact (Pinto et al., 2006), over-fishing (Penczak & Kruk, 1999) and water and habitat disturbance (Casatti et al., 2006). However, Penczak & Kruk (1999) proposed a threshold regarding a minimal number of species caught in the sample when applying ABC method on riverine fish assemblages. Bearing all this in mind, we here aimed to test the performance of the ABC method in assessing the changes in the fish community as a response to environmental degradation in lotic systems. Furthermore, we tested how species richness influences the utility of ABC method to detect the anthropogenic disturbance in riverine environments.

Material and methods

Study area

The source of Southern Morava River, also known as Binačka Morava, is in the Skopska Crna Gora Mountains, Macedonia. This river flows in the roughly northerly direction. At the 49th kilometer it coalesces with the Preševska Moravica and at 295th kilometer it discharges in the Morava, tributary of Danube and therefore part of the Black Sea catchment area.

The Southern Morava River has a catchment area of 15,469 km^2, of which 14,372 km^2 (92.91%) are in Serbia and 1,097 km^2 (7.09%) in Bulgaria through its right-hand tributary the river Nišava. It has 157 tributaries but most of them dry out during summer. Larger, permanent left-hand tributaries are Jablanica, Veternica, Toplica and Pusta Reka rivers. Right-hand tributaries include Vlasina, Nišava (the longest) and Sokobanjska Moravica rivers (Gavrilovic & Dukic, 2002).

Sampling

Fish fauna was sampled along the Southern Morava River basin in the period between 2003 and 2011. During the investigated period, out of total number of 35 sampling sites (**Fig. 1**), 12 were sampled ones, 18 twice, 2 three and 3 four times. Since each sampling occasion was considered as separate entity in data processing, the final data matrix was consisted of 66 samples. The electrofishing procedure was conducted using the DC electrofisher “Aquatech” IG 1300 (2.6 kW, 80–470 V). A more detailed sampling procedure is described in Stojkovic et al. (2013).

Together with the fish data collection, water and habitat quality variables were measured for each sample in order to characterize the extent of stress. Water quality was expressed by five variables strongly dependent on anthropogenic disturbance (dissolved oxygen (DO), electro-conductivity (EC), concentrations of ammonia nitrogen (NH_4), nitrate nitrogen (NO_3) and orthophosphates (PO_4)). Dissolved oxygen and electro-conductivity were estimated by a WTW multi 340i probe, while the concentrations of ammonia nitrogen, nitrate nitrogen and orthophosphates were measured using the Spectrophotometer Shimatzu UV–VIS. Habitat quality was presented by three disturbance variables: hydrological alteration (HA), channel alteration (CA) and land use intensity (LU). Each site was given a score of 1, 3, or 5 if slight, moderate, or severe alteration for each habitat disturbance variable was observed (Stojković et al., 2014).

Data analysis

To test how species richness influences the output of the ABC method, two data matrix have been constructed. The first data matrix (A) contained all samples collected during the sampling period, which finally counts 66 samples, regardless of the number of species caught. In contrast, the second data matrix (B) was constructed to contain only samples where species richness was greater than 5, as suggested by Penczak & Kruk (1999), finally presenting 28 samples.

According to Warwick (1986), condition of an aquatic community can be illustrated by using combined k-dominance plots of abundance and biomass, where species are ranked in the order of importance on the x-axis (logarithmic scale) with percentage dominance on the y-scale (cumulative scale). The area between the two curves is called the Warwick or W statistic, calculated according to the following formula (Clarke, 1990).

$$\mathrm{W} = \frac{\sum_{j=1}^{S}\left[\left(\sum_{j=1}^{i} bj\right)-\left(\sum_{j=1}^{i} aj\right)\right]}{50(S-1)},$$

where W is the standardized sum of the differences between each pair of species’ cumulative biomass $\left(\sum_{j=1}^{i} bj\right)$ and cumulative abundance $\left(\sum_{j=1}^{i} aj\right)$ value ranked in decreasing order. The curves classify the quality of the environment (Magurran, 2004) either as undisturbed (biomass curve overlaps that of abundance, W > 0) or disturbed (abundance curve overlaps that of biomass, W < 0). W ranges from -1 to +1. W statistic was calculated using the PRIMER v6 (Clarke & Gorley, 2006), a multivariate statistical package developed at Plymouth Marine Laboratory.

Since some variables in this study were presented as ordinal, categorical principal components analysis (CATPCA) was used to reveal the relationship between W statistic and disturbance variables. The data matrix were consisted of 9 variables, out of with 6 were numerical and 3 categorical (given in columns), measured along the 66 and 28 samples (given in rows), depending on the data matrix used in the analysis. The CATPCA analysis was performed using software SPSS version 15.0 (SPSS Inc, Chicago, IL, USA).

Results

Dominance of abundance or biomass was calculated for all 66 samples. The W statistics values, observed at the majority of sites, were positive, with an exception of a few sites, mainly situated on upper river courses (**Tab. 1**). According to this, the ABC method indicated that the majority of sites were undisturbed, as represented by positive values of W statistic. Nevertheless, there were several sites having the positive values the W statistic but close to zero, where both curves roughly coincided, indicating a moderately disturbed condition.

Table 1. Description of code, stream order and W statistic value for each sample collected along the Southern Morava River basin. After the each site code, abbreviation for year of sampling is included

River	Code	Stream order	W statistic	River	Code	Stream order	W statistic
Southern Morava	*1-03	2	0.428	Visočica	NTV1-08	1	0.109
Southern Morava	*1-10	2	-0.031	Visočica	NTV1-10	1	0.536
Southern Morava	*2-03	2	0.247	Visočica	NTV1-11	1	0.501
Southern Morava	*2-08	2	0.094	Visočica	NTV2-06	2	0.308
Southern Morava	*3-03	3	-0.124	Visočica	NTV2-10	2	-0.126
Southern Morava	*4-03	3	0.111	Dojkinačka reka	NTVD-08	1	0.000
Southern Morava	*4-08	3	0.122	Jelovička reka	NTVJ-08	1	0.280
Southern Morava	*5-03	4	0.090	Jerma	NJ1-10	1	0.109
Southern Morava	*5-08	4	0.176	Jerma	NJ1-11	1	-0.158
Southern Morava	*6-10	4	0.200	Jerma	NJ2-10	1	0.380
Jablanica	Jb1-03	2	0.217	Jerma	NJ2-11	1	0.143
Jablanica	Jb2-03	2	0.088	Pusta reka	P1-10	2	0.153
Sokobanjska Moravica	M1-10	1	-0.020	Pusta reka	P2-03	2	0.232
Sokobanjska Moravica	M2-08	1	0.053	Pusta reka	P2-10	2	0.634
Sokobanjska Moravica	M3-08	1	0.162	Toplica	T1-03	1	0.175
Sokobanjska Moravica	M3-10	1	0.334	Toplica	T1-10	1	-0.205
Nišava	N1-10	2	0.120	Toplica	T2-08	2	0.180
Nišava	N1-11	2	0.081	Toplica	T2-10	2	0.256
Nišava	N2-10	3	0.019	Toplica	T3-03	2	0.144
Nišava	N2-11	3	0.139	Toplica	T3-08	2	0.284
Nišava	N3-03	3	0.197	Toplica	T4-03	2	0.201
Nišava	N3-08	3	0.180	Toplica	T4-10	2	0.257
Nišava	N3-10	3	0.299	Banjska reka	TB-08	1	0.223
Nišava	N3-11	3	0.242	Lukovska reka	TL-08	1	-0.133
Nišava	N4-08	3	0.022	Lukovska reka	TL-10	1	0.007
Nišava	N4-10	3	0.160	Veternica	Ve1-10	2	0.070
Nišava	N4-11	2	0.253	Vlasina	Vl1-03	1	0.158
Temska	NT1-03	1	-0.160	Vlasina	Vl1-04	1	0.000
Temska	NT1-08	1	-0.109	Vlasina	Vl1-08	1	0.000
Temska	NT1-10	1	-0.433	Vlasina	Vl1-10	1	-0.739
Temska	NT1-11	1	-0.068	Vlasina	Vl2-10	1	0.165
Temska	NT2-10	2	0.264	Vlasina	Vl3-03	2	0.291
Temska	NT2-11	2	-0.128	Vlasina	Vl3-08	2	0.030

Table 2. Contributions of the W statistic and water and habitat quality variables to the two fist axis of the CATPCA and the total variance accounted for (VAF) for a) data matrix A, b) data matrix B

a)	**Component Loadings**		**Total VAF**	b)	**Component Loadings**		**Total VAF**
	Axis				Axis		
	1	2			1	2	
W	**-0.431**	0.230	0.189	W	**-0.397**	**0.490**	0.288
NO3	**-0.860**	-0.146	0.433	NO3	**0.842**	0.219	0.486
PO4	**-0.827**	-0.152	0.430	PO4	**0.822**	0.391	0.509
NH4	**-0.840**	0.085	0.379	NH4	**0.757**	-0.193	0.380
EC	**-0.722**	-0.335	0.913	EC	**0.518**	**0.633**	1.000
DO	**0.893**	0.064	0.462	DO	**0.875**	-0.064	0.478
HA	-0.030	**0.949**	0.468	HA	-0.004	**-0.790**	0.323
CA	**-0.857**	0.256	0.436	CA	**0.953**	-0.328	0.466
LU	**-0.844**	0.157	0.377	LU	**0.764**	-0.352	0.449

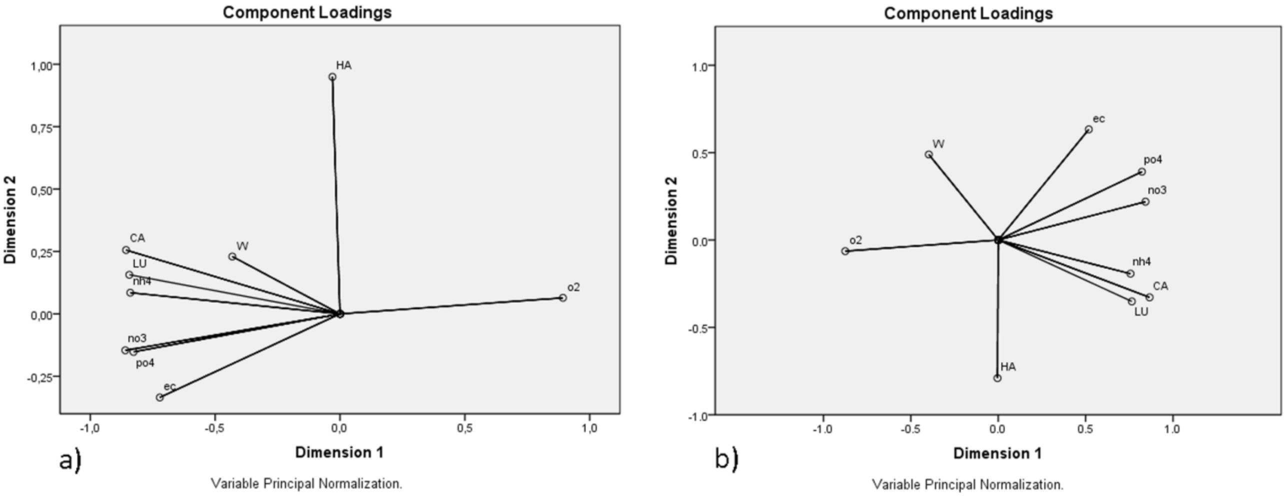

Fig. 2. CATPCA plots showing relationships between W statistic and stressor gradient based on a) data matrix A and b) data matrix B

The CATPCA analysis, conducted under the data matrix A, extracted the first and the second dimensions, which explained 56.45% and 13.46% of the total variance between 66 samples, respectively. The first axis was associated with all factors, excluding factor HA. Also, the first axis had high loading for all factors except for W (**Tab. 2, Fig. 2a**). The CATPCA plot A indicated that W statistic is positively correlated with some factors associated with the first axis that define water and habitat quality and negatively correlated with DO. According to this result, positive and high values of W statistic occur when the water and habitat quality parameters indicate stress condition (**Fig. 2a**). On the other side, in the CATPCA result of the data set B, the first and second axis accounted for 49.82% and 19.31% of the observed variation, respectively (**Fig. 2b**). The CATPCA plot B showed that values of W statistic increase when high values of DO and the decrease of water and habitat quality variables were observed.

Discussion

The W statistics values, according to the CATPCA plot A, showed correlation with factors defining stress condition but in the opposite than expected direction (**Fig.2a**). Such a result could be explained as a consequence of a low number of species found at some particular sites situated on upstream reaches (Penczak & Kruk, 1999) which caused unexpected negative values of W statistic. Despite the premise that the undisturbed water courses should be characterized by greater species richness and diversity indices (Argent et al., 2003; Gafny et al., 2000), fish richness and diversity are strongly influenced by stream order and longitudinal heterogeneity (Platts, 1979; Barila et al., 1981). Longitudinal zonation in stream fish assemblages revealed that species diversity increases from upstream to downstream areas due to the greater variety of habitat diversity (Gorman & Karr, 1978; Foltz, 1982; Bain et al., 1988). Likewise, as stream order increases, the richness and total number of fish specimens also increase (Platts, 1979; Thomas & Hayes, 2006). Similar problem was detected when using the taxonomic distinctness index applied on freshwater fish (Clarke & Warwick, 1998; Bhat & Magurran, 2006). Bhat & Magurran (2006) found that the sites on the first and second stream order fell below the confidence limits, indicating false environmental disturbance. Explanation provided in that study suggested that this may be caused by the fact that total species richness and taxonomic distinctness increase with stream order (Bhat, 2004), as downstream areas contained several upstream species as well as species unique to downstream area, whereas upstream sites tended to include closely related species. Another factor considered necessary to emphasize is that the total fish biomass decrease in the upstream direction (Schlosser, 1991; Thiel et al., 1995; Hicks, 2003) which was also reflected on negative values of W statistic at the upper river courses.

In contrast, considering the second CATPCA plot, where upper river courses were excluded from analysis, W statistic showed the expected direction of response to the extent of human alteration. This result unambiguously confirms presumed obstacles in applying ABC method on riverine fish assemblages, which are mainly caused by natural longitudinal heterogeneity in lotic systems. Consequently, we believe that ABC method may be a promising tool for characterization of lotic systems under stress conditions, but may be limited to the sites with greater species richness.

Conclusion

The results of this study have shown limited effectiveness of the ABC method in pinpointing effects of the disturbance at upstream sites, since the resulting values of W statistic were highly confusing and not aligned with the real picture of the fish fauna. In some instances, the real situation in the fish community was presumably hidden by influences of longitudinal heterogeneity (Bhat & Magurran, 2006). However, we stressed that this approach has significant power for detecting environmental quality disturbance but may be limited due to effects of habitat variability in riverine ecosystems. We feel that further research should be undertaken to test the sensitivity of ABC method to recognize the influence of some socio-economic factors on riverine fish assemblages, such as effects of commercial and recreational fisheries.

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