Original Research

Impact of Agricultural Land Use on Macroinvertebrate Fauna in Lithuania

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Abstract

The present study aims at assessing changes in macroinvertebrate metrics in relation to the effects of agricultural land use in a lowland river. Cluster analysis techniques were applied to group river sites according to the similarity of total and relative abundances of taxonomic groups. Riverbed morphology and riparian vegetation were the main environmental variables differentiating between clusters. The total abundance of macroinvertebrates, and absolute and relative abundances of EPT, Coleoptera, and Trichoptera were significantly higher in the river sites with a narrow belt of riparian forest in comparison with groups of deforested and straightened river sites. Macroinvertebrate community status based on biotic indices was significantly higher in the natural forested river reaches and was classified as good or even very good, whereas the status of most of the rest of the sites was recognized to be moderate or poor. None of macroinvertebrate variables correlated with water quality parameters. The presence of forest belts along riversides seems to support the good status of macroinvertebrate communities, even if concentrations of nitrogen and phosphorus in the river are elevated due to agricultural runoff and exceed maximum permissible concentrations valid in Lithuania. However, single macroinvertebrate metrics, differently from integral metrics, indicated alterations in water quality of the studied river.

Keywords: macroinvertebrates, bioassessment, DSFI, HBI, river, ecological status

Introduction

Agricultural practices affect streams, changing their riparian vegetation, altering channel morphology and in-stream habitats, and increasing sediment and nutrient loads [1]. Changes in water quality and aquatic communities due to agricultural runoff are widely documented [2-4]. Straightening of riverbeds and deforestation along the edges of natural watercourses also influence the physicochemical conditions, as well as the hydrological regime of river ecosystems [5-7].

The catchment of the Nevėžis River (Nemunas River basin), the fourth largest river in Lithuania, is among the most affected by agricultural activities [8-10]. As a result, alterations in aquatic communities are also expected. Changes in the composition of aquatic communities responding to human pressure are most frequently indicated by groups of macroinvertebrates [11], since they are sensitive to water quality [12-13] and specific anthropogenic disturbances [14]. Many of them have relatively long life cycles of a year or more and are especially important biological indicators of site conditions over time. Macroinvertebrates respond predictably to habitat changes because they have limited migration possibilities [15] and are, therefore, especially valuable in cases where chemical-specific analysis cannot separate the cumulative effects of multiple stressors. Considering this, the macroinvertebrate metrics should indicate both physicochemical and morphological changes in their habitats.

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Table 1. General morphological characteristics of the investigated reaches of the Nevėžis River (Nemunas basin, Lithuania).

Site No.	Longitude	Latitude	Altitude (m a.s.l.)	Distance from source (km)	Average width (m)	Average depth (m)	Bottom substrate	River bed morphology	Riverside
1	24º45’47”	55º31’19”	82.1	12	8	1.0	gravel	straightened	deforested
2	24º37’32”	55º35’39”	74.1	25	9	0.9	gravel	straightened	deforested
3	24º27’38”	55º41’20”	58.2	52	15	1.8	pebble	natural	forest
4	24º13’46”	55º43’55”	41.4	75	10	1.5	pebble	natural	forest
5	24º07’13”	55º35’39”	33.1	106	17	0.9	gravel	natural	deforested
6	24º02’09”	55º25’04”	29.3	124	25	0.6	pebble	natural	forest
7	23º55’37”	55º13’45”	24.7	152	20	0.6	gravel	natural	deforested
8	23º49’12”	55º10’10”	22.9	168	19	1.4	pebble	natural	forest
9	23º46’43”	55º05’56”	21.7	182	33	1.9	gravel	natural	deforested
10	23º48’12”	54º58’21”	20.6	197	61	2.4	gravel	natural	deforested

Given this context, the objective of our study was:

(i) to make a comparative assessment of macroinvertebrate metrics in sites with natural and altered morphology of the Nevėžis River receiving agricultural runoff

(ii) to establish which factors, changes in water quality, or morphological alterations have a stronger impact on macroinvertebrate status.

The overall status of macroinvertebrate communities was assessed by two biotic indices differing in the assessment concept: the semi-quantitative Danish Stream Fauna Index (DSFI) [16], which is officially adopted in Lithuania, and the quantitative Hilsenhoff biotic index (HBI) [17].

Materials and Methods

Our study was conducted in August 2009 in the Nevėžis River (Nemunas River basin), flowing in the Mid-Lithuanian Lowland. The length of the river is 208.6 km, draining a catchment of 6,140.5 km^2 with an average slope of 0.035% and an average discharge of 30.2 m^3·s^{-1} [8]. The basin is dominated by agricultural lands occupying about 45% of the total area [9]. The dense hydrographic network of the Nevėžis River catchment has 89 tributaries longer than 10 km; 25% of their total length is straightened [10]. The majority of riversides are deforested but patchy narrow belts of forest still exist along some river stretches.

Ten sampling sites, differing in morphology, were selected for our study along the Nevėžis River (Fig. 1). The average width of the riverbed at sampling sites ranged from 8 to 61 m with an average depth from 0.6 to 2.4 m. Gravel and pebble dominated strata. The upper reaches of the river (sites 1 and 2) are straightened, whereas the remaining stretch of the river is a natural watercourse. Agricultural fields extend along the river and narrow natural riparian vegetation belts are present only at sites 3, 4, 6, and 8 (Table 1). Rooted hydrophyte (*Potamogeton*) species characteristic of lotic habitats dominated in natural reaches. Floating pleustophytes, *Lemna minor* and *Spirodela* sp. prevailed in the straightened stretch of the river.

Macroinvertebrate samples were dredged from four 0.1 m^2 areas at each of the sites by the kick-sampling method [18] (500 μm mesh net). Additional samples of macroinvertebrates (2 samples per site) were taken from plants, stones or stumps to determine the DSFI. A total of 60 samples were collected, sieved using a 500 μm mesh, transferred into plastic flasks and stored in a 4% formaldehyde solution. In the laboratory, all animals were separated, counted, and identified to the species or genus level (except Oligochaeta) under a binocular dissecting microscope.

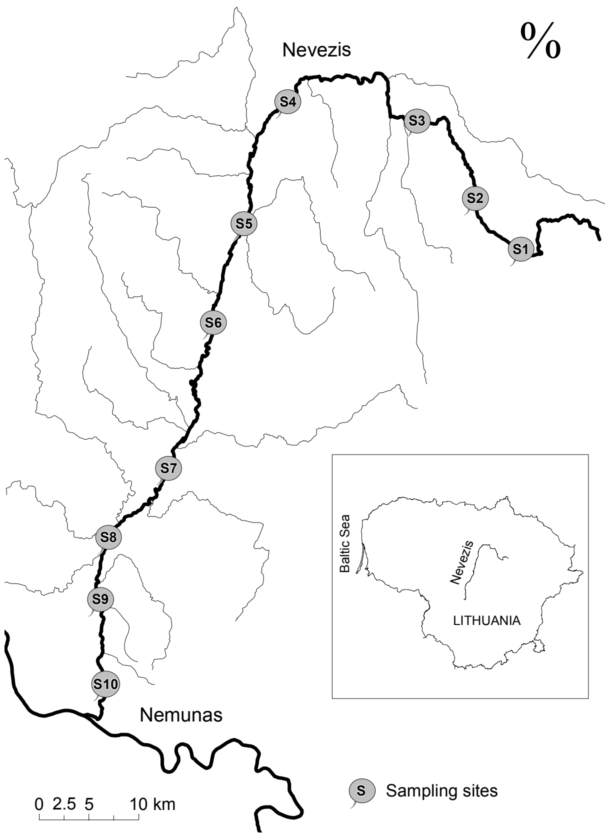

Fig. 1. Map of Nevėžis River and distribution of study sites in 2008.

DSFI [16] and Hilsenhoff biotic index (HBI) [17] were calculated to assess the ecological status of investigated river sites. HBI tolerance values were taken from Bode et al. [19]. We also calculated macroinvertebrate taxa richness (SR), EPT richness, Shannon-Weaver diversity index (H') [20], as well as the total abundance (ind m^{-2}) and relative abundance (%) of indicatory taxonomic groups (Plecoptera, Ephemeroptera, Trichoptera, EPT, Coleoptera, Chironomidae, Oligochaeta, and Isopoda).

Similarities in the macroinvertebrate taxa abundance between samples were assessed using the Bray-Curtis similarity index [21] in the CLUSTER program of the PRIMER 5.2.3 package. Similarities in the percentage of abundance of indicatory taxonomic groups were assessed by squared Euclidean distances using Ward's linkage method in the Cluster analysis program of the Statistica for Windows 6.0 package.

The General Linear Model ANOVA and Fisher LSD test were used to determine differences in macroinvertebrate metrics and morphological characteristics among groups of river sites. All species data were log(1+x) transformed prior to analysis. Calculations were done with Statistica for Windows 6.0.

Values of the main physiochemical variables (measured at the end of July) in investigated sites were obtained from the Environmental Protection Agency of Lithuania.

Results

The measured values of the main physiochemical variables in investigated sites are presented in Table 2. Total nitrogen concentrations exceeded the maximum permissible concentration, approved by the Ministry of the Environment of Lithuania [22], in all investigated sites, and nitrate concentrations in almost all investigated sites; whereas elevated phosphate and total phosphorus concentrations were found in the lower reaches of the river.

A total of 94 macroinvertebrate taxa (including 68 identified species) belonging to 46 families were identified in the investigated river. The greatest taxa richness was recorded for the groups Trichoptera (20 taxa: 18 species and 2 genera), Mollusca (13 species), and Ephemeroptera (11 species). The chironomids *Rheotanytarsus* sp., *Cricotopus algarum,* and oligochaetes were detected in all investigated sites.

The total number of macroinvertebrate taxa (SR) and the number of EPT taxa were highly variable across the river, ranging respectively within 17-45 and 3-16. Total and relative abundances of different taxonomic groups of macroinvertebrates also ranged within a broad scale (Table 3). Specimens of *Baetis*, *Caenis*, *Siphlonurus*, and *Hydropsyche* genera were the most abundant representatives of EPT taxa (14.3-86.6 %). The Shannon-Weaver diversity index (H') ranged from 2.76 to 4.36. According to DSFI and HBI, the ecological status of the majority of sites was good or even very good, except for the upper reaches (which are straightened) and lower reaches of the river (Table 3). No macroinvertebrate variables, including DSFI and HBI indices, were significantly correlated with water quality parameters.

Table 2. The values of chemical variables in the investigated reaches of the Nevėžis River (Nemunas basin, Lithuania) (Data from the Environmental Protection Agency of Lithuania).

Site No.	NH_4-N	NO_3-N	N total	PO_4-P	P total
	mg·l^{-1}				
(MPC)	(0.10)	(2.3)	(2.5)	(0.065)	(0.10)
1.	0.009	2.3	**3.8**	0.020	0.045
2.	0.012	**2.48**	**3.53**	0.025	0.062
3.	0.011	**2.4**	**4.2**	0.011	0.032
4.	0.035	**3.3**	**4.1**	0.007	0.028
5.	0.033	**3.0**	**4.0**	**0.090**	**0.2**
6.	0.038	**2.47**	**3.9**	**0.104**	**0.203**
7.	0.027	**4.1**	**5.3**	**0.097**	**0.18**
8.	0.069	2.25	**4.85**	**0.27**	**0.96**
9.	0.09	**5.53**	**7.85**	**0.076**	**0.13**
10.	0.044	**3.0**	**4.1**	**0.12**	**0.20**

In bold exceed maximum permissible concentrations approved by Ministry of Environment of Lithuania [22].

The Bray-Curtis similarity index defined 5 groups of sites (Fig. 2), while Hierarchical Cluster Analysis of the percentage of indicatory taxonomic groups of macroinvertebrates defined three major clusters (Fig. 3). Cluster 1 corresponded to group I defined by the Bray-Curtis similarity index, cluster 2 joined groups II and III, and cluster 3 joined groups IV and V.

Sites belonging to cluster 1 (group I) were dominated by the tolerant isopod species *Asellus aquaticus*. In other sites this species was absent or found in low abundances. Groups of sites (II and III) joined by cluster 2 were characterized by the presence and dominance of mysidae *Limnomysis benedeni* and *Paramysis lacustris* (group II), and by a relatively high abundance of mayflies *Caenis macrura* and chironomids (group III). Groups of sites (IV and V) joined by cluster 3 differed from the rest of Bray-

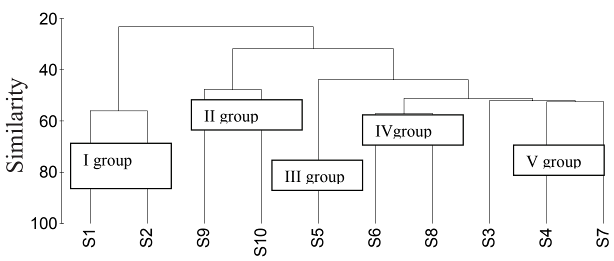

Fig. 2. Bray-Curtis index cluster analysis dendrogram showing similarity between macroinvertebrate taxa abundances at the sampling sites of the Nevėžis River (Nemunas basin, Lithuania).

Table 3. Values of macroinvertebrate metrics in the investigated reaches of the Nevežis River (Nemunas basin, Lithuania).

Metric	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Morphology	S, D	S, D	F	F	D	F	D	F	D	D
Richness measures										
SR	20	17	45	28	32	36	30	32	23	21
EPT	3	4	16	11	6	12	12	7	6	4
Diversity measures										
H’	3.23	2.89	3.55	4.36	3.74	3.86	4.12	3.98	2.83	2.76
Number of individuals (ind m^{-2})										
Total abundance	940±61	450±21	2137±52	653±33	753±41	2797±298	523±22	1083±86	1077±50	2123±14
Ephemeroptera	77±12	93±22	200±35	107±12	213±3	310±61	50±6	140±15	423±7	30±10
Trichoptera	73±7	3±1	123±18	137±7	17±7	960±122	63±3	230±6	13±6	10±5
Plecoptera	0	0	97±20	9±1	0	30±4	0	0	0	0
EPT	150±6	97±23	420±62	253±14	230±6	1300±182	113±9	370±15	437±7	40±10
Coleoptera	10±3	7±1	1210±95	120±6	13±7	533±24	170±23	150±6	13±6	5±1
Isopoda	350±29	190±15	0	0	7±1	17±10	0	0	0	0
Chironomidae	127±14	83±9	90±15	60±17	223±7	270±32	100±15	117±12	53±3	85±25
Oligochaeta	77±12	10±2	100±50	20±6	110±10	170±55	33±7	150±26	10±2	55±10
Percentage of individuals (%)										
Ephemeroptera	8.1±0.7	20.7±4.7	9.3±1.8	16.4±2.3	28.3±1.9	11.1±1.0	9.6±0.7	12.9±0.7	39.3±1.8	1.4±0.1
Trichoptera	7.8±1.1	0.8±0.2	5.7±0.7	21.0±1.8	2.2±0.7	34.3±0.9	12.0±0.5	21.2±1.5	1.2±0.4	0.5±0.1
Plecoptera	0	0	4.5±0.2	1.3±0.2	0	1.1±0.2	0	0	0	0
EPT	15.9±0.2	21.5±3.9	19.6±3.1	38.7±3.2	30.5±1.9	46.5±1.8	21.6±3.0	34.2±1.8	40.5±1.2	1.9±0.1
Coleoptera	1.1±0.5	1.5±0.4	56.6±2.1	18.4±0.5	1.7±0.4	19.0±1.9	32.5±1.4	13.8±0.8	1.2±0.1	0.2±0.01
Isopoda	37.2±1.9	42.2±3.5	0	0	0.9±0.1	0.6±0.2	0	0	0	0
Chironomidae	13.5±1.8	18.4±2.6	4.2±0.6	9.2±2.2	29.6±1.0	9.6±0.8	19.1±2.6	10.8±0.2	4.9±0.1	4.0±0.9
Oligochaeta	8.2±1.1	2.2±0.1	4.7±2.2	3.1±0.7	14.6±2.0	6.1±2.8	6.3±1.0	13.8±1.3	0.9±0.1	2.6±0.3
Biotic indices scores										
DSFI value	3	4	6	6	5	6	5	5	4	4
DSFI status	P	M	VG	VG	G	VG	G	G	M	M
HBI value	7.02	6.86	3.48	4.24	5.89	3.78	4.87	5.12	4.92	5.97
HBI status	P	P	E	VG	FP	VG	G	F	G	FP

(Morphology: S – straightened, D – deforested, F – forest; status: E – excellent, VG – very good, G – good, M – moderate, P – poor, F – fair, FP – fairly poor; values of abundance and composition metrics are mean±SE)

Curtis similarity groups of sites by statistically significantly higher rates of total species richness, EPT abundance, H’, and absolute and relative abundance of Trichoptera and Coleoptera (Fisher LSD test, $P<0.05$). Sites were dominated by caddisflies *Hydroptila* spp. (group IV) and beetle larvae *Limnius volckmari* (group V).

Sites belonging to different clusters differed mainly in two environmental descriptors: riverbed morphology and status of riparian vegetation. Cluster 1 included straightened deforested sites, cluster 2 included deforested sites with natural riverbed morphology, and cluster 3 included sites with natural riverbed morphology and a narrow belt of forest along the riverside (except site 7) (Fig. 3, Table 3). Neither water quality metrics nor average depths significantly differed among groups of river sites belonging to different clusters (Fisher’s LSD test).

After rearrangement of sites to groups according to differentiating environmental descriptors (site 7 was attributed to the group of deforested sites with the natural riverbed), statistically significant differences were found in total abundance of macroinvertebrates, absolute (ind. m^{-2}) and relative (%) abundances of EPT, Coleoptera, and Trichoptera. The values of these metrics were significantly higher in the sites with the natural riverbed, where narrow belts of riparian forest still exist (Table 4). The group of straightened sites significantly differed from the rest of sites by high abundance of Isopoda and low abundance of Ephemeroptera. No macroinvertebrate metrics in deforested sites with the natural riverbed significantly differed from those in other groups of sites: values of metrics were comparable either to the values in straightened or in forested sites (Table 4). The macroinvertebrate community status based on both DSFI and HBI indices was significantly higher in natural forested river reaches and was classified as good or even very good, whereas the status of most of the rest of sites was recognized to be moderate or poor.

Table 4. Mean±SE characteristics of macroinvertebrate metrics at straightened deforested (S, D), natural deforested (D) and natural forested (F) reaches of the Nevėžis River (Nemunas basin, Lithuania).

Metrics	Sites		
	S, D	D	F
Richness			
SR	18±1*	26±3	35±4*
EPT	3±1*	7±2	11±2*
Number of individuals (ind m^{-2})			
Total abundance	695±113	1119±177	1667±258*
EPT	123±16	205±46	586±129*
Trichoptera	38±16	26±7	362±108*
Coleoptera	8±4	50±23	503±134*
Ephemeroptera	85±12*	179±50	189±28
Isopoda	270±38*	2±1	4±1
Percentage of individuals (%)			
EPT	17.7±2.6	18.3±4.2	35.1±3.2*
Trichoptera	5.5±1.7	2.3±0.5	21.7±3.1*
Coleoptera	1.2±0.3	4.5±0.4	30.2±5.2*
Isopoda	38.8±2.2*	0.2±0.01	0.2±0.01
Biotic indices scores			
DSFI	3.5±0.5	4.5±0.3	5.7±0.2*
HBI	6.9±0.1*	5.4±0.3*	4.1±0.3*

*Statistically significant difference from all other study reaches (non-parametric Kruskal-Wallis ANOVA, $P < 0.05$; Fisher's LSD test, $P < 0.05$).

Discussion

There is a large number of publications dealing with the impact of water pollution and riverbed regulation on macroinvertebrate communities [5, 23-26]. Riparian vegetation also plays an important role in structuring macroinvertebrate fauna [27-28]. However, until now only the impact of pollution and straightening of riverbeds on macoinvertebrate fauna has been studied in Lithuania [29], while the influence of riparian vegetation has not been considered.

The results of our investigation showed that Trichoptera, Coleoptera and EPT metrics, total abundance of macroinvertebrate individuals, and overall status of macroinverte-

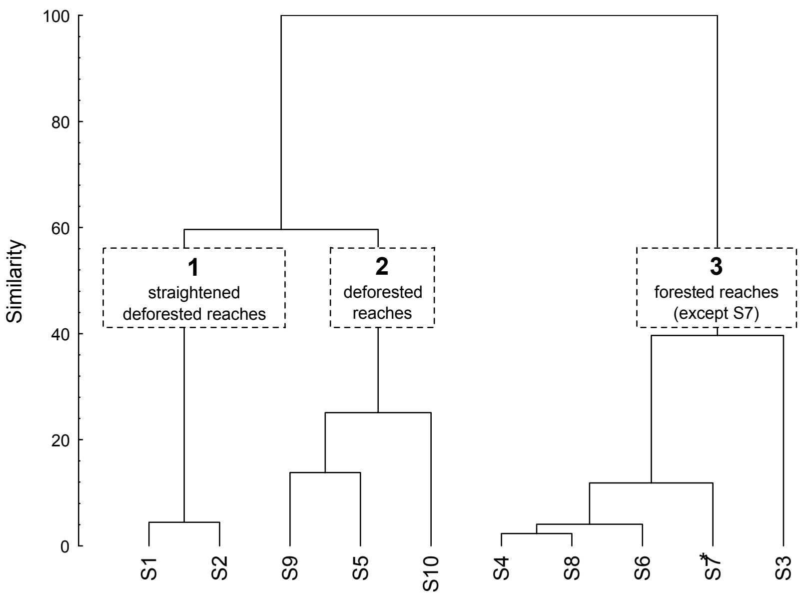

Fig. 3. Hierarchical cluster analysis dendrogram showing similarity between indicatory macroinvertebrate taxa relative abundances at the sampling sites of the Nevėžis River (Nemunas basin, Lithuania).

brate communities were significantly higher in forested sites if compared to straightened and/or deforested sites. This is comparable with the findings that:

(i) the occurrence of EPT taxa may be affected by factors associated with riparian cover [30-31]

(ii) forest shade and coverage increase EPT abundance and taxa diversity [32]

(iii) forests may support greater terrestrial invertebrate abundance than adjacent habitats [33-34].

According to Couceiro et al. [35], deforestation affects macroinvertebrate fauna in a way similar to water pollution, i.e. causing reduction in taxa richness and simplifying insect community composition. The impact of deforestation on macroinvertebrates may occur due to differences in the relative availability of basal food resources, with agricultural stream communities dependent on *in situ* primary production and forest stream communities dependent largely on food resources of terrestrial origin [36].

Since macroinvertebrates are considered to be good indicators of ecological status because of their wide sensitivity variation toward contaminants [37-38] and a possibility to integrate the combined effects of all impacts acting on a water body [39], macroinvertebrate-based biotic indices were expected to reflect both changes in the river morphology and water quality. However, biotic indices were not able to identify soundly any of the aspects of disturbance in the studied river. Despite small differences in impact assessment, DSFI and HBI indices showed a strong impact of river straightening and deforestation. However, they did not clearly detect decreases in water quality. This may have been due to several reasons. Concentrations of biogenic matter in the river water, though exceeding the highest permissible values, might not be so elevated as to radically change the status of macroinvertebrate communities. This is consistent with Timm et al. [40], who indicate that straightening of the riverbed is far more important for the biota of Estonian streams than organic pollution. On the other hand, the integral metrics of macroinvertebrate taxa can fail to reflect all aspects of changes in macrozoobenthos communities due to diffused organic pollution. Small changes in some of the metrics can have little effect on the absolute value of the integral or biotic index.

Single specific macroinvertebrate metrics, differently from integral metrics, indicated the presence of diffused pollution in the investigated river. Specimens of *Baetis*, *Caenis Siphlonurus*, and *Hydropsyche* genera were the most abundant representatives of EPT taxa in the studied sites. *Baetis* and *Caenis* are the main representatives of usually intolerant EPT taxa in agriculturally impacted streams [41-42], while the abundance of individuals of *Siphlonurus* and *Hydropsyche* was estimated to be much greater in Lithuanian rivers receiving diffused pollution compared to reference rivers [43-44]. Stoneflies, which are the most sensitive to pollution among insects [45] and which are abundant in reference rivers and absent from considerably polluted Lithuanian rivers [44], were found in low abundances only in 3 of 10 investigated sites. Caddisflies, which are generally thought to be a group with intermediate pollution tolerance (greater than that of mayflies and stoneflies but lower than that of dipterans [46, 47]), were among the dominant in the sites with natural morphology of the studied river. Lenat [48] reported that Coleoptera replaced sensitive EPT taxa in the streams receiving agricultural runoff; they were ranked as relatively more tolerant to agricultural inputs [49]. Our results are in high agreement with this: coleopterans (particularly *Limnius volckmari*) were among the most abundant or even dominant macorinvertebrate groups in the river sites with natural morphology. High densities of *Chironomus* larvae have been regarded as excellent bioindicators of poor quality water [50], in which the increase in their density in response to organic enrichment by anthropic actions frequently eliminates all other Chironomidae genera [51]. Dominant chironomid taxa such as *Cricotopus*, *Dicrotendipes*, *Ablabesmyia*, and certain *Polypedilum* are known to be associated with agricultural and sewage inputs [52]. *Cricotopus* and *Ablabesmyia* were among the dominant chironomid genera almost in all our sites, thus indicating the presence of disturbance in water quality. Finally, longitudinal gradient, which is recognized as an important factor in structuring macroinvertebrate communities in the rivers [53-54], was not well expressed in the studied river, as some of both upstream and downstream sites were classified into the same cluster defined by the Bray-Curtis similarity index. The absence of longitudinal gradient is known to be characteristic of streams impacted by agricultural land use [3].

The results of our study confirm the importance of riparian vegetation in structuring taxonomic composition of macroinvertebrate fauna. The presence of forest belts along riversides seems to support good overall status of macroinvertebrate communities, even if concentrations of nutrients in the river are elevated due to agricultural runoff.

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