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INFLUENCE OF HYDROPOWER DAMS ON THE STATE OF MACROINVERTEBRATES ASSEMBLAGES IN THE VIRVYTE RIVER, LITHUANIA

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Abstract. Macroinvertebrate organization along the Virvytė River was examined to relate biological response in environmental changes. Benthic macroinvertebrates and a range of environmental variables were sampled from three study sections: control, HPP dams and below HPP dams. Total macroinvertebrate taxon number (NT = 28), EPT taxon number (NT = 13) and Shannon-Wiener diversity index (H′ = 3.85) were the highest in control sites of the river and the smallest in HPP dams (17, 5, 2.75, respectively). Taxon number and total abundance of macroinvertebrates declined significantly both in HPP dams and below them in comparison with the control sites. Total macroinvertebrate abundance in the control sites (698±41 ind.m^{-2}) was significantly higher than in HPP dams and below them (430±21 ind.m^{-2} and 425±22 ind.m^{-2}, respectively). The obtained data show that the investigated sections differed in terms of composition and relative abundance of different taxa of macroinvertebrates. Compared to reference conditions (control sites), macroinvertebrate samples from the sites below the dams and in them had relatively more Chironomidae larvae, Oligochaeta and Mollusca and fewer of the more sensitive taxa Plecoptera, Ephemeroptera and Trichoptera. According to Danish Stream Fauna Index and Hilsenhoff biotic index, water quality in the Virvytė River control sites was higher in comparison with water quality in HPP dams and below-dam sites.

Keywords: Virvytė River, HPP dams, benthic macroinvertebrates, water pollution.

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Introduction

Modification of natural flow regimes alters the abundance and composition of biological conditions in aquatic environments (Wright *et al.* 2002; Winterwerp, Kesteren 2004; Ambers 2007; Soulsby *et al.* 2010). Dams affect ecosystems in a number of ways: by altering the natural flow fluctuations, modifying the physicochemical characteristics of riverine water and fragmenting the continuity of rivers (Grzybkowska, Dukowska 2002; Bahuguna *et al.* 2004; Lamsodis, Vaikasas 2005; Penczak, Kruk 2005; Pietraszewski *et al.* 2008; Zdankus *et al.* 2008; Vaikasas 2010).

Hydropower dams (HPP) block rivers, reducing connectivity and resulting in negative effects on stream biota upstream and downstream from the impoundment (Céréghino *et al.* 2002; Grubbs, Taylor 2004; Greathouse *et al.* 2006; WFD & Hydropower 2007; Hu *et al.* 2008). Dams also block movement of fishes and affect habitat and physicochemical conditions of streams by converting lotic habitats to lentic, changing stream flow, altering water quality and modifying channel morphology and bed structure by increasing siltation upstream and erosion downstream (Sear *et al.* 2004; Malik, Richardson 2009). These alterations cause changes in assemblage structure of fishes and macroinvertebrates via shifts in composition, abundance and diversity both upstream and downstream from the impoundment.

The responses of macroinvertebrates to regulated river systems are often complex and variable. Considerable evidence, however, exists that hydraulic conditions are the driving forces affecting distribution and abundance patterns of benthic invertebrates (Christopher *et al.* 2007).

Some authors have reported changes in taxonomic composition of macroinvertebrate communities due to alteration of fluvial habitats by effect of large dams (Lessard, Hayes 2003), while others have found a relatively minor impact of small dams on the river

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biota in downstream reaches (Sharma *et al.* 2005; Ambers 2007). According to Principe (2010), differences in taxonomic composition between upstream and downstream reaches have not been detected; however, analysis of variance (ANOVA) showed some changes in richness and diversity, in the density of filtering collectors and shredders and in the abundance of some species. These results indicate that small dams have only a moderate impact compared to the documented impact of large dams.

Studies that focused on benthic macroinvertebrates usually found that sampling sites immediately downstream of dams were characterised by lower taxonomic diversity than unaffected sites upstream or sites further downstream where dam effects have attenuated (Céréghino *et al.* 2002; Camargo *et al.* 2005). Other studies have documented either higher diversity just below a dam than at sites further downstream or decreases only in certain taxonomic groups like Ephemeroptera, Plecoptera, Trichoptera (EPT), with little difference in total diversity between upstream and downstream sites (Lessard, Hayes 2003). Likewise, total abundance has been found either to decrease or to increase in dam tailwaters, the latter occurring when dominance of certain taxa like Chironomidae becomes pronounced (Munn, Brusven 1991).

Ambers (2007) pointed out that the impact of small dams declined to negligible ecological levels a few kilometres downstream. Large dams produce notable changes in macroinvertebrate communities by elimination of habitats, flow regulation and alteration of thermal regime (Lessard, Hayes 2003; Grubbs, Taylor 2004; Doyle *et al.* 2005; Marčiulionienė *et al.* 2011). As a result, sensitive species disappear and density of entropic species increases.

There is a large number of publications dealing with the impact of hydropower ponds on macroinvertebrate communities (Cortes *et al.* 2002; Maiolini *et al.* 2007; Katano *et al.* 2009; Tszydel *et al.* 2009; Principe 2010). Until now the impact of hydropower ponds on macroinvertebrate fauna has not been studied in Lithuania streams or rivers.

The aim of this study was to assess the effect of small HPP dams on stream habitats and on the structure of benthic macroinvertebrate community of the Virvytė River in Lithuania.

1. Materials and methods

The study was conducted in April 2010 in the Virvytė River. The length of the river is 99.7 km, draining a catchment of 1.134 km^2 with an average slope of 0.035% and an average discharge of 9.93 m^{3}s^{-1} (Gailiušis *et al.* 2001). Ten hydropower plants are built on the Virvytė River (Fig. 1).

The macroinvertebrates for our study were collected in 23 sampling sites differing in morphology along the Virvytė River (Table 1): 3 control sites (dam-unaffected), 10 sites in HPP dams and 10 sites below HPP dams. Gravel and pebble were dominating bottom substrate.

The samples of macroinvertebrates were collected by the kick-sampling method in three 0.1 m^2 areas at each study site (Kleemola, Söderman 1993). Additional samples of macroinvertebrates (2 samples per site) were taken from plants, stones or stumps to determine the Danish Stream Fauna Index (DSFI). A total of 115 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.

We calculated total number of macroinvertebrate taxa (NT), number EPT taxa, Shannon-Wiener diversity index (H′) as well as the total abundance (ind. m^{-2}) and relative abundance (%) of indicatory taxonomic groups (EPT, Chironomidae, Oligochaeta, Mollusca, Coleoptera and Isopoda).

DSFI (Arbačiauskas 2009) and Hilsenhoff biotic index (HBI) (Hilsenhoff 1988) were calculated to assess the ecological status of investigated river sites. HBI tolerance values were taken from Mandaville (2002).

The relationships between macroinvertebrate metrics and water quality values were determined using Sperman rank correlation. The General Linear Model ANOVA and Fisher Least Significant Difference (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, version 6.0 (Sakalauskas 2003).

2. Results and discussion

The measured values of the main physiochemical variables in the investigated sites of the Virvytė River are presented in Table 2. Total nitrogen concentrations in water exceeded the maximum permissible concentration, approved by the Ministry of Environment of Lithuania (Lithuanian Standards 2010), in and below hydropower dams of Kapėnai, Skleipiai and Gudai. The values of N total in sediments of HPP dams were higher in comparison with the values below HPP dams and in control sites.

A total of 69 macroinvertebrate taxa belonging to 37 families were identified in the investigated river. The greatest taxa richness was recorded for Trichoptera (11 taxa: 10 species and 1 genus), Mollusca (11 species) and Ephemeroptera (11 species). Chironomids

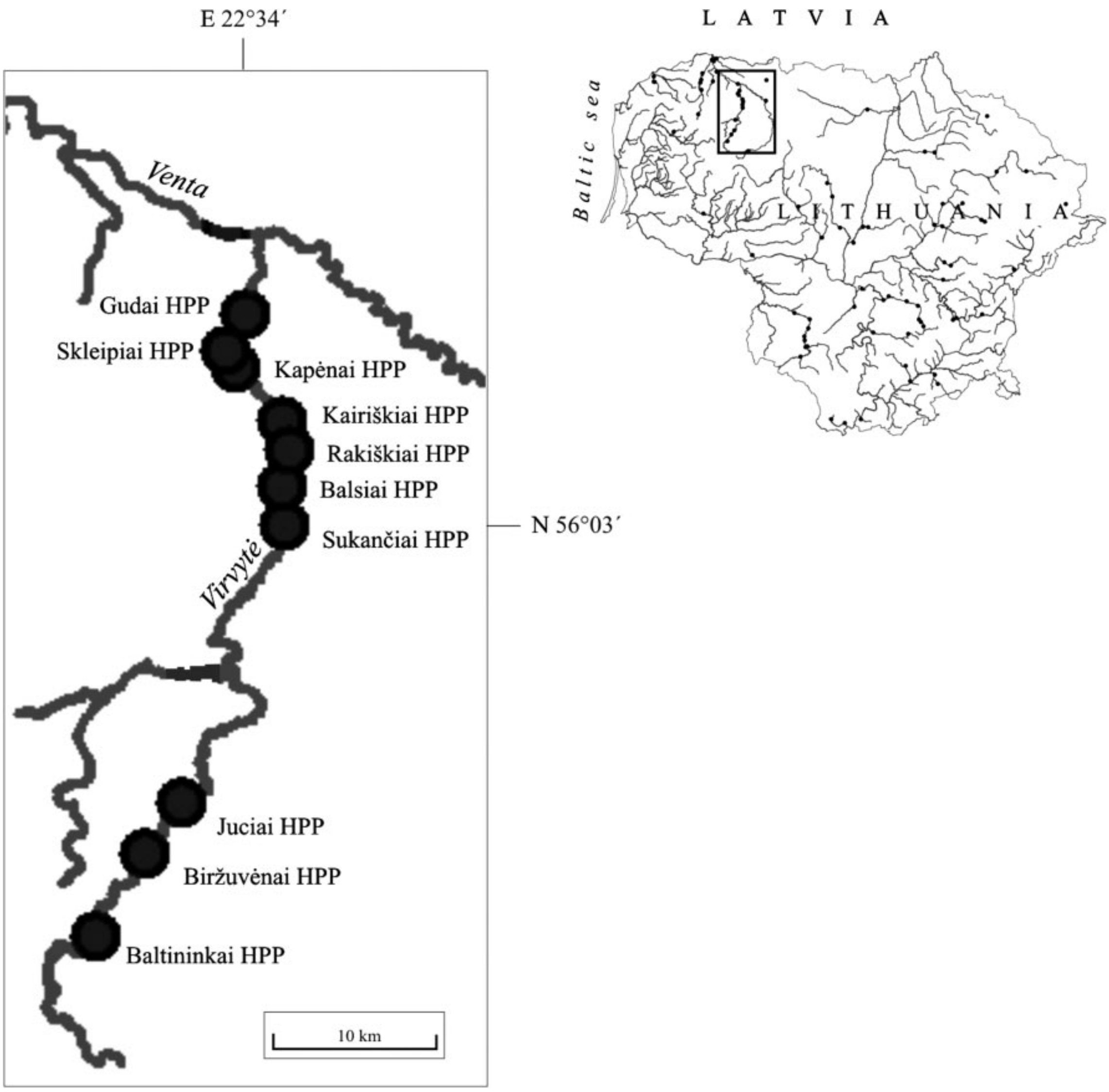

Fig. 1. Location of HPP in the river Virvytė

Cricotopus algarum and oligochaetes species (sp.) were detected in all investigated sites.

The total number of macroinvertebrate taxa (NT) and the number of EPT taxa were highly variable across the river, ranging within 12–30 and 2–14, respectively (Fig. 2). According to Munn and Brusven (1991), the major factors contributing to the simplified macroinvertebrate community are the reduced habitat diversity, fluctuating water levels, altered thermal regime, and possibly altered food supply.

The results obtained show that macroinvertebrate community compositions from the three sections – control sites, sites in HPP dams and sites below HPP dams – were different. Caddisflies *Notidobia ciliaris, Ithytrichia lamellaris, Hydroptila* sp., mayflies *Heptagenia sulphurea*, water beetles *Elmis* sp., molluscs *Ancylus fluviatilis* and dipterans *Dicranota bimaculata* species were absent from the sites in and below dams. The sites in and below the dams of the Virvytė River were dominated by Diptera and Oligochaeta in abundance. Ephemeroptera, Trichoptera and Plecoptera dominated in control sites of the Virvytė River.

The Shannon-Wiener diversity index (H′) ranged from 1.59 to 3.87 in the Virvytė (Fig. 2). The lowest H′ was detected in the Baltininkai HPP dam, where the amount of N total in sediments was the highest. The total number of macroinvertebrate taxa was the lowest (12) in this HPP dam, too.

The total abundance of benthic macroinvertebrates was found to range from 250 to 770 ind. m^{-2} in the Virvytė River (Fig. 3).

Relative abundances of different taxonomic groups of macroinvertebrates also ranged within a broad scale. Stoneflies were not found in HPP dams, and constituted only 0% to 8.7% below HPP dams and 15.1% to 20.5% in control sites (Fig. 4). According to Bahuguna *et al.* (2004), stoneflies were absent from the regulated stretch. Mayflies were the most abundant

Table 1. General morphological characteristics in studied sites of Virvytė River (Nemunas basin, Lithuania)

Site no			Longitude	Latitude	Distance from mouth, in km	Bottom substrate
1	Janapole	control	55°48′59′′	22°22′11′′	88.8	pebble
2	Baltininkų HPP	HPP dam	55°50′53′′	22°24′30′′	77.7	gravel
3		below HPP dam	55°50′56′′	22°24′40′′		pebble
4	Biržuvėnų HPP	HPP dam	55°53′35′′	22°27′21′′	72.0	gravel
5		below HPP dam	55°53′41′′	22°27′24′′		gravel
6	Jucių HPP	HPP dam	55°55′18′′	22°29′24′′	65.2	gravel
7		below HPP dam	55°55′21′′	22°29′24′′		gravel
8	Mažikai	control	55°56′43′′	22°30′18′′	58.1	pebble
9	Sukončių HPP	HPP dam	56°4′21′′	22°34′57′′	29.8	silt-sand
10		below HPP dam	56°4′24′′	22°35′1′′		gravel
11	Balsių HPP	HPP dam	56°5′38′′	22°34′47′′	27.7	gravel
12		below HPP dam	56°5′43′′	22°34′53′′		pebble
13	Rakiškių HPP	HPP dam	56°6′50′′	22°35′11′′	23.2	gravel
14		below HPP dam	56°6′54′′	22°35′17′′		gravel
15	Kairiškių HPP	HPP dam	56°7′48′′	22°34′39′′	20.2	gravel
16		below HPP dam	56°7′50′′	22°34′46′′		pebble
17	Kapėnų HPP	HPP dam	56°9′29′′	22°31′56′′	13.4	silt-sand
18		below HPP dam	56°9′32′′	22°31′53′′		pebble
19	Skleipių HPP	HPP dam	56°9′58′′	22°31′21′′	10.8	silt-sand
20		below HPP dam	56°10′3′′	22°31′29′′		pebble
21	Gudų HPP	HPP dam	56°11′12′′	22°32′23′′	6.6	gravel
22		below HPP dam	56°11′15′′	22°32′30′′		pebble
23	Gyvuoliai	control	56°12′40′′	22°33′23′′	2.8	pebble

Table 2. The values of chemical variables (*N* – nitrogen, *P* – phosphorus) and suspended (sediments SS) in studied sites of Virvytė River

Site no.	*N* total in water, mg l^{-1}	*P* total in water, mg l^{-1}	SS, mg l^{-1}	*N* total in sediments, mg kg^{-1}	*P* total in sediments, mg kg^{-1}
1	1.34	0.040	5.2	350	290
2	1.54	0.052	3.6	5023	650
3	1.33	0.041	6.2	716	342
4	1.34	0.039	2.2	1051	224
5	1.55	0.039	7.4	390	189
6	1.59	0.040	4.8	2745	638
7	1.29	0.053	3.0	257	147
8	1.66	0.045	13.4	228	239
9	2.10	0.050	9.0	2774	425
10	2.36	0.047	10.0	650	254
11	2.36	0.042	22.4	744	247
12	2.10	0.040	10.0	375	187
13	2.10	0.046	8.4	2190	606
14	2.50	0.044	12.6	1577	376
15	2.48	0.049	40.8	1022	247
16	2.36	0.052	9.6	738	333
17	**2.72**	0.053	14.2	2628	1063
18	**2.60**	0.044	8.0	467	217
19	**2.77**	0.059	57.8	2920	472
20	**2.71**	0.059	20.0	686	244
21	**2.59**	0.051	14.1	423	301
22	**2.65**	0.052	9.0	248	254
23	1.51	0.042	7.8	291	250

Note: In bold – exceeded means of maximum permissible concentrations approved by Ministry of Environment of Lithuania (Lithuanian Standards 2010).

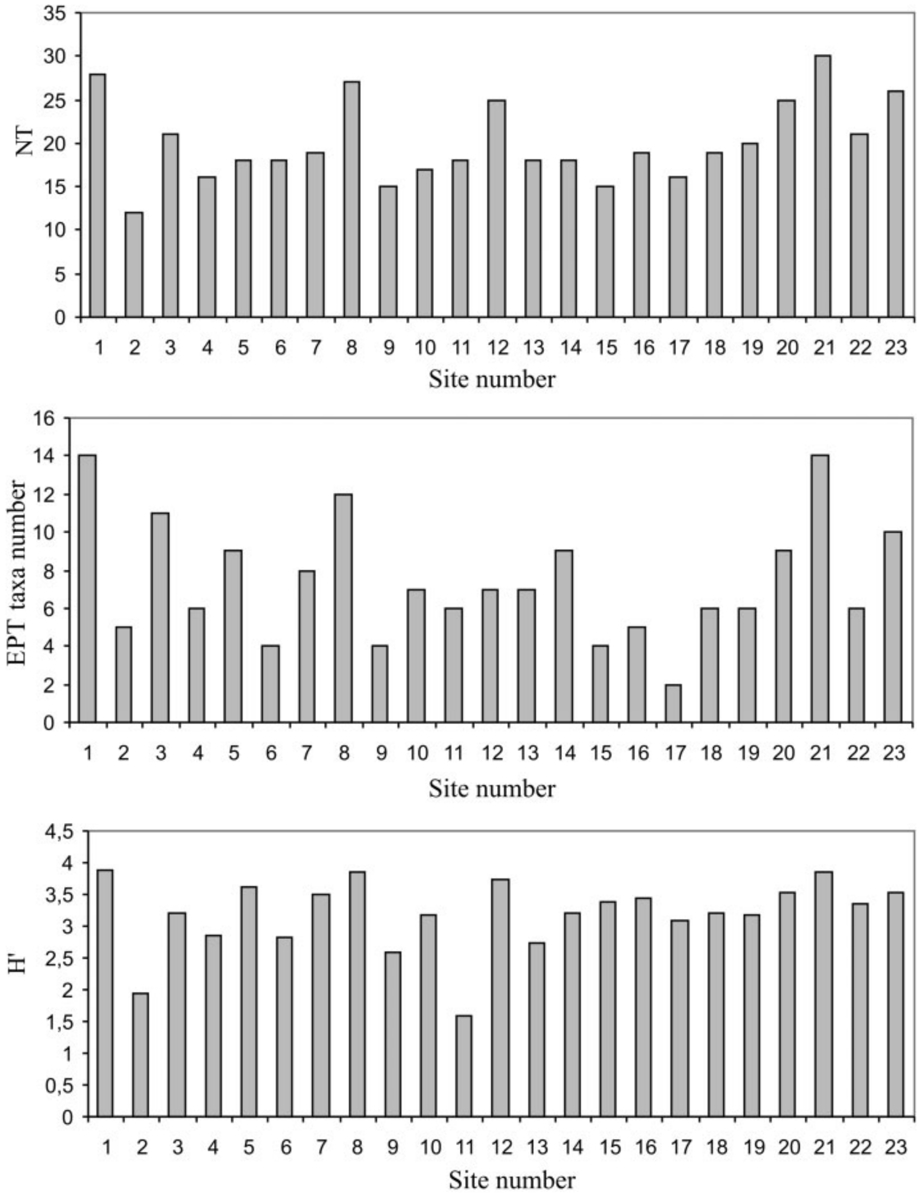

Fig. 2. Distribution of NT, EPT taxa number, H′ in studied sites of Virvytė River

group of macroinvertebrates in control sites (sites 1, 8, 23) and below Rakiškės (site 14) and Kairiškės HPP dams (site 16). We found that mayflies *Baetis rhodani*, *Siphlonurus alternatus* and *Caenis macrura* were more abundant in and below HPP dams. The mayfly *Heptagenia sulphurea* was absent. Other studies revealed increase of Baetidae and Caenidae and decrease of Heptageniidae due to flow reduction (Mantel *et al.* 2010).

Chironomids were the most abundant in HPP dams in our study, while caddisflies were found in smaller numbers (Fig. 4). The relative abundance of mayflies in and below HPP dams was lower, too.

We found that NT was negatively correlated with N total in sediments (Table 3). The total abundance of individuals and relative abundance of caddisflies, EPT and water beetles larvae was negatively correlated with N total in water, and molluscs showed an opposite trend in relation to N total in water (Table 3).

The relative abundance of caddisflies was negatively correlated with *P* total in water (Table 3). Relative abundance of EPT, water beetles larvae, and DSFI were negatively correlated with *P* total in sediments, whereas relative abundance of oligochaetes and molluscs showed an opposite trend in relation to *P* total in sediments (Table 3). Relative abundance of molluscs was positively correlated with N total in water and N total in sediments (Table 3). No reliable correlation was found between *P* total in water and macroinvertebrate metrics (Vaikasas, Lamsodis 2011).

After rearrangement of sites to groups according to differentiating environmental descriptors (control, HPP dam, below HPP dam), statistically significant differences were found in NT, EPT taxa number, H′, total

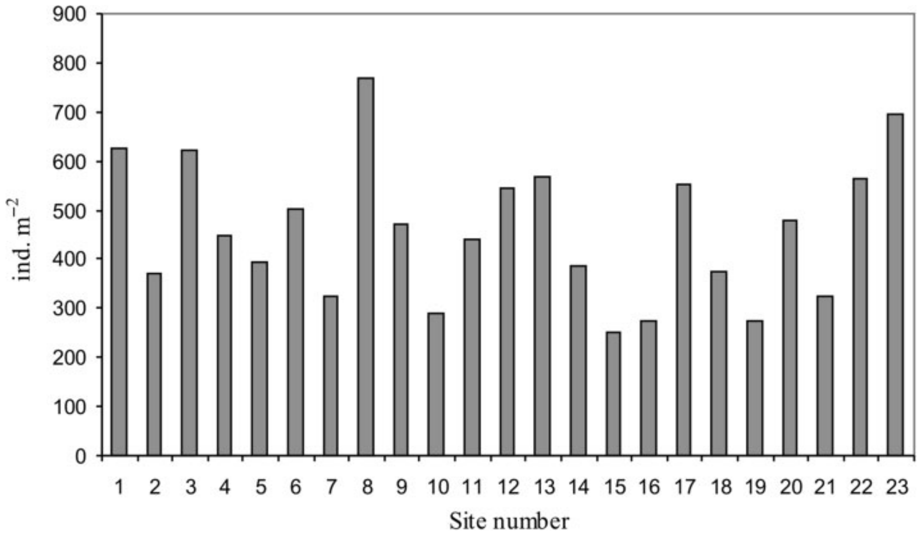

Fig. 3. Total macroinvertebrate abundance in studied sites of Virvytė River

abundance of macroinvertebrates (ind.m^{-2}) and relative (%) abundance of Plecoptera, Trichoptera EPT, Chironomidae and Oligochaeta in the Virvytė River (Figs 5, 6; Table 4). According to Greathouse *et al.* (2006), significant differences were found between dammed and undammed sites for many macroinvertebrate taxa.

The values of NT (ANOVA F = 6848.83, p = 0.0004), EPT taxa number (ANOVA F = 979.27, p = 0.002), H′ (ANOVA F = 2566.4, p = 0.002), total abundance of macroinvertebrates (ANOVA: F = 25214.17, p = 0.00001), percentage of Trichoptera and percentage of EPT were significantly higher in the control sites than in the sites in and below HPP dams in the investigated river (Figs 5, 6; Table 4) (Fisher's LSD test). The relative abundance of Plecoptera was significantly higher in the control sites (17.2) than in the sites below HPP dams (2.5), and the relative abundance of Ephemeroptera were significantly higher in the control sites (48.7) than in HPP dams (24.4) in the investigated River (Fisher's LSD test) (Table 4). Ecosystem health has an inverse relationship with human impacts resulting in the presence of few tolerant species in very large numbers (Brown 2005; Novotny *et al.* 2005). According to Nichols *et al.* (2006), macroinvertebrate samples from sites below dams had relatively more Chironomidae larvae and Oligochaeta and fewer of the more sensitive taxa, Plecoptera, Ephemeroptera and Trichoptera.

The Shannon-Wiener diversity index (H′) was significantly lower (ANOVA F = 2566.4, p = 0.002) in

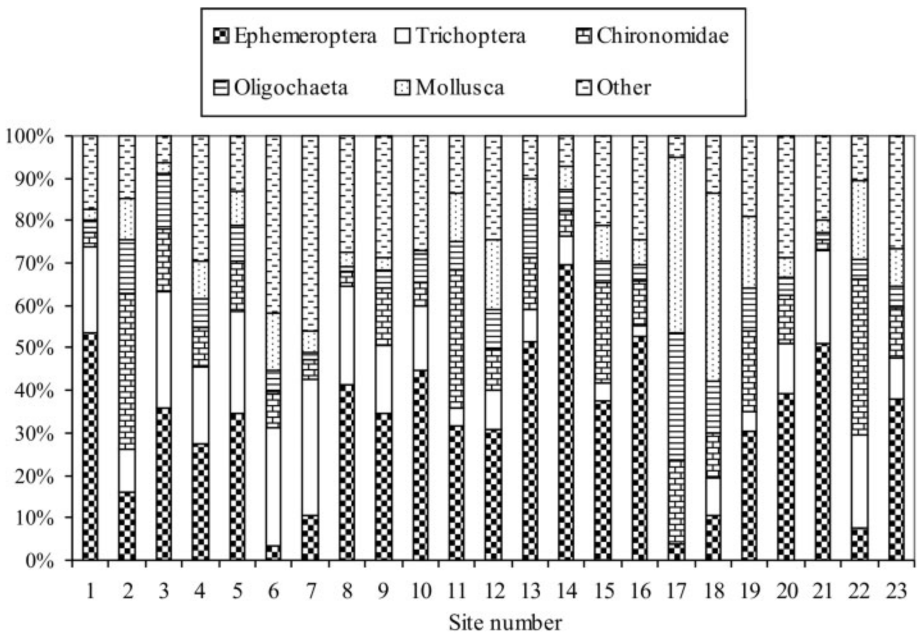

Fig. 4. Relative abundances of the main benthic macroinvertebrate groups in studied sites of Virvytė River

Table 3. Spearman's rank correlation coefficient between macroinvertebrate metrics and chemical parameters in the Virvytė River

	N total, mg l^{-1} in water	*P* total, mg l^{-1} in water	*N* total in sediments	*P* total in sediments
NT	ns	ns	−0.46**	ns
EPT	ns	ns	ns	ns
Total abundance of individuals (ind m^{-2})	−0.26*	ns	ns	ns
Percentage of individuals (%)				
Plecoptera	ns	ns	−0.33*	ns
Trichoptera	−0.74**	−0.30*	ns	ns
EPT	−0.34*	ns	ns	−0.25*
Coleoptera	−0.18*	ns	−0.36*	−0.39*
Chironomidae	ns	Ns	ns	Ns
Oligochaeta	ns	ns	0.45*	0.63**
Mollusca	0.40 *	ns	ns	0.35
Biotic index				
DSFI	ns	ns	ns	−0.55*
HBI	ns	ns	ns	ns

* $p<0.05$, ** $p<0.01$.

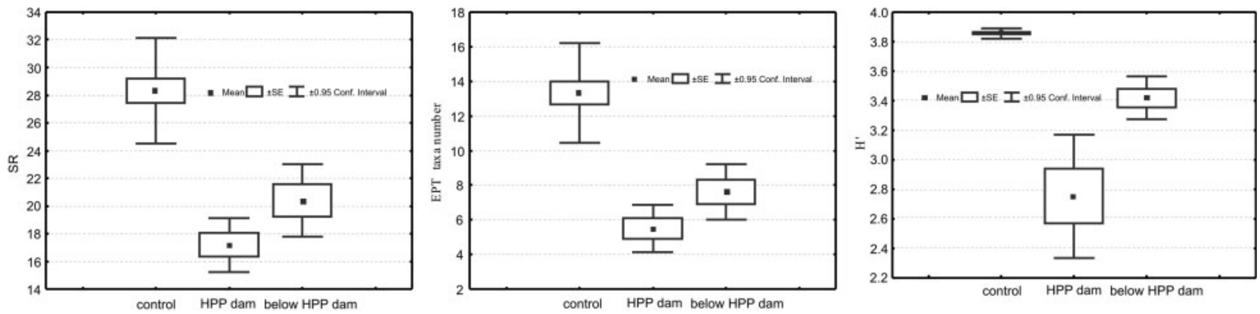

Fig. 5. The number of total macroinvertebrate taxa (NT), sensitive to pollution EPT taxa and the means of Shannon-Wiener diversity index (H´) in studied sites of Virvytė River

HPP dams in comparison with control sites and sites below HPP dams (Fig. 5).

Dam building has significant impacts on the composition of macroinvertebrates just above the dam site, probably as a result of deposition of inorganic material within a small reservoir and changes in water velocity (Doyle *et al.* 2005; Sharma *et al.* 2005). We found that both of the disturbed sites (in HPP dams and below dams) had lower taxa number of macroinvertebrates (both total and EPT taxa) than the control sites (Fig. 5, Table 4) (Fisher's LSD test). These findings are supported by the study of Jesus *et al.*

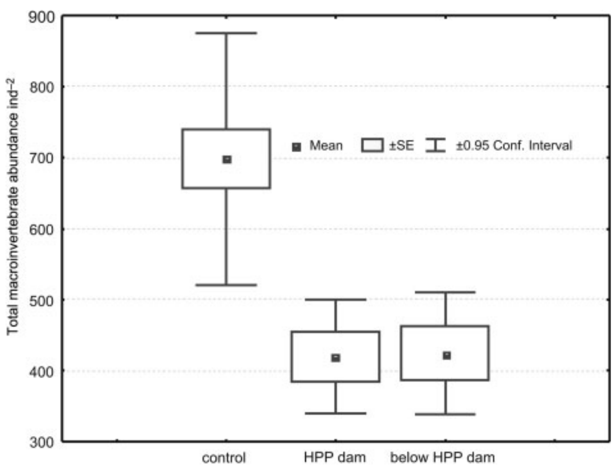

Fig. 6. The means of total macroinvertebrate abundance in studied sites of Virvytė River

Table 4. Mean±SE characteristics of macroinvertebrate metrics at control, HPP dam, below HPP dam reaches of Virvytė River

Metric	Control	HPP dam	Below HPP dam
Total macroinvertebrate taxa number	28±1*	17±1	20±2
EPT taxa	13±1*	5±1	8±1
Percentage of individuals (%)			
Ephemeroptera	48.7±3.8*	24.4±5.1*	36.7±3.6
Trichoptera	21.8±0.9*	11.4±2.9*	14.7±3.1
Plecoptera	17.2±1.6*	0	2.5±0.9*
EPT	87.7±1.4*	35.8±4.8*	53.9±4.6*
Coleoptera	4.7±1.1	4.3±1.4	10.0±2.6
Chironomidae	3.0±0.3*	21.2±3.4*	9.8±1.0*
Oligochaeta	2.1±0.4*	9.7±2.4	6.9±1.1
Mollusca	2.9±0.1*	13.8±3.4*	10.2±4.0
Isopoda	0	6.9±2.5	4.8±2.5

*Statistically significant difference from all other study reaches Fisher's LSD test, $p<0.05$.

(2004), who described the use of EPT taxa richness (in %) as the most descriptive tool in analyzing biological data to ensure the most effective investigation of water quality.

In a study by Katano *et al.* (2009), the change in assemblage structure did not involve a substantial loss of taxa or disappearance of EPT taxa; instead, a shift occurred in the dominant taxa. An increase in macroinvertebrate density below dams compared to above-dam sites is commonly accompanied by a significant reduction in taxonomic diversity, disappearance of EPT taxa or dominance of dipterans (Munn, Brusven 1991). The values of relative abundance of Chironomidae, Oligochaeta and molluscs were significantly lower in the control sites in comparison with the sites in and below the dams (Table 4) (Fisher's LSD test). The proportion of tolerant chironomids and non-insect individuals (oligochaetes) increased at degraded sites and were dominating in organically polluted sites (Masese *et al.* 2009).

Our results suggest that hydropower plants have a negative impact on water quality. DSFI value was the highest in control sites and reliably differed from the value in HPP dams (ANOVA $F = 11336.6$, $p = 0.0001$). Water quality was classified as very good in control sites, good in sites below HPP dams and moderate in HPP dams (Fig. 7). The HBI showed a significant variation between control river segments and segments in and below HPP dams (ANOVA $F = 4113.28$, $p = 0.0001$). According to HBI, water quality was excellent in the Virvytė River control sites, fair below HPP dams and fairly poor in HPP ponds. The results of investigations by Thomson *et al.* (2005) also showed that sites downstream of the dam had poorer HBI scores than upstream (control) sites. Cortes *et al.* (2002) found that in the regulated segment of the river, poor water quality and lack of litter input affected mainly the shredders group.

In conclusion, construction of hydropower plants induces cardinal changes in species composition of macrozoobenthos and water quality of the river. Not only most reophylic species of macrozoobenthos become extinct, but also distribution and abundance of the surviving spices changes, which affects distribution and life quality of other vertebrate and invertebrate animals.

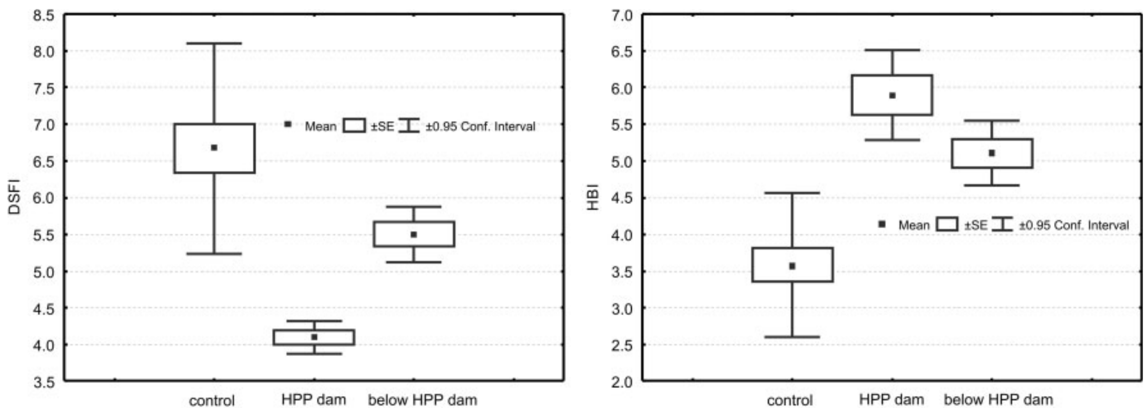

Fig. 7. The means of biotic indices score in studied sites of Virvytė River

Conclusions

1. Dam building has significant impacts on macroinvertebrate composition in the Virvytė River. Both of the disturbed sites (in and below HPP dams) have significant lower taxa number of macroinvertebrates (both total and EPT taxa) compared to the control sites. The total abundance of macroinvertebrates was significantly higher in control sites of river than in the sites in and below HPP dams.

2. The macroinvertebrate assemblages in control sites dominated pollution sensitive EPT (87.7% of total abundance) and in HPP dams pollution tolerant chironomids (21.2% of total abundance).

3. According to DSFI, water quality was classified as very good in the control sites, good below HPP dams and moderate in HPP dams. Water quality according to HBI was excellent in the Virvytė River control sites, fair below HPP dams and fairly poor in HPP dams.

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