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IMPACT OF SMALL HYDROPOWER PLANTS ON PHYSICOCHEMICAL AND BIOTIC ENVIRONMENTS IN FLATLAND RIVERBEDS OF LITHUANIA

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Abstract. The impact of a small hydropower plant (SHP) on river water quality and macroinvertebrates has been investigated in 5 Lithuanian rivers and involved 17 dams, ten of which are in a sequence in the same river system. The hydrostatic head of SHP dams ranged from 2.75 to 14.50 m and the capacities of their reservoirs varied from 40×10^3 to $15{,}500\times10^3$ m^3. Physicochemical characteristics, as well as macroinvertebrate communities, were evaluated in sites above and below the SHP dams comparing them with reference sites.

It was established that construction of SHP dams (H<15 m) in Lithuania substantially changed regimes of suspended solids, fine particles and nutrients only locally regardless of hydrostatic head of the dam. Compared to reference sites, SHP reservoirs and sites below SHP dams had relatively more *Chironomidae* larvae and *Oligochaeta*, and less *Coleoptera* larvae as well as the relative abundance of pollution-sensitive *Ephemeroptera* and EPT. Water quality according to biotic indexes (DSFI and HBI) in the sites influenced by SHP dams was recognised to be moderate or poor, but impact was only local. This suggests that increment of catchment's area and intensive land use for agriculture within the river basin plays more important role than SHP dams.

Keywords: *SHP dams, environmental impact, macroinvertebrates, nutrients, suspended solids*.

Introduction

The construction of Small Hydropower Plants (SHP) with hydrostatic head H<15 m and installed capacity of 0.5 to 10 MW (ESHA, 2004) as a useful additional source of renewable energy is based on modification of stream potential energy gradient (Abbasi, T., Abbasi, S.A., 2011; Lejeune, Hui, 2012). While hydropower uses water and gravity, economical incentive to increase electricity production by upgrading hydrostatic head in cross-section (and thereby height of the SHP dam) is evident. Therefore, a spillway dam is the most important structure of the SHP. There are a lot of references on dams' impact on the environment and stream ecosystem (Water Framework Directive and Hydropower, 2007; Kantoush *et al*., 2011; Kibler, Tullos, 2013; Rimkus *et al*., 2013). International Energy Agency (IEA) notes that SHP tends to have a relatively small and localized impact on the environment (IEA, 2000). However a conflict between the human demand and the ecological water requirement on aquatic ecosystems may increase (Baskaya *et al*., 2011). Results of Kibler and Tullos (2013) reveal that biophysical impact of small hydropower may exceed even those of large hydropower, particularly with regard to habitat security and hydrologic change.

The equilibrium of the ecological features in rivers and their riparian zones, coherent with both the transport and the retention of the suspended sediments and also the nutrients after SHP construction can be disturbed (Eiseltová, 1995; EEA, 2003; Mourad, van der Perk 2004; Wu *et al*., 2009; SHERPA, 2010; Kantoush *et al*., 2011). In dammed segments, organic mud and silt is not washed from the riverbed and are accumulated there. The researchers established that due to accumulation of sediment in SHP reservoirs with a huge organic load and uneven discharges of regularly switched on/off turbines re-suspension of fine sediment was possible as well as secondary water pollution below the dam (Stanley, Doyle, 2002; Ren, Packman, 2002). Deep reservoirs (when water depth > 10 m) can also act as bioreactors, i. e. they change the temperature and the regime of the water flowing through bottom openings of SHP dam and even increase the risk of biogenic pollution by retention of a considerable amount of organic silt particles (Kantoush *et al*., 2011). Thus, SHP installation changes the river hydromorphological characteristics, which also affects flora and fauna of the river. Ecological responses to dam construction still are poorly understood, especially for downstream benthic algal communities (Wu *et al*., 2009). It is obvious that SHP dams can significantly affect river's sediment and nutrient loads as well as the natural flow regime that organizes and defines river ecosystems security (Poff *et al*., 1997).

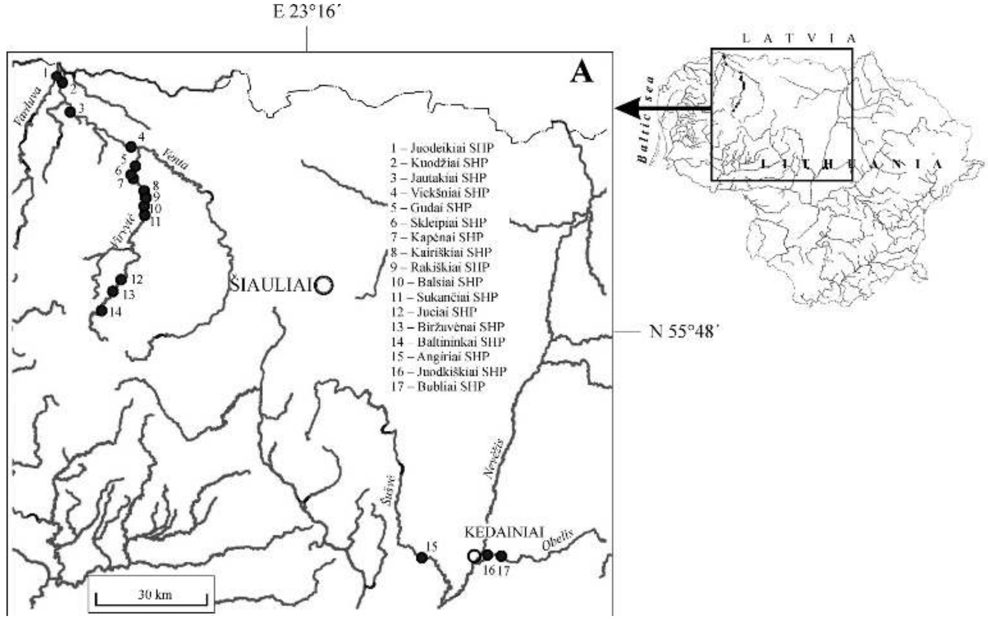
Multiple-dam systems fragment streams and completely hinder longitudinal movement of aquatic biota, which results in aquatic population segmentation. The smaller population is between the dams, the lower its viability under ambient changes. Some studies indicated that even low-head SHP dams interfered with upstream migration of biota (Lopardo, Seoane, 2004; Bellucci *et al*., 2011). A breakdown of the benthic invertebrate biomass (between 40 and 60%) can be observed within the few kilometres of river length as well as the reduction of the fish fauna within the same order of magnitude and it correlates well with the amplitude of the flow fluctuations in downstream of SHP (Moog, 1993). Macroinvertebrates many of which are sensitive to the changes in water bodies (including water chemistry and flow regime) play the important role in stream ecosystem function, providing an essential link in the food chain and the source of food for higher animals (Gupta, 2010). Therefore the abundance of macroinvertebrate communities can be a good indicator of the dam impact on biotic environment (Cortes *et al*., 2002; Maiolini *et al*., 2007; Katano *et al*., 2009; Tszydel *et al*., 2009; Alvarez-Cabria *et al*., 2010; Principe, 2010).

The potential energy of the Lithuanian rivers was rather intensively used in the past. According to the sources 10 water-mills on the Virvytė river in 1900-1940 were built (Jablonskis *et al*., 2008). These old structures were reconstructed and water-turbines were arranged in 1959-1990. Some reservoirs that were built for purposes of irrigation and recreation in 70'ies and 80'ies of the 20 century had been also restructured for the hydropower production. The new SHP in the Venta, the Varduva, the Obelis and the Šušvė rivers were installed somewhere around the same period. All investigated SHP were operating without fish-ladder, consequently upstream fauna movement is disturbed.

Now there are 90 SHP with a total capacity of 30 MW, producing up to 66.1×10^6 kWh/yr of electricity, currently operating in Lithuania (Punys, Pelikan, 2007). Under the conditions of plain relief generally a low-head (with a fall of water H<5 m) and medium head (with H = 5-15 m) SHP are prevailing, but even they can increase segmentation of river channels, which can cause changes in the natural flow regime and can disturb ecological integrity of free-flowing river systems (Poff *et al*., 1997; Jablonskis *et al*., 2008). Until now the impact of small hydropower plants on ecosystem stability has been studied insufficiently in Lithuania (Rimkus *et al*., 2013). This study aims to compare sediment and nutrient regimes downstream and upstream of the SHP dam and to assess their impact on river's environmental security according quantity and composition of macroinvertebrate communities in sites.

Materials and methods

The investigations were carried out in Lithuania and involved 17 SHP dams built on four rivers of the 3rd to 4th order (Fig. 1A). The Venta, Varduva and Virvytė rivers represented Western Lithuania (the Venta basin), whereas the Šušvė and Obelis rivers represented Central Lithuania (Nevėžis basin) hydrological regions with their typical hydrological regimes and geomorphological conditions (Gailiušis *et al*., 2001). The distribution of daily flow rates during the typical moderate year before SHP installation measured in hydrographical gauging-stations of all 5 rivers is shown in (Fig. 1B) (Latvian…, 1962; Lithuanian…, 1963). About 36-49% of the total annual runoff flows during the spring floods, 11-13% in summer and the rest part during the autumn and winter. The highest flow rates take place in February – March – April, due to increasing water levels and decreasing hydrostatic heads in this period some low-head SHP are stopped. The mean annual specific discharge from the Obelis river catchment is 4.6 l/s km^2 and is least in comparison with the Šušvė (5.7 l/s km^2), the Venta (7.0 l/s km^2), the Virvytė (10.3 l/s km^2) and the Varduva (10.4 l/s km^2) catchments specific discharges.



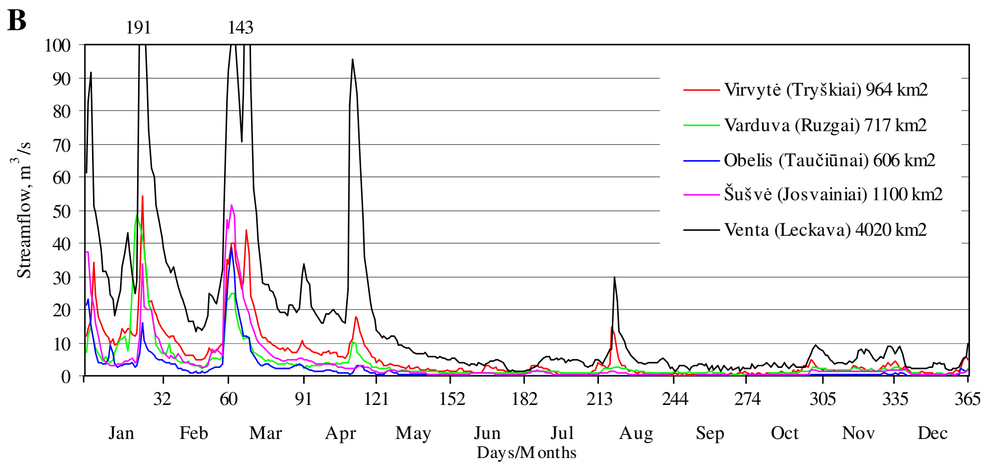


Fig. 1. A) Location map of studied dams, B) The distribution of daily flow rates during the typical moderate year before SHP installation.

The hydrostatic head of the SHP dams and the capacities of their reservoirs ranged from 2.75 to 14.50 m and from 40×10^3 to $15{,}500\times10^3$ m^3 respectively. Derivative quantities – discharge rate (K_Q) and reservoir filling rate (K_{rez}) characterize the possible impact of installed capacity of turbines on the natural flow regime were used (Table 1) (Environmental …, 2010).

Based on the assumption that higher SHP dams due to the larger capacity of reservoirs can be more substantial on natural flow regimes they were conditionally classified as low-head if the hydrostatic head is up to 5 m and medium-head if the hydrostatic head ranged from 5 to 15 m (ESHA, 2004).

Water samples and riverbed substances were taken simultaneously in reservoirs about 50 m upstream of a SHP dam (site II) and in a river channel about 50 m downstream of a dam (site III). Reaches of the investigated rivers, which were located far enough (4–11 km) upstream from the SHP's has been chosen as a reference sites (I). In the Virvytė river with multiple SHP dam system there were chosen 3 least impacted reference sites. The sampling was conducted annually in spring approximately at the same time from 2009 to 2011. At each sampling occasion aggregate samples were taken in each cross-section of the river site (on the left, the right and the middle of the riverside). Water sampling depth was about 0.3–0.5 m below the water surface. During the investigations in total 195 water and sediment samples were collected.

Macroinvertebrate communities were analysed along with the physicochemical characteristics of water: total suspended solids (by filtration and then drying at 105°C: LAND 46-2007), total nitrogen (by ISO 11905-1:1997: LAND 59-2003) and total phosphorus (by molybdenum with stannous chloride: LAND 58-2003). Riverbed substances were sampled to determine their grain-size composition and percentage of fine particles (less than 0.01 mm). The data were analysed considering the hydrostatic head of the SHP dams (either less or more than 5 m). Cumulative impact of multiple dam system was also investigated in the Virvytė river. The differences of investigated parameters subject to river sites and hydrostatic head of the SHP dams were tested at the significance level $p<0.05$. Estimation of data variation (F-Test for variances) in the sites and t-Test for means was made.

Biotic indexes based on benthic macroinvertebrate taxa, which are currently used worldwide to measure river ecological quality, were used in this study (Damásio *et al.*, 2011). The samples of benthic macroinvertebrate were collected by the kick-sampling method in three 0.1 square meter areas at each study site. Additional macroinvertebrates were taken by multihabitat samples collected over the 10-minutes period with a hydrobiological dip net from all possible biotopes at each study site (Arbačiauskas, 2009). A total of 96 samples were collected from 24 investigated sites. The samples sieved using a 500 μm mesh, transferred into plastic flasks and stored in a 4% formaldehyde solution. In the laboratory, all animals were separated and counted and identified under a binocular dissecting microscope. Specimens were identified to the species or genus level (except Oligochaeta).

The Danish Stream Fauna Index (DSFI) as the official bio monitoring method in Lithuania (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). Total macroinvertebrate taxa number (TTN), EPT (*Ephemeroptera*, *Plecoptera*, *Trichoptera*) taxa number as well as the relative abundance (%) of *Ephemeroptera*, *Plecoptera, Trichoptera*, *Coleoptera*, *Mollusca*, *Chironomidae* and *Oligochaeta* were calculated.

Fisher's LSD test was used to determine differences in macroinvertebrate metrics and morphological characteristics among groups of river sites. The relationships between macroinvertebrate metrics and water quality values were determined using Spearman's rank correlation. Calculations were done with Statistica for Windows 6.0 (Sakalauskas, 2003).

Table 1. Characteristics of SHP dams and reservoirs (*Source*: Environmental Protection Agency of Lithuania. *Aplinkosauginių rekomendacijų hidroelektrinių (HE) neigiamam poveikiui aplinkai sumažinti parengimas* [Environmental Recommendations how to Reduce Negative Impact of Hydropower Plants (HPP). Final Report] 2010).

River	SHP name	L km	A $\times10^6$m^2	H m	V $\times10^3$ m^3	F ha	K_{rez}	Q_{riv} m^3/s	Q_{turb} m^3/s	K_Q	P kW
Virvytė	Gudai	6.6	1129	2.75	150	7.9	2321	11.04	12.0	1.09	264
	Skleipiai	10.8	1069	3.50	50	4.5	6585	10.44	3.6	0.34	264
	Kapėnai	13.4	1045	5.50	230	13.6	1385	10.10	6.5	0.64	288
	Kairiškiai	20.2	980	4.80	70	7.6	4302	9.55	6.0	0.63	110
	Rakiškiai	23.2	975	3.70	50	8.7	6017	9.54	7.9	0.83	270
	Balsiai	27.7	972	2.95	110	11.2	2514	8.77	7.9	0.90	187
	Sukančiai	29.8	971	3.25	130	10.0	2120	8.74	8.0	0.92	320
	Juciai	65.2	435	3.30	40	2.4	3627	4.60	4.0	0.87	120
	Biržuvėnai	72.0	420	3.50	40	8.7	3177	4.03	7.1	1.76	200
	Baltininkai	77.7	392	4.30	60	32.6	-	n/a	-	-	250
Venta	Kuodžiai	189.5	4020	4.45	480	25.3	1951	29.70	16.9	0.57	600
	Jautakiai	199.0	3392	2.92	490	25.5	1461	22.70	10.7	0.47	250
	Viekšniai	221.8	3021	3.00	280	17.0	2489	22.10	4.0	0.18	95
Obelis	Juodkiškis	5.4	660	9.80	4,400	83.4	24	3.31	4.9	1.48	510
	Bubliai	10.5	604	7.40	6,440	152	15	3.10	3.5	1.13	150
Šušvė	Angiriai	24.6	1050	14.5	15,500	248	12	6.00	10.5	1.75	1300
Varduva	Juodeikiai	6.7	580	12.5	10,520	9.6	18	6.15	6.15	1.00	820

L – distance from mouth; A – river catchment area at the dam; H – hydrostatic head; V – capacity of SHP reservoir; F – area of SHP reservoir; $K_{rez} = Q_{riv} \cdot t/V$ – reservoir filing rate, t – reservoir filling time in seconds per year; Q_{riv} – the mean flow rate in the river (long-term average), Q_{turb} – the volume of water flowing through the turbine per second; $K_Q = Q_{turb}/Q_{riv}$ – discharge rate; P – installed capacity.

Results

Physicochemical characteristics of the investigated sites

Total suspended solids (TSS). It was established that concentrations of TSS varied widely (0.4–24.0 mg/l) without reference to the sampling sites in which they were measured (Table 2). The regimes of suspended solids were running differently subject to both the hydrostatic head of SHP dam and reservoir capacity. In the case of the low-head dams, the mean concentration of TSS exhibited some tendency to decline (by about 16%) due to water delay in the reservoirs and then followed a more noticeable increase (by about 24%) as water drained off into the river channel through the SHP turbines and even somewhat exceeded the values of TSS concentrations that were measured in reference sites. However, these differences between the TSS concentrations in the reservoirs and in the river downstream of the dams were not significant at $p<0.05$.

Table 2. Averaged physicochemical parameters in reference sites (I), SHP reservoirs (II) and below SHP dams (III)

Parameters	Low-head (H <5 m)			Medium-head (H = 5 – 15 m)		
	I	II	III	I	II	III
TSS, mg/l	8.3±2.4	6.9±1.7	8.6±2.1	2.9±0.8	4.3±1.6*	2.2±1.1
FP, %	9.0±4.8	19.5±3.7*	6.5±1.8	8.8±4.7	12.4±2.7*	5.7±2.2
TN in water, mg/l	1.8±0.2	1.8±0.2	1.8±0.2	5.3±1.5	7.1±1.6	6.0±2.2
TN in sediment,mg/kg	1503±969	2302±710*	690±283	937±634	831±183	898±380
TP in water, mg/l	0.042±0.009	0.048±0.005	0.047±0.005	0.042±0.009	0.089±0.044	0.065±0.036
TP in sediment,mg/kg	314±92	497±118*	262±52	311±64	300±49	297±104

Mean±confidence interval at significance level α=0.05; *statistically significant difference (t-Test, $p < 0.05$)

The mean values of TSS concentrations in reservoirs of medium-head dams (4.3±1.6 mg/l) were significantly higher (by about 50%) than the ones in the river channels downstream of the dam (2.2±1.1 mg/l) and increased by about 48% compared to the low-head dams. It should be noted that mean TSS concentration in reference sites also differed significantly: were threefold higher in the hillside rivers the Virvytė and Venta than in the flatland rivers the Obelis and the Šušvė (8.3±2.4 and 2.9±0.8 mg/l respectively). These differences are caused by higher wash flow velocities and riverbed gradients, which are about 10-times higher than the first ones (1-2 ‰ and 0.1-0.2 ‰ respectively).

Fine particles (FP). The data revealed that all SHP reservoirs were trapping a certain amount of suspended sediments including the finest of them. As a result, the percentage of FP in the reservoir bed substrates increased about twofold in proportion to the percentage of the analogous particles in the riverbed in reference sites, but statistically significant differences at $p<0.05$ were determined only in the case of low-head dams. In the sites below the dams, because of the increased flow velocity and turbulence when water drained off through turbines, the finer particles were scoured out from bed substrates resulting in both some increase in TSS concentrations and the progress of armouring of river channel beds downstream from the SHP dams without reference to their hydrostatic head. In fact, the mean percentages of FP were two and threefold less in the river sites downstream the SHP dams compared to the bed substrates in the SHP reservoirs. These differences were statistically significant (t-Test, $p<0.05$).

A moderate linear correlation (r = 0.68) was found between the percentage of FP deposited in reservoirs of low-head dams and their capacities. In contrast, there was a negative correlation (r = -0.66) between the reservoir capacities and the percentage of FP in the riverbed substrates below the dams (Fig. 2).

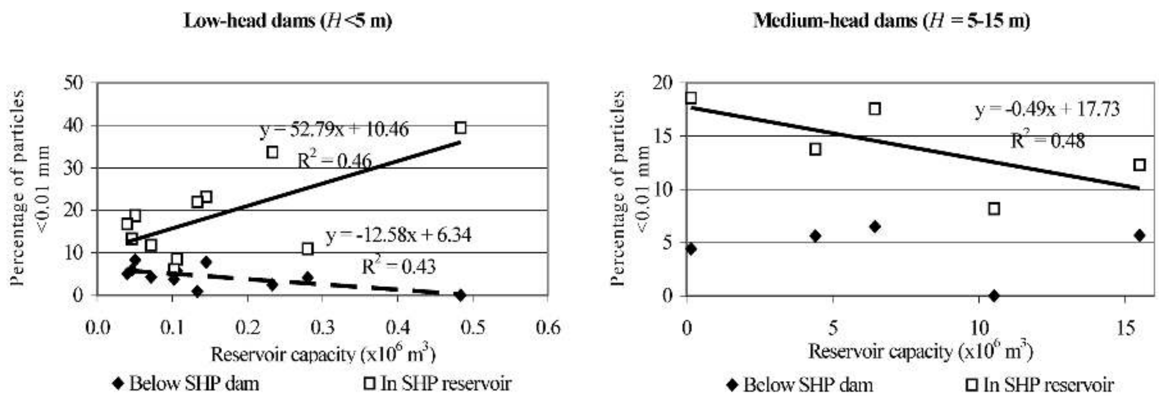


Fig. 2. Dependence of percentage of fine particles in bed substrates (mean values) upon reservoir capacity

In the case of medium-head dams, the dependence between reservoir capacity and percentage of FP in reservoir bed substrates revealed the inverse trend (r = -0.69). The percentage of FP in riverbed below the medium-head dams demonstrated no dependence upon their reservoir capacity. It was also found that the mean percentage of FP in reservoirs of medium-head dams was significantly less (t-Test, $p<0.05$) in comparison with reservoirs of low-head dams (12.4 and 19.5% respectively). This may be because of the concentration of FP in the wash load is normally a function of supply, i. e. its primary source is the river catchment including sheet and rill erosion, gully erosion and upstream bank erosion (Van Rijn, 1993).

Although alterations were detected in both the mean TSS concentrations and percentage of FP and relationships of those variables with the magnitude of the reservoirs, the available data did not demonstrate any interdependent behaviour of TSS concentrations and percentage of FP either in the reservoirs or in the river channels downstream the dams.

Nutrients (TN and TP). In hillside rivers (Virvytė and Venta) dammed with low-head dams mean values of TN and TP concentrations in sampling sites ranged slightly: 1.76-1.83 and 0.042-0.048 mg/l respectively. Consequently differences between investigated sites considering TN and TP concentrations in water were statistically insignificant. In flatland rivers (Obelis and Šušvė) with medium-head dams TN concentrations were 3-4-times higher (5.3-7.1 mg/l). It should be noted that arable land prevails here taking up 63% of the basins area, whereas in the basins of the Venta and Virvytė rivers only about 40% of land is used for crop cultivation. It is evident that more intensive agriculture activity in flatland river basins, soil's composition and relief has resulted in a higher amount of nutrients here.

In reference sites of the investigated rivers, mean TP concentrations were the same (0.042 mg/l) but in the reservoirs of medium-head dams, TP concentrations were about twice higher (0.089 mg/l) in comparison with reservoirs of low-head dams (0.048 mg/l). Although the variation of data was very high (V = 94%) these differences cannot be considered as statistically significant. The available data showed some tendencies towards alterations of the nutrient concentrations when water was being delayed in the reservoirs and then drained off downstream. All reservoirs of medium-head dams demonstrated some reducing effect on the TN and TP concentrations (by about 15 and 27% respectively) but the same cannot be said about reservoirs of low-head dams. Although the concentrations of TN and TP in such reservoirs mostly demonstrated some positive correlation to their capacities (r = 0.54), their impact on TN in water downstream the dams is insignificant. The concentrations of TP in water drained off into the river channels via the SHP turbines showed a more significant correlation with reservoir capacities (r = 0.70; Fig. 3). In the case of medium-head dams, the dependencies of TN and TP concentrations in major of SHP reservoirs upon their capacities were negative (for TN r = -0.89; for TP r = -0.70). Such dependency could be related to the fine sediment accumulation and retention here, and TSS decrease that did an impact on the concentrations of nutrients in bed substrates, TP particularly (r = 0.72) due to the sedimentation. Compared with reservoirs, the increase (25%) of TSS concentrations in the river channels downstream of the low-head dams can be the result of re-suspension or the scouring of the native rock of the riverbed, which is usually poor in nitrogen but some richer in phosphorus.

There was just one variable – the TSS concentration, for which mean value always increased in water below the dams (Table 2). It is likely the outflow hydrograph regime dependent on installed capacity of turbines. Although there was found no relationship between the TSS concentrations and nutrient concentrations in the SHP reservoirs, the analogous relationship existed in river channels below the dams (r_{TP} = 0.72). For example, Anderson *et al.* (2006) stated that increases in upstream sediment deposition were accompanied by an increase in the amount of exposed bedrock immediately downstream the dam. Therefore may be predicate that some of the suspended solids below the dams are additionally scoured from the catchment's area and riverbed rock.

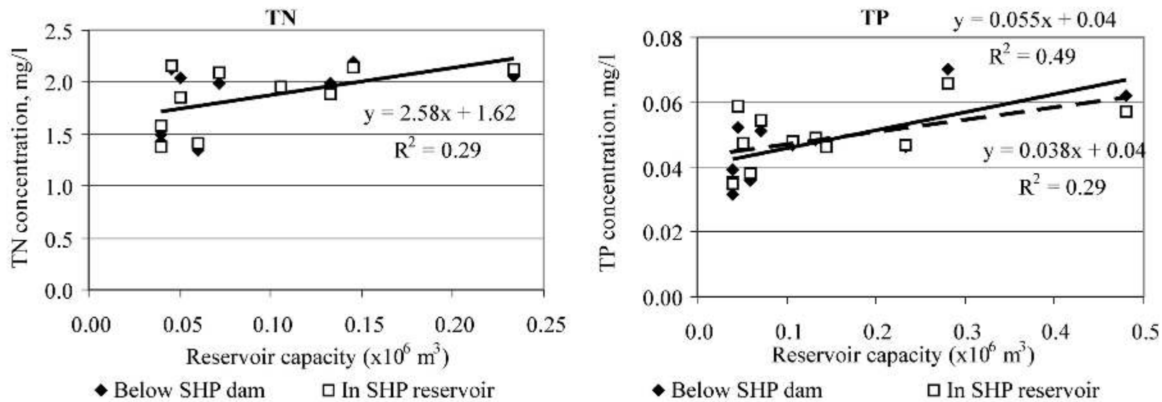


Fig. 3. Dependences of TN and TP concentrations in water upon reservoir capacities in the case of low-head dams ($H < 5$ m)

The mean amounts of TN and TP augmented considerably (by about 53-58%) in the reservoirs bed substrate of the low-head dams in comparison with reference sites. However, the concentrations of both nutrient species ranged widely in all the studied rivers and most sampling sites (coefficients of variation V_{TN} = 32–89%, V_{TP} = 24–53%). Consequently, the differences between the means of the concentrations were found not highly significant even if their values were high.

In bed substrates of SHP reservoirs the conspicuous alterations making about 70% for TN and about 47% for TP there were found compared to that in river channels below the low-head dams. In contrast, the differences of TN and TP amounts in reservoirs' bed substrates of medium-head dams were below 10% because the silt and clay particles move along these comparatively large-scale reservoirs differently in time (mostly in decelerating – depositing turbidity currents) and may be re-entrained into the stream flow by turbulence generated by the operating turbines (where it becomes a part of the suspended load and is transported downstream). This indicates that reservoir area extent and land use within the river basin can play more important role on nitrogen dynamics in bed load substrates than hydrostatic head size of SHP.

Cumulative impact of multiple dam system in the Virvytė River

The results obtained show that when SHP are in operation, TSS concentration (herewith water turbidity) in SHP reservoirs tend to increase when distance of SHP dams from the mouth is decreasing. However, the values of TSS were practically constant below SHP reservoirs as well as in reference sites of the river (Fig. 4).

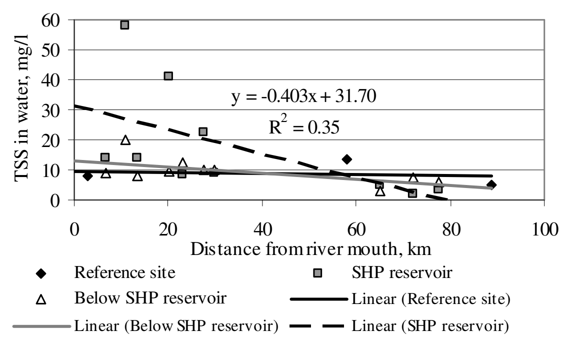


Fig. 4. Trends of TSS concentration in multiple SHP dam system on Virvytė river

TN concentrations in water below SHP dams showed a strong negative (r = -0.96-0.97), TP concentrations – moderate (r = -0.54) relationship with location distance from the river mouth. However, a weak positive relationship of TN (r = 0.43) and TP (r = 0.33) in reservoir sediments was detected (Fig. 5). This indicates that increase of catchment's area and cumulative effect from intensive land use for agriculture within the river basin can play more important role on nutrients inflow and accumulation in stream water than retention of fine sediment with large biogenic load in SHP reservoirs.

The strong positive trend of abundance of pollution-sensitive EPT and macroinvertebrates (r = 0.97) and strong negative trend of pollution-tolerant chironomides (r = 0.93) is likely related to this retention (Fig. 6). Thus, the cumulative effect of multiple SHP dam system does not exist.

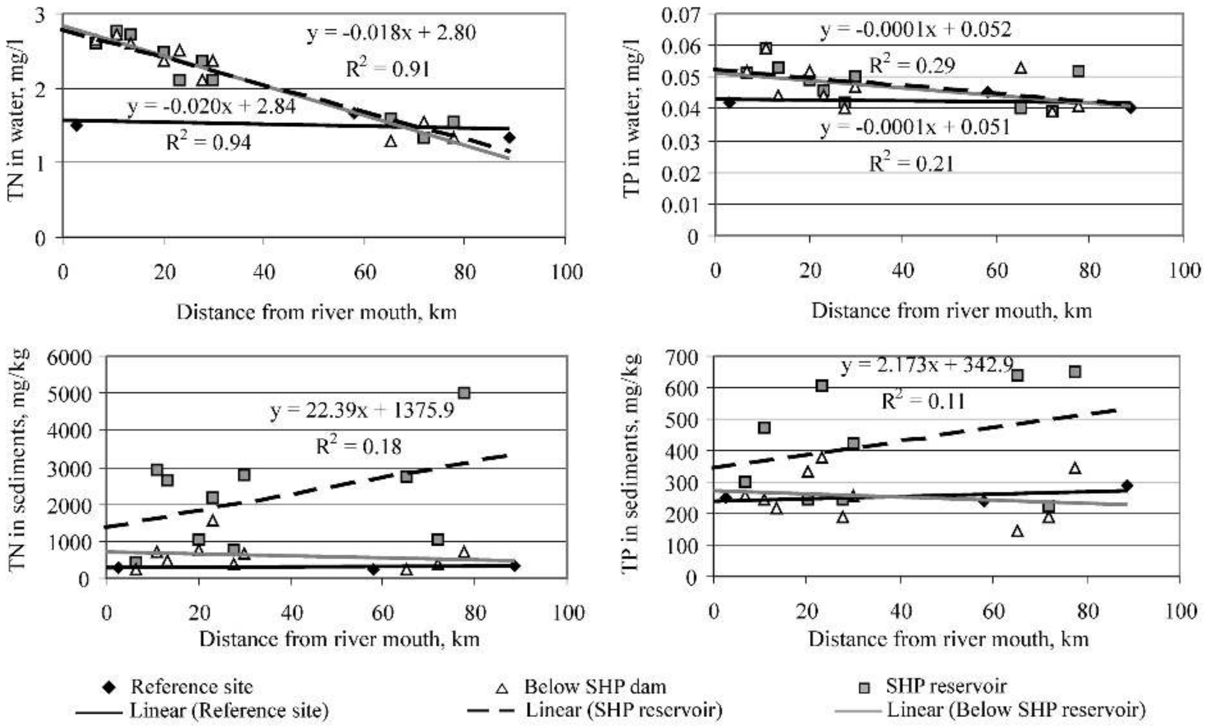


Fig. 5. Trends of nutrients (TN and TP) in water and bed sediments along the Virvytė river with multiple SHP dam system

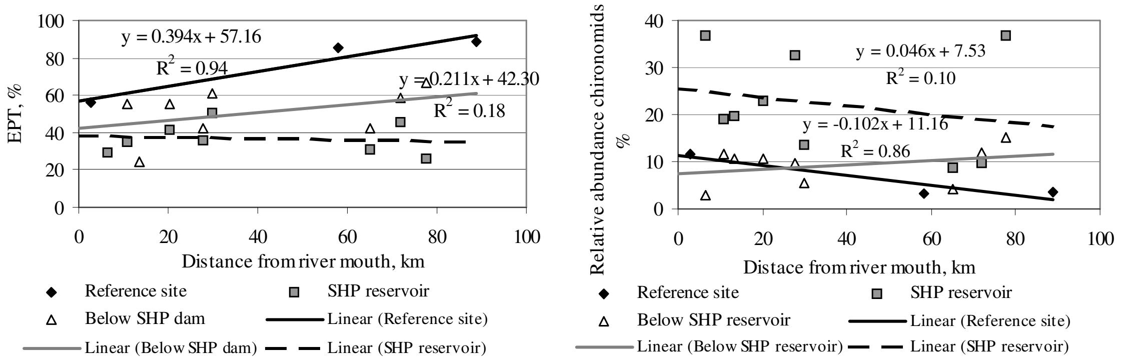


Fig. 6. Relative abundance of pollution-tolerant Chironomidae and pollution-sensitive macroinvertebrates (EPT) in the Virvytė river

Impact of SHP on macroinvertebrate communities

The total number of macroinvertebrate taxa (TTN) and the number of EPT taxa were highly variable across the investigated rivers' sites, ranging within 11-38 and 3-16, respectively (Fig. 7). The abundance of taxa in the reference sites was significantly higher (Fisher's LSD test) with regard to the same indices in SHP reservoirs and below SHP dams.

The different compositions of macroinvertebrate community (%) in reference sites, in SHP reservoirs, and below SHP dams were obtained (Table 3).

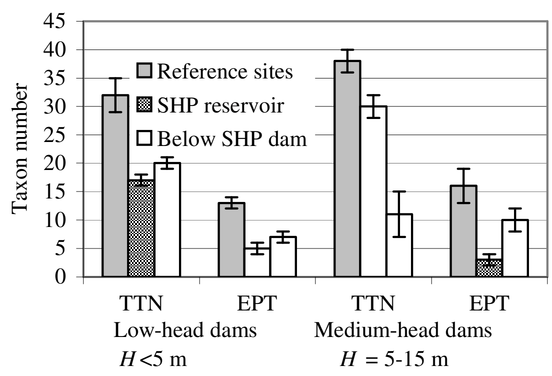


Fig. 7. The total number of macroinvertebrate taxa (TTN) and the number of EPT taxa in studied rivers (mean ± *SE*)

Table 3. Characteristics of macroinvertebrate metrics (mean ± *SE*)

Macroinverte-brate species	Reference sites	SHP reservoir	Below SHP dam
	Low-head dams		
Oligochaeta	8.4±3.4	10.9±2.6	14.8±3.8
Mollusca	15.8±3.9	18.4±6.2	10.5±2.5
Ephemeroptera	24.4±6.2	21.0±4.8	28.5±4.9
Trichoptera	15.8±3.4	9.5±2.7	11.6±2.2
Plecoptera	6.1±2.8	-	1.6±0.6
EPT	46.3±10.5	30.5±5.3	41.6±5.6
Coleoptera	15.0±2.7*	3.6±1.2*	9.3±1.6*
Chironomidae	8.0±1.6*	23.0±4.6*	17.5±2.9*
	Medium-head dams		
Oligochaeta	3.0±0.4*	20.4±5.9*	10.5±4.4
Mollusca	3.9±1.2	37.8±14*	5.3±1.0
Ephemeroptera	27.9±3.0*	3.4±1.0	9.9±1.5
Trichoptera	11.8±2.1	6.8±2.0	21.6±3.9
Plecoptera	5.0±0.9	-	-
EPT	44.7±5.1*	10.2±0.9*	31.5±3.5
Coleoptera	15.1±3.1*	-	0.7±0.3*
Chironomidae	16.2±1.6*	32.3±10.0	46.2±3.4

DSFI value was highest in reference sites and reliably differed from the value in SHP reservoirs and below SHP dams (Fig. 8, Fisher's LSD test). Water quality was classified as very good in reference sites, good in sites below SHP dams, and moderate in SHP reservoirs. According to Hilsenhoff biotic index (HBI), water quality was very good in reference sites and fairly poor or poor in SHP reservoirs whereas in sites below SHP dams water quality was considered fairly poor only below medium-head dams.

Total number of macroinvertebrate taxa in low-head SHP dams was negatively correlated with total nitrogen in the water (Spearmans' rank correlation, r_s = -0.42) (Table 4). TTN and the number of EPT taxa at the sites of medium-head SHP dams negatively correlated with TN and TP in sediments (r_s = -0.35 – -0.48). The relative abundance of caddisflies negatively correlated with TN in water at the sites of low-head SHP dams (r_s = -0.75). In the case of medium-head dams DSFI was negatively correlated with TN and TP in sediments (r_s = -0.44 and r_s = -0.53 respectively). HBI showed a positive trend in relation to TN and TP (r_s = 0.56 and r_s = 0.37 respectively). No reliable correlation was found between nutrients in water and both DSFI and HBI indexes in sites of low-head SHP dams.

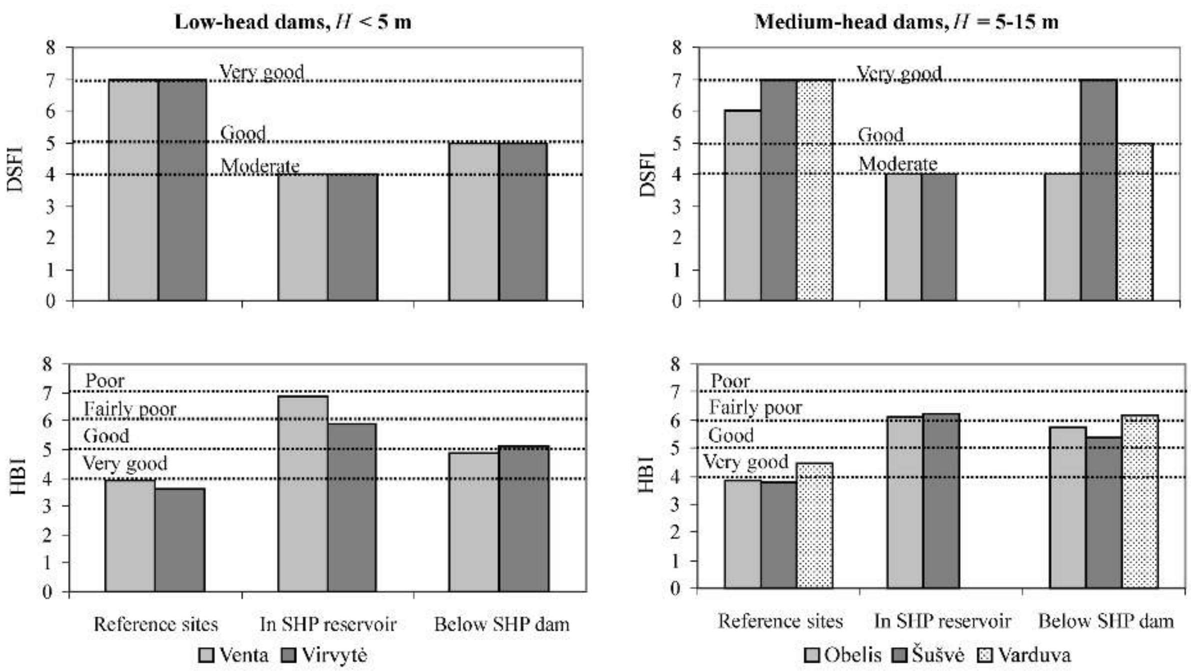


Fig. 8. Water quality according the Danish Stream Fauna Index (DSFI) and the Hilsenhoff Biotic Index (HBI) in investigated rivers

Discussion

SHP dams in Lithuania, typically with shallow reservoirs, can modify the progress of natural flood events and the wash-product transport cycles as well as annual hydrographs only slightly. It is because the installed capacities of turbines are comparatively low and the discharge rates (K_Q=Q_{turb}/Q_{riv}) are <1. Only in the case of medium-head SHP K_Q>1 and that determine major flow disturbances. For example, the maximal flow disturbance after Angiriai SHP operations with the largest discharge rate K_Q=1.75 was found (Table 1, Fig. 9). Notwithstanding, a lot of references suggest that even such small structures still manage to affect the scouring processes and erosion or settling of wash products followed by deposition of adsorbed nutrients, composition and relative abundance of different taxa of macroinvertebrates close to the upstream and the downstream of the dam (Lopardo, Seoane, 2004; Bustamante *et al*., 2004; Mander *et al*., 2000; Baskaya *et al*., 2011; Stanley, Doyle, 2002).

Table 4. Spearman' rank correlation coefficient between macroinvertebrate metrics and chemical parameters in the river (significance: $p < 0.05$)

Macroinvertebrate metrics	TN in water, mg/l	TP in water, mg/l	TN in sediment, mg/kg	TP in sediment, mg/kg
	Low-head dams		Medium-head dams	
TTN	-0.42*	ns	-0.48	-0.35
EPT	ns	ns	-0.39	-0.41
	Percentage of individuals (%)			
Trichoptera	-0.75**	ns	ns	ns
Coleoptera	ns	ns	-0.68	ns
Chironomidae	ns	ns	0.85	ns
	Biotic index			
DSFI	ns	ns	-0.44	-0.53
HBI	ns	ns	0.56*	0.37

The increased water depths and decreased flow velocities in the reservoirs resulted in the deposition of suspended particles in a particular order: the coarse sand particles were accumulated at the beginning of the reservoir, smaller ones travelled along the reservoir and settled below, silt particles reached the dam, and only the smallest clay particles managed to be transferred downstream via the dam (Zdankus *et al*., 2008; van Rijn, 2013). However, if the SHP reservoir is large enough, the settling of suspended clay particles associated with various pollutants is possible here as well (Kantoush *et al*., 2011). The positive dependence of the percentage of fine particles in bed substrates in low-head SHP reservoirs upon their capacities and the negative one in the case of medium-head SHP reservoirs (Fig. 2) agree with the results of the above-mentioned authors.

From an ecological standpoint, the placement of SHP's in a river network, and its position relative to one another, may be more important than the size or total number of dams (Anderson *et al*., 2006; Wu *et al*., 2012). The cumulative impacts of multiple small dams resulting from consecutive construction may be greater than that of a single large dam (March *et al*., 2003; Odom, 2010). The sequence of small dams could pose a greater threat to ecosystems and natural landscapes over the large ones (Kibler, Tullos, 2013). However some researchers suggested that construction of such SHP had no significant impact on water chemistry, but physical variables (such as current velocity and water depth) could vary significantly among the sites (Zhou Sh. *et al*., 2009). The results of our investigation show no evident cumulative SHP impact on biogenic substances (TN and TP) in water of the Virvytė river (Fig. 5). Maybe, it is due to the fact that these SHP are constructed with comparatively long (2.1-35.2 km) distances in-between, and TN, TP or TSS accumulation in water is originated from the cumulative non-point sources pollution in the river catchment (Sileika *et al*., 2006). This indicates that increment of catchment's area and increased flow paths through the upper soil horizons and surface runoff within the Lithuanian agricultural river basins can play a more important role on cumulative nutrients regime in rivers than their retention in SHP reservoirs.

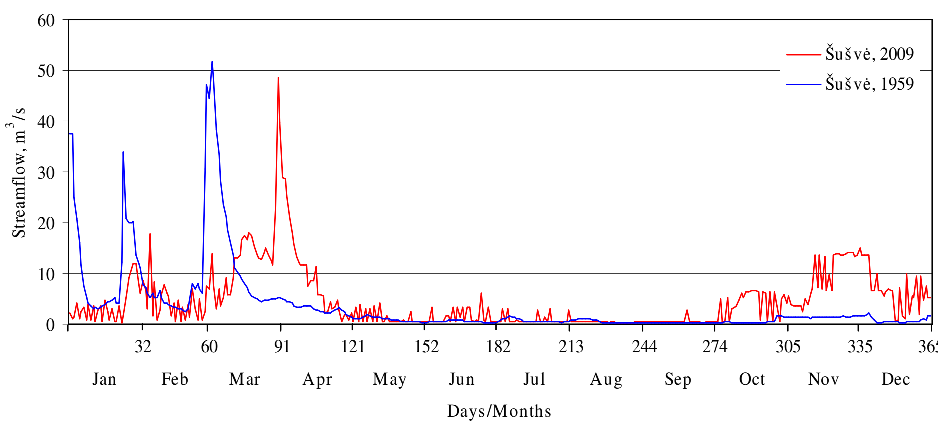


Fig. 9. A comparison of the pre- and post-dam hydrographs for the Šušvė river at Angiriai SHP

Trends of average values of TN and TP amounts in bed sediments of the Virvytė show a local comparatively week sediment retention capacity in such SHP reservoirs.

However, increased nutrient content in impounded river reaches can have a very significant effect on the water quality and ecological state of the river. SHP reservoirs located further downstream, as mentioned by Jungwirth *et al*. (2005), "are heavily degraded due to the loss of fluvial dynamics and intensive sedimentation of suspended materials". Any change of the flow hydraulic characteristic and regime leads to distortion of the natural hydrodynamic equilibrium and results in long-lasting adjustment of this regime to the new environment system (SHERPA, 2010). Loss of in-stream natural sand/gravel bars due to the bed silting, and raised water level both radically altered habitat quality for various original species. Fu *et al*. (2008) concluded that direct impact of SHP dams on aquatic macroinvertebrate communities may be principally due to alteration of habitat. The findings of Kemp *et al*. (2000) showed that each functional habitat tend to occur in fairly distinct depth and velocity conditions. River flow in the downstream reach of SHP remains in the initial depth and there will be no evident changes, but dams and reservoirs may impart changes in the environment through disruption of sediment equilibrium regimes in impounded reaches. Each switching off/on of SHP turbines can cause rapid or even daily fluctuations in river flow, *Fr* number and energy (Jowett, 1993). For example, in impounded reaches above SHP dams of the Virvytė river, low *Fr* number habitats ($0.04 > Fr > 0.0007$) were created and the negative dam impact on the local biotic communities was observed (Vaikasas, Poškus, 2006).

Increase of turbulence up to a certain limit may be favourable for benthos and juvenile fish, because turbulent oscillations of flow velocity are the only source of oxygen in the bottom layer. But a simultaneous increase in both fluctuations of velocity and pressure as well as turbidity results in stress and negative impact on habitat conditions (Debolsky, Dolgopolova, 2002). The hydropower release had a consistent "washing effect", continuously dislodging organic matter and most part of the macroinvertebrate community (Maiolini *et al*., 2007; Jesus *et al*., 2004). According to our findings, water regime fluctuations when SHP is operating have a significant impact on the composition of macroinvertebrates: both of the disturbed sites (in SHP reservoirs and below SHP dams) had lower taxa number of macroinvertebrates (both total and EPT taxa) than the undisturbed reaches of the investigated rivers (reference sites). Dam building has a significant but local impact on the composition of the macroinvertebrate community just above the dam site, probably as a result of deposition of fine particles and inorganic material within a SHP reservoir and changes in water velocity (Doyle *et al*., 2005; Pedersen, Friberg, 2009). Stoneflies were absent in SHP reservoirs and below medium-head dams, and constituted only 1.6% of total abundance below low-head dams. According to Bahuguna *et al*. (2004), stoneflies were absent in the regulated reaches. We found that mayflies *Baetis rhodani*, *Siphlonurus alternatus* and *Caenis macrura* were more abundant in SHP reservoirs and at the sites below SHP dams. The mayfly *Heptagenia sulphurea* was absent in SHP reservoirs. Other studies revealed an increase of *Baetidae* and *Caenidae* and a decrease of *Heptageniidae* due to the flow reduction (Mantel *et al*., 2010). The values of relative abundance of *Chironomidae* in the sites of rivers of low-head and medium-head dams, *Oligochaeta* and molluscs in the reference sites of medium-head SHP dams were significantly lower in comparison with SHP reservoirs and below SHP dams. Other investigations showed that the proportion of pollution tolerant chironomids and non-insect individuals (oligochaetes) increased at degraded sites and were dominating in organically polluted sites (Masese *et al*., 2009). According to the obtained results, the relative abundance of *Ephemeroptera* and EPT was significantly higher in the reference sites of medium-head dams in comparison with the sites in SHP reservoirs and below SHP dams. S. Nichols *et al*. (2006) also state that macroinvertebrate samples from sites below dams had relatively more *Chironomidae* larvae and *Oligochaeta* and fewer of only the more sensitive taxa, *Plecoptera*, *Ephemeroptera* and *Trichoptera.*

According to HBI, water quality was very good in the reference sites and fairly poor or poor in SHP reservoirs. The results of other investigations (Thomson *et al*., 2005) also showed that sites downstream of the dam had poorer HBI scores than upstream (control) sites.

Conclusions

1. It was established that SHP dams changed regimes of suspended solids, fine particles and nutrients in Lithuanian rivers water and sediment. However SHP dams (both low-head and medium-head) has only a local impact on water hydrochemical parameters, which are determined by geomorpfic conditions. About 3 times fewer amounts of total suspended solids were found due to relatively less flow turbulence in natural canals of larger rivers. The flow of small rivers transports more fine particles which are able to accumulate and retain more total nitrogen, deposited in reservoirs of low-head dams. Although the total nitrogen concentration in the water in all the studied sites was significantly higher (3 to 3.9 times) near medium-head SHP dams, reservoirs of low-head dams retained 1.6 times more fine particles, 3.9 times more total suspended sediments and respectively more (2.8 times) total nitrogen in sediments. Comparing the low and medium-head dams phosphorus concentrations in water and in sediments were not significantly different in all studied sites.
2. SHP dams have a significant but local impact on macroinvertebrate composition in the investigated rivers. Both of the disturbed reaches (in SHP reservoirs and below SHP dams) have significantly lower taxa number of macroinvertebrates (both total and EPT taxa) compared to the reference sites of the rivers. In reference sites above the medium-head dams, pollution-sensitive EPT (45.2% of total abundance) dominated while in SHP reservoirs and below SHP

dams, the most part of pollution-tolerant chironomids (32.3% and 46.2% of total abundance) was found. The relative abundance of pollution-tolerant and scour-protected *Chironomidae* in reservoirs and downstream below the medium-head SHP dams was significantly higher in comparison with reservoirs and sites below the low-head ones.

3 According to DSFI and HBI indexes, ecological water quality in the reference sites was higher in comparison with river sites influenced by SHP dams. In the case of medium-head SHP dams DSFI was negatively correlated with TN and TP in sediments (r_s = -0.44 and r_s = -0.53 respectively). HBI showed a positive trend in relation to TN and TP (r_s = 0.56 and r_s = 0.37 respectively). No reliable correlation was found between nutrients in water and both DSFI and HBI indexes in sites of the low-head SHP dams.

4 Based on studies carried out in Lithuania no evident cumulative impact of multiple SHP dam system (10 SHP in sequence) on water quality in the Virvytė River was detected because the SHPs were arranged with comparatively long (2.1-35.2 km) distances in-between. This suggests that increment of catchment's area and intensive agriculture practices in the river basin may lead to a higher amount of nutrients in-flow and accumulation in rivers rather than retention of fine sediment with large biogenic load in SHP reservoirs studied.

References

Abbasi, T.; Abbasi S.A. 2011. Small hydro and the environmental implications of its extensive utilization. *Renewable and Sustainable Energy Reviews*, 15(4), 2134–2143. http://dx.doi.org/10.1016/j.rser.2010.11.050

Alvarez-Cabria, M.A.; Barquín, J.; Juanes, J.A. 2010. Spatial and seasonal variability of macroinvertebrate metrics: Do macroinvertebrate communities track river health? *Ecological Indicators*, 10(2), 370–379. http://dx.doi.org/10.1016/j.ecolind.2009.06.018

Anderson, E.P.; Freeman, M.C.; Pringle, C.M. 2006. Ecological consequences of hydropower development in Central America: impacts of small dams and water diversion on neotropical steam fish assemblages. *River Research and Applications*, 22, 397–411. http://dx.doi.org/10.1002/rra.899

Arbačiauskas, K. 2009. *Bentoso bestuburiai. Gyvunijos monitoringo metodai* [Fauna monitoring methods] Vilnius: VU Ekologijos Institutas, 22–45.

Bahuguna, B.K.; Nautiyal, R.; Nautiyal, P.; Singh, H.R. 2004. Stream regulation: Variations in the density, composition and diversity of benthic macroinvertebrates occurring in the up and downstream sections of the impounded zone of the river Ganga in the foothills. *Tropical Ecology*, 45(2), 251–261. http://tropecol.com/pdf/open/PDF_45_2/45207.pdf

Başkaya, Ş.; Başkaya, E.; Sari, A. 2011. The principal negative environmental impacts of small hydropower plants in Turkey. *African Journal of Agricultural Research*, 6(14), 3284–3290. http://dx.doi.org/10.5897/AJAR10.786

Bellucci, C.J.; Becker, M.; Beauchene, M. 2011. Characteristics of Macroinvertebrate and Fish Communities From 30 Least Disturbed Small Streams in Connecticut. *Northeastern Naturalist*, 18(4), 411–444. http://dx.doi.org/10.1656/045.018.0402

Bustamante, M.A.; Morillo, S.; Freyer, Z.I.; Ruiz, M., Angelaccio, C.; Rodríquez, M. I. 2004. The water quality modelling and environmental impact of an Azud (little dam) construction in Cuarto River (Argentina). In: *Aquatic Habitats: Analysis & Restoration.* Fifth International Symposium on Ecohydraulics, 2004, Madrid, Spain. Madrid: IAHR, 1189–1193 [online], [cited 15 February 2011]. Available at: http://www.ina.gov.ar/pdf/Cirsa-Limnologia-9%20Riocuarto.pdf

Cortes, R.M.V.; Ferreira, M.T.; Oliveira, S.V.; Oliveira, D. 2002. Macroinvertebrate community structure in a regulated river segment with different flow conditions. *River Research and Applications*, 18(4), 367–382. http://dx.doi.org/10.1002/rra.679

Damásio, J.; Fernández-Sanjuan, M.; Sánches-Avila, J.; Lacorte, S.; Prat, N.; Reieradevall, M.; Soares, A.M.; Barata, C. 2011. Multi-biochemical responses of benthic macroinvertebrate species as a complementary tool to diagnose the cause of community impairment in polluted rivers. *Water Resourses*, 45(12), 3599–616. http://dx.doi.org/10.1016/j.watres.2011.04.006

Debolsky, V.K.; Dolgopolova, E.N. 2002. Statistical Model of River-Bed Stream: Parameters of Turbulence, Energy Characteristics. *Hydrological Models for Environmental Management*, 79, 147–155. http://dx.doi.org/10.1007/978-94-010-0470-1_12

Doyle, M.W.; Stanley, H.E.; Strayer, D.I.; Jacobson, R.B.; Schmidt, J.C. 2005. Effective discharge analysis of ecological processes in streams. *Water Resour Research*, 41, W11411, 1-16. http://dx.doi.org/10.1029/2005wr004222

EEA (European Environment Agency) 2003. *Europe's environment: the third assessment* [online], [cited 12 May 2010]. Available at: http://eea.europa.eu/publications/environmental_assessment_report_2003_10/kiev_chapt_00.pdf.

Eiseltová, M. 1995. Overview. In: M. Eiseltová; J. Biggs. *Restoration of Stream Ecosystems: An Integrated Catchment Approach*. IWRB Publication, 37, 1–4.

Environmental Protection Agency of Lithuania. *Aplinkosauginių rekomendacijų hidroelektrinių (HE) neigiamam poveikiui aplinkai sumažinti parengimas* [Environmental Recommendations how to Reduce Negative Impact of Hydropower Plants (HPP). Final Report. 2010 (in Lithuanian).

Fu, X.; Tang, T.; Jiang, W.; Li, F.; Wu, N.; Zhou, S.; Cai, Q. 2008. Impacts of small hydropower plants on macroinvertebrate communities. *Acta Ecologica Sinica*, 28(1), 45–52. http://dx.doi.org/10.1016/S1872-2032(08)60019-0

Gailiušis, B.; Jablonskis, J.; Kovalenkovienė, M. 2001. *Lietuvos upės. Hidrografija ir nuotėkis* [Lithuanian Rivers. Hydrography and Runoff]. Kaunas: Lietuvos energetikos institutas. 792 p. (in Lithuanian).

Gupta, S.K. 2010. *Modern hydrology and sustainable development*. Wiley-Blackwell, 464 p. ISBN 978-1-4051-7124-3. http://dx.doi.org/10.1002/9781444323962

Hilsenhoff, W.L. 1988. Rapid field assessment of organic pollution with a family-level biotic index. *Journal of North American Benthological Society*, 7, 65–68 [online], [cited 15 February 2011]. Available at: http://www.webpages.uidaho.edu/fish415/Wilhelm%20files/2435%201988%20Hilsenhoff.pdf

International Energy Agency (IEA) 2000. *Hydropower and the Environment: Survey of the environmental and social impacts and the effectiveness of mitigation measures in hydropower development*. Technical Report. 111 p. [online], [cited 15 February 2011] Available at:

http://www.ieahydro.org/reports/IEA%20AIII%20ST1%20Vol%20I.pdf

Jablonskis, J.; Jurgelenaite, A.; Tomkevičienė, A. 2008. Lithuanian hydropower and environment protection. In: *The 7th International Conference "Environmental Engineering"*: Selected papers, vol. 2. May 22–23, 2008, Vilnius, Lithuania. Vilnius: Technika, 557–562.

Jesus, T.; Formingo, N.; Santos, P.; Tavares, G.R. 2004. Impact evaluation of the Vila Vicosa small hydroelectric power plant (Portugal) on the water quality and on the dynamics of the benthic macroinvertebrate communities of the Ardena river. *Limnetica*, 23(3-4), 241–256 [online], [cited 20 May 2006]. Available at: http://www.limnetica.com/Limnetica/Limne23/L23b241_Impact_hydroelectric_power_plant.pdf

Jowett, I.G. 1993. A method for objectively identifying pool, run, and riffle habitats from physical measurements. *New Zeland Journal of Marine and Freshwater Research,* 27, 241–248. http://dx.doi.org/10.1080/00288330.1993.9516563

Jungwirth, M.; Haidvogl, G.; Hohensinner, S.; Muhar, S.; Schmutz, S.; Waidbacher, H. 2005. Leiobild-specific measures for the rehabilitation of the heavily modified Austrian Danube River. *Archiv für Hydrobiologie, Supplemenband, Large River,* 15(1–4), 17–36. http://dx.doi.org/10.1127/lr/15/2003/17

Kantoush, S. A.; Sumi, T.; Murasaki, M. 2011. Evaluation of sediment by pass efficiency by flow field and sediment concentration monitoring techniques. *Annual Journal of Hydraulic Engineering*, JSCE 55, 169–173. http://dx.doi.org/10.2208/jscejhe.67.I_169

Katano, I.; Negishi, J.; Minagawa, T.; Doi, H.; Kawaguchi, Y.; Kayaba, Y. 2009. Longitudinal macroinvertebrate organization over contrasting discontinuities: effects of a dam and tributary. *Journal of North American Benthological Society*, 28(2), 331–351. http://dx.doi.org/10.1899/08-010.1

Kemp, J.L.; Harper, D.M.; Crosa, G.A. 2000. The habitat-scale ecohydraulics of rivers. *Ecological Engineering*, 16, 17–29. http://dx.doi.org/10.1016/S0925-8574(00)00073-2

Kibler, K.M.; Tullos, D.D. 2013. Cumulative biophysical effects of small and large hydropower development, Nu River, China. *Water Resources Research.* Article first published online: 3 June 2013. http://dx.doi.org/10.1002/wrcr.20243

Latvian Hydrometeorological Service. Hydrological Yearbook. Vol.1, Issue 4. Leningrad. 1962 (in Russian).

Lejeune, A.; Hui, S.L. 2012. 6.02 – Hydro Power: A Multi Benefit Solution for Renewable Energy. *Comprehensive Renewable Energy*, 6, 15–47. http://dx.doi.org/10.1016/B978-0-08-087872-0.00602-8

Lithuanian Hydrometeorological Service. *Hydrological Yearbook.* Vol.1, Issue 5, 6. Leningrad. 1963 (in Russian).

Lopardo, R.A.; Seoane, R. 2004. Environmental impact of large and small hydraulic structures. In: *Aquatic Habitats: Analysis & Restoration.* Fifth International Symposium on Ecohydraulics, 2004, Madrid, Spain. Madrid: IAHR, 867–872. [online], [cited 15 February 2011]. Available at: http://www.gbv.de/dms/weimar/toc/773104712_toc.pdf

Maiolini, B.; Silveri, L.; Lencioni, V. 2007. Hydroelectric power generation and disruption of the natural stream flow: effects on the zoobenthic community. *Studi Trentini di Scienze Naturali Acta Biologica*, 83, 21–26 [online], [cited 15 February 2012]. Available at: http://www2.muse.it/pubblicazioni/5/actaB83/02_maiolini.pdf.

Mandaville, S.M. 2002. *Benthic macroinvertebrates in freshwaters. Taxa tolerance values, metrics, and protocols.* Project H-1 Report. Halifax: Soil and water conservation society of metro Halifax [online], [cited 15 February 2010]. Available at: http://lakes.chebucto.org/H-1/tolerance.pdf.

Mander, Ü.; Kull, A.; Kuusemets, V.; Tamm, T. 2000. Nutrient runoff dynamics in a rural catchment: Influence of land-use changes, climatic fluctuation and ecotechnological measures. *Ecological Engineering,* 14, 405–427. http://dx.doi.org/10.1016/S0925-8574(99)00064-6

March, J.G.; Benstead, J.P.; Pringle, C.M.; Scatena, F.N. 2003. Damming tropical island streams: problems, solutions and alternatives. *BioScience*, 53, 1069–1078 [online], [cited 12 September 2007]. Available at: http://www.fs.fed.us/global/iitf/pubs/ja_iitf_2003_march001%20bios.pdf

Masese, F.O.; Raburu, P.O.; Muchiri, M. 2009. A preliminary benthic macroinvertebrate index of biotic integrity (B-IBI) for monitoring the Moiben River, Lake Victoria Basin, Kenya. *African Journal of Aquatic Science*, 34(1), 1–14. [online], [cited 5 September 2010]. Available at: http://www.ajol.info/index.php/ajas/article/view/42953.

Moog, O. 1993. Quantification of daily peak hydropower effects on aquatic fauna and management to minimize environmental impacts. *Regulated Rivers: Research & Management*, 8 (1-2), 5–14. http://dx.doi.org/10.1002/rrr.3450080105

Mourad, D.; van der Perk, M. 2004. Modelling nutrient fluxes from diffuse and point emissions to river loads: the transboundary Lake Peipsi/Chudskoe basin (Russia/Estonia/Latvia). *Water Science and Technology*, 49(3), 21–28. [online], [cited 5 September 2011] http://www.iwaponline.com/wst/04903/wst049030021.htm

Nichols, S.; Norris, R.; Maher, W.; Thoms, M. 2006. Ecological effects of serial impoundment on the Cotter River, Australia. *Hydrobiologia*, 572, 255–273. http://dx.doi.org/10.1007/s10750-005-0995-6

Odom, O. 2010. *Energy v. Water*. Ecology Law Quarterly. University of California, Berkeley School of Law, 37, 353–380 [online], [15 January 2011]. Available at: http://scholarship.law.berkeley.edu/elq/vol37/iss2/3

Pedersen, M.L.; Friberg, N. 2009. Influence of disturbance on habitats and biological communities in lowland streams. *Fundamental and Applied Limnology*, 174 (1), 27–41. http://dx.doi.org/10.1127/1863-9135/2009/0174-0027

Poff, N.L.; Allan, J.D.; Brain, M.B.; Karr, J.R;, Prestegaard, K.L.; Richter, B.D.; Sparks, R.E.; Stomberg, J.C. 1997 The natural flow regime. *BioScience*, 47(11), 769–784. [online], [cited 4 December 2010]. Available at: http://www.jstor.org/stable/1313099.

Principe, R. 2010. Ecological effects of small dams on benthic macroinvertebrate communities of mountain streams (Córdoba, Argentina). *Annales de Limnoligie – International Journal of Limnology*, 46, 77–91. http://dx.doi.org/10.1051/limn/2010010

Punys, P.; Pelikan, B. 2007. Review of small hydropower in the new Member States and Candidate Countries in the context of the enlarged European Union. *Renevable and Sustainable Energy Reviews*, 11(7), 1321–1360. http://dx.doi.org/10.1016/j.rser.2005.12.008

Ren, J.; Packman, A.I. 2002. Effects of particle size and background water composition on stream-subsurface exchange of colloids. *Journal of Environmental Engineering*, 128, 624–634 [online], [cited 10 March 2007]. Available at:

http://dx.doi.org/10.1061/(ASCE)0733-9372(2002)128:7(624)

SHERPA. 2010. *Hydropower and Environment - Technical and Operational Procedures to Better Integrate Small Hydropower Plants in the Environment*. Intelligent Energy for Europe and Small Hydropower Energy Efficiency Campaign Action (SHERPA). APER, Italy, 23 p.

Sakalauskas, V. 2003. *Data analysis with STATISTIKA*. Vilnius. 235 p. (In Lithuanian)

Stanley, E.H., Doyle, M.W. 2002. A geomorphic perspective on nutrient retention following dam removal. *BioScience*, 52, 693–701 [online], [cited 20 January 2012] Available at: http://limnology.wisc.edu/personnel/ehstanley/files/stanley__doyle_bioscience_2002.pdf

Sileika, A.S.; Stålnacke, P.; Kutra, S.; Gaigalis, K.; Berankiene, L. 2006. Temporal and spatial variation of nutrient levels in the Nemunas River (Lithuania and Belarus). *Environmental Monitoring and Assessment*, 122(1-3), 335–354. http://dx.doi.org/10.1007/s10661-006-9186-9

Thomson, J.P.; Hart, D.D.; Charles, DF.; Nightengale, T.L.; Winter, D.M. 2005. Effects of removal of a small dam on downstream macroinvertebrate and algal assemblages in a Pennsylvania stream. *Journal of North American Benthological Society*, 24(1), 192–207. http://dx.doi.org/10.1899/0887-3593(2005)024<0192:EOROAS>2.0.CO;2

Tszydel, M.; Grzybkowska, M.; Kruk, A. 2009. Influence of dam removal on trichoptera assemblages in the lowland Drzewiczka River, Poland. *Hydrobiologia*, 630(1), 75–89. http://dx.doi.org/10.1007/s10750-009-9781-1

Vaikasas, S.; Poškus, V. 2006. Preliminary evaluation of hydroecological regime of the river Šušvė (Šušvės upės hidroekologinio režimo preliminarus įvertinimas). *Konferencijos straipsnių rinkinys. Hidro-2006*, Spalio 12-13, Birštonas, Lithuania, 30–33 (in Lithuanian).

Van Rijn, L.C. 1993. *Principles of sediment transport in rivers, estuaries and coastal seas*. Amsterdam: Aqua publications, The Netherlands. 111 [online], [cited 30 April 2010]. Available at: http://www.aquapublications.nl/Contentsbook2part1.pdf.

Van Rijn, L.C. 2013. *Sedimentation of sand and mud in reservoirs in rivers* [online], [cited 15 January 2012]. Available at: http://www.leovanrijn-sediment.com/papers/Reservoirsiltation2013.pdf.

Water Framework Directive & Hydropower, 2007. *Common Implementation Strategy* Workshop. Issues Paper. Berlin, 4-5 June 2007. 20 p. [online], [cited 10 January 2013]. Available at: http://www.envir.ee/sites/default/files/veepoliitikajahudroenergia.pdf

Wu, N.; Tang, T.; Sh Zhou, X.; Jia, D.; Li, R.; Liu, Cai, Q. 2009. Changes in benthic communities following construction of a run-of-river dam. *Journal of the North American Benthological Society*, 28(1), 69–79. http://dx.doi.org/10.1899/08-047.1

Wu, N.; Cai, Q.; Fohrer, N. 2012. Development and evaluation of a diatom-based index of biotic integrity (D-IBI) for rivers impacted by run-of-river dams. *Ecological Indicators*, 18, 108–117. http://dx.doi.org/10.1016/j.ecolind.2011.10.013

Zdankus, N.; Vaikasas, S.; Sabas, G. 2008. Impact of a hydropower plant on the downstream reach of a river. *Journal of Environmental Engineering and Landscape Management*, 16, 128–134. http://dx.doi.org/10.3846/1648-6897.2008.16.128-134

Zhou Sh.; Tao Tang; Naicheng Wu; Xiaocheng Fu; Wanxiang Jiang; Fengqing Li; Qinghua Cai. 2009. Impacts of cascaded small hydropower plants on microzooplankton in Xiangxi River, China. *Acta Ecologica Sinica*, 29(1), 62–68. http://dx.doi.org/10.1016/j.chnaes.2009.04.008

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