

Role of hydrological and hydromorphological factors in ecological quality of medium-sized lowland streams

Gunta Springe, Laura Grinberga and Agrita Briede

ABSTRACT

The development of biological communities is an important research issue regarding biological quality elements. However, it is still uncertain how different organism groups and their metrics are affected by different environmental factors. A study of high-quality sites of medium-sized lowland streams typical for Latvia (ecoregion Baltic province) was carried out with an emphasis on hydrological and hydromorphological characteristics. The investigations were carried out within the STAR project using the project designated standard methods. We found that the level of saprobity according to benthic macroinvertebrates was mainly linked with substrate type and stream depth. The trophic diatom index for diatoms on a soft substratum had a negative correlation with altitude and a positive correlation with distance from the source and also stream depth. There were no significant correlations between macrophyte trophic indices and environmental factors associated with stream hydrological conditions. The European fish index was influenced mainly by stream width and distance from the source, which agrees with the results of other researchers. In general, a direct or indirect role of hydrological and hydromorphological factors was evident in the forming of communities characterizing stream ecological quality.

Key words | biological indices, high quality reaches, hydrological factors, hydromorphological factors, lowland streams

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INTRODUCTION

The EU Water Framework Directive (Directive 2000/60/EC: Establishing a Framework for Community Action in the Field of Water Policy) defines the aim to reach a good status of European waterbodies by 2015. For this purpose, the assessment of biotic indicators (macrobenthic fauna, fish fauna and aquatic flora) as main water quality elements was proposed for all hydroecosystems, including streams and rivers. Streams ecosystems are structured by abiotic (e.g. physico-chemical), biotic (e.g. predation) or by a combination of abiotic/biotic factors.

The assessment of links between ecology and physical habitat has become a major issue in river research and management. Key drivers include concerns about the conservation implications of human modifications

(e.g. abstraction, climate change) and the explicit need to understand the ecological importance of hydromorphology as prescribed by the WFD (Vaughan *et al.* 2009). Nevertheless, it is still uncertain which hydrological and hydromorphological factors have the main effect on different organism groups used for assessment of ecological quality expressed by biological quality indices.

Aquatic ecosystems are generally affected by substantial anthropogenic impact alongside natural environmental factors. Human-induced stress diminishes the natural differences between stream communities (Verdonschot 2006), and it is hard to separate the role of natural environmental factors. However, in Latvia there are still streams with sites corresponding to “conditions that are

representative of a group of minimally disturbed sites, i.e. reference site, described by selected physical, chemical and biological characteristics” (Reynoldson *et al.* 1997). In this study, we examine the role of natural hydrological and hydromorphological factors in the forming of stream ecological quality described by biological indices for different organism groups in the high-quality stretches of streams.

MATERIAL AND METHODS

According to the Water Framework Directive 2000/60/EC, System A typology (Annex II) (European Commission 2000), 27 high quality reaches (Figure 1) from medium-sized (catchment area 100–1,000 km²), lowland (<200 m) streams of Latvia (ecoregion 15, Baltic) were sampled in the framework of the EVK1-CT-2001-00089 project ‘Standardisation of River Classifications: Framework method for calibrating different biological survey results against ecological quality classifications to be developed for the Water Framework Directive’ or STAR project. All of the investigated streams were permanent streams.

The sampling sites were selected by considering criteria for reference site selection according the STAR field protocols (Furse *et al.* 2006) and were based on existing information and expert judgement. Preliminary selection of high-quality river sites was based on information from

topographical maps (1:50,000) such as the existence of dams, accessibility, point source pollutants and land use patterns. Reynoldson *et al.* (1997) stated that a reference condition is one which is representative of a group of minimally disturbed sites, i.e. reference site described by selected physical, chemical and biological characteristics. All preliminary selected sites were inspected in the field for local pollutant sources and hydromorphological stress.

Sampling and sample processing was carried out according to STAR protocols (<http://www.eu-star.at/frame-set.htm>). Samples of benthic invertebrates were collected using a Surber sampler in 50–100 m stream length, and a sample consisted of 20 subsamples representing microhabitat types. Diatoms were removed for hard substratum (stones) by toothbrush and by ladle from soft substratum (sand). Sampling of benthic invertebrates and diatoms was performed during spring to early summer in 2003. Macrophytes were sampled in July 2003, and fish were sampled using electric fishing by wading from July to September 2003. Both 100-m long stream stretches were studied. Site-related information (e.g. stream geology, land use in the floodplain, etc.) and sample-related information (e.g. human impacts on sampling site, mineral and biotic microhabitats, water chemistry, etc.) including hydrology and hydromorphology were estimated.

For all parameters of the STAR site protocol in this study we used hydrological variables such as stream velocity, discharge, stream width, depth, altitude, gradient

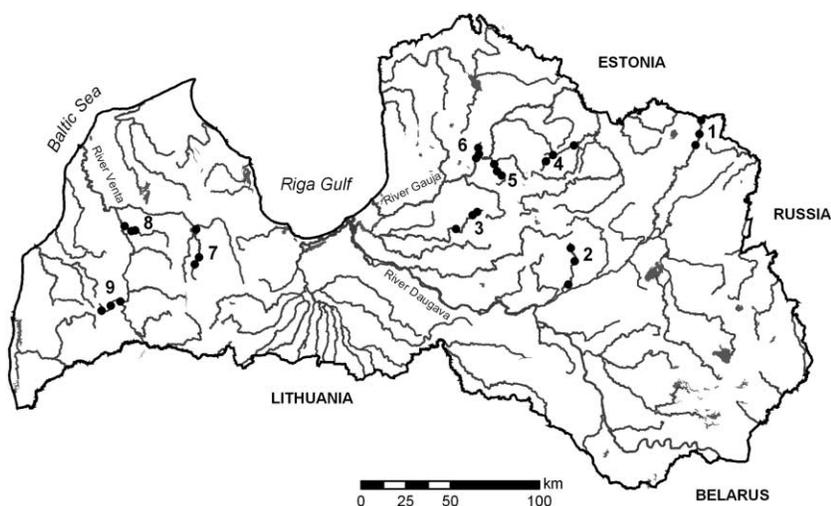


Figure 1 | Location of high-quality sampling sites in streams within the territory of Latvia.

slope, distance from source and substrate, which are strongly related to stream hydrological regime.

Laboratory processing of benthic macroinvertebrates, benthic diatoms, macrophytes and fish were carried out according to the STAR approach (Furse *et al.* 2006). Different biological quality indices based upon macrophytes, benthic invertebrates and benthic diatoms were calculated by STAR project groups. The European fish index (EFI) was provided by the FAME project (<http://fame.boku.ac.at>).

From the wide range of ecological quality indices available, we selected biological indices which are widely used and approved. Mean trophic rank (MTR) (Dawson *et al.* 1999) and macrophyte biological index for rivers (IBMR) (Haury *et al.* 2002) were used as macrophyte trophic metrics, since they have been identified as the most useful in streams and rivers (Szozskiewicz *et al.* 2006). Trophic diatom index (TDI) (Kelly & Whitton 1995) was used for benthic diatoms as it is one of the most variable among fourteen diatom indices (Springe *et al.* 2006). TDI was calculated for diatoms on two different substrates: sediment or soft substrate (TDI_S) and pebbles or hard substrate (TDI_H). For benthic invertebrates, the saprobic index (SI) (Zelinka & Marvan 1961) was applied. The European fish index (EFI) was used for fish.

The links between biological and hydrological characteristics were evaluated by Pearson correlation coefficients calculated by Statistical Package for the Social Science (SPSS) 12.0.1. Streams were grouped according to the

STAR site protocol for width: (1) <1 m; (2) 1–5 m; (3) 5–10 m; (4) 10–20 m; and (5) >20 m and substrate: (1) pebble/gravel; (2) sand; and (3) silt.

RESULTS

The investigations covered all biological quality elements demanded by the WFD: fish, macrophytes, benthic macroinvertebrates and diatoms. We summarized information on indices characterizing stream trophic and saprobic level by these organism groups (Figure 2).

Our results show that, even in sampling sites corresponding to reference conditions, biological indices (MTR and IBMR for macrophytes, TDI for benthic diatoms, SI for benthic invertebrates and EFI for fish) are highly variable (Figure 2): MTR varies from 28.3 to 60.0; IBMR from 8.1 to 15.00; TDI_S from 48.1 to 76.8; TDI_H from 25.9 to 76.8; SI from 1.3 to 2.7; and EFI from 0.2 to 0.6. The most inconsistent are EFI (mean \pm standard deviation = 0.4 ± 0.1) and TDI_H (mean \pm standard deviation = 56.7 ± 13.8).

Simultaneously, the environmental characteristics of the sampled reaches varied considerably more in comparison to biological indices (Table 1).

The Pearson correlation coefficients of the selected metrics and environmental variables indicate that several factors are important for estimated biological indices and hence stream communities (Table 2).

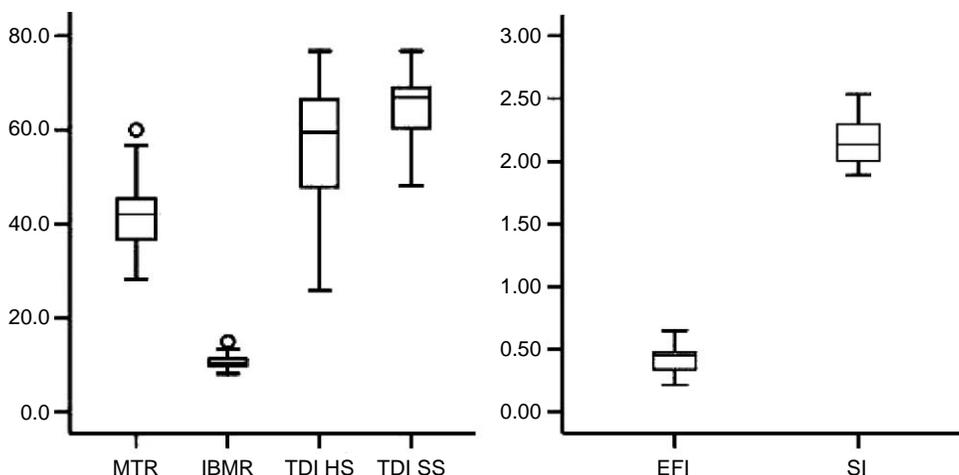


Figure 2 | Values of biological quality indices: EFI, MTR, IBMR, SI, TDI_S and hard TDI_H.

Table 1 | Range, mean values and standard deviation of hydromorphological and hydrological variables in high-quality reaches of medium-sized lowland streams

Hydromorphological and hydrological factors	Range	Mean \pm standard deviation
Altitude (m)	10–189	91 \pm 54.87
Slope (%)	0.1–1.3	0.43 \pm 0.3
Width (m)	2.5–13.0	6.63 \pm 2.75
Depth (m)	0.1–1.0	0.34 \pm 0.24
Distance to source (km)	3.00–47.50	21.17 \pm 13.66
Stream velocity (m s^{-1})	0.14–0.87	0.42 \pm 0.21
Discharge (s^{-1})	50–3300	614.3 \pm 717.88

We may therefore conclude that that SI, which characterizes organic pollution, is related to stream depth as well as substrate composition. Data concerning the impact of hydromorphological and hydrological factors on TDI demonstrate an obvious negative connection between TDI on soft substratum and altitude, as well as a positive correlation with distance to the source and depth. TDI on soft substratum is also affected by stream width. In our case, we did not find a significant correlation between macrophyte trophic indices (MTR, IBMR) and environmental factors connected with stream hydrological conditions. This study revealed that EFI in high-quality sites is influenced mainly by stream width and distance from the source. Among studied indices, the closest connection with hydromorphological factors was demonstrated by TDI_S substratum followed by SI (Table 2).

DISCUSSION

The WFD 2000/60/EC (European Commission 2000) of good water quality assurance is based on the assessment of ecological status by biological quality elements such as fish, macrophyte, benthic invertebrates and diatoms. These groups proposed by the WFD presumably indicate the impact of environmental change to the structure and function of aquatic ecosystems. The influence of environmental variables (including hydromorphological and hydrological parameters) on the different organism groups used as biological quality elements is investigated.

It is considered that the strength of observed patterns among environmental variables and the biological quality

elements depend on the extent to which various mechanisms act in concert; clear patterns arise when several processes act in one direction and observed patterns may have multiple explanations (Gaston & Blackburn 1999). Different taxonomic groups show different relationships to environmental gradients, leading to relatively low levels of concordance (Muotka *et al.* 2004). A question therefore arises regarding the relative role of each environmental factor (Soininen 2004).

Much scientific literature has been devoted to the relations between the stream physical environment and benthic macroinvertebrates. Community structure of benthic invertebrates is a conservative measure of water quality (Leland & Fend 1998), and it is thought that discharge (channel width, depth, current velocity) frequently plays an overriding role in the regulation of the development of benthic organisms in general (e.g. Hart & Finelli 1999). In Finnish moving water, the species distribution of macroinvertebrates is also mostly related to channel width as well as conductivity and pH (Soininen & Könönen 2004). Our previous study shows that biodiversity of macroinvertebrates could be associated with water hardness, alkalinity, chloride, slope, stream velocity and oxygen, which are linked to river basin genesis (Springe *et al.* 2006). In this study we found that SI, which characterizes organic pollution, is related to stream depth as well as substrate composition (Table 2). That is not surprising, as a larger content of organic matter is typical for slower and deeper river stretches where sediments are represented mainly by silt or silty sand.

Another small-bodied organism group, diatoms, are generally considered to be good indicators of changes and are used as such in water chemistry (Steinberg & Schiefele 1988; Soininen & Könönen 2004). However, it is also thought that current velocity influences species composition and the colonization rate of diatoms (Stevenson 1983; Steinman & McIntire 1986) and that it is the major factor which controls diatom distribution in streams (Passy 2001). Stable substrata and flow provide for higher diatom biomass (Iversen *et al.* 1991; Biggs 1996). The variation in diatom communities is also related to geographical factors such as latitude and altitude (Potapova & Charles 2002). Our investigation concerning the impact of hydromorphological and hydrological factors on TDI demonstrates an obvious

Table 2 | Pearson linear correlation coefficients between biological quality indices (SI, TDI_H, TDI_S, EFI, MTR and IBMR) and hydrological and hydromorphological parameters

	Altitude (m)	Slope (%)	Distance to source (km)	Width (m)	Depth (m)	Stream velocity (m s ⁻¹)	Discharge (s ⁻¹)	Substrate	SI	TDI_H	TDI_S	MTR	IBMR	EFI
Altitude (m)	1													
Slope (%)	0.338	1												
Distance to source (km)	-0.356	-0.383*	1											
Width (m)	-0.172	-0.272	0.752**	1										
Depth (m)	-0.478*	-0.521**	0.147	0.219	1									
Stream velocity (m s ⁻¹)	0.003	0.122	0.089	0.035	-0.132	1								
Discharge (s ⁻¹)	-0.126	-0.379	0.555**	0.568**	0.162	0.526**	1							
Substrate	-0.193	-0.508**	-0.039	0.103	0.583**	-0.061	0.127	1						
SI	-0.210	-0.238	-0.241	-0.264	0.453*	-0.248	-0.262	0.485*	1					
TDI_H	-0.339	-0.231	0.281	-0.009	0.093	-0.074	0.014	0.054	0.054	1				
TDI_S	-0.581**	-0.160	0.405*	0.380	0.417*	0.093	0.217	0.264	-0.040	0.439*	1			
MTR	-0.103	0.002	0.234	0.171	-0.042	-0.050	0.098	-0.028	-0.286	0.162	0.221	1		
IBMR	-0.120	-0.029	0.202	0.114	-0.080	-0.174	0.013	-0.012	-0.244	0.255	0.192	0.946**	1	
EFI	-0.280	0.067	0.370	0.445*	0.103	0.208	0.188	0.070	-0.086	0.310	0.475*	0.424*	0.348	1

* $p < 0.05$; ** $p < 0.01$ ($N = 27$).

negative connection between TDI on soft substratum and altitude, as well as a positive correlation with distance to the source and depth (Table 2). TDI on soft substratum is also affected by stream width. These results correspond to the findings of Potapova & Charles (2002) and confirm that, in addition to water chemical composition, hydromorphological factors affect ecological quality as described by TDI.

The role of the current has already been recognized as the chief factor governing the distribution and abundance of aquatic macrophytes (Butcher 1933). Other environmental factors such as stream size, water chemistry, flow velocity and substratum composition are also important in the formation of aquatic plant communities (e.g. Holmes *et al.* 1998; Riis *et al.* 2000; Riis & Biggs 2003).

In the STAR project it was found that slope and shading affected macrophyte communities as well as their trophic indices MTR and IBMR (Brabec & Szoszkiewicz 2006). The presence and development of macrophytes in unshaded lotic systems confirmed that they are primarily controlled by the hydrologic regime (Biggs 1996; Riis & Biggs 2003). Hydrological conditions and substrate can be major determinants for many taxa (Westlake 1975; Dawson 1988; Haslam 2006). Higher discharge and wider reaches are associated with species richness (Baatrup-Pedersen *et al.* 2006). In our case, we did not find a significant correlation between macrophyte trophic indices (MTR, IBMR) and environmental factors connected with stream hydrological conditions (Table 2). This might be explained by the fact that most of the analyzed sites were poor in macrophyte species. In most cases, the species number did not conform to that recommended for the calculation of indices. We assume that the poor macrophyte abundance could generally be explained by shading.

Investigations of the fish community in relation to environmental variables revealed that different factors contribute to fish distribution. Huet (1949) assumed that drag forces of stream currents were influenced by slope as well as by width. He related fish zonation to these two parameters. In addition, altitude, distance from the source, stream width, substrate (Jowett & Richardson 2003) and flow (Lammert & Allan 1999) are important. Distance from the source, altitude and surface area of catchment could explain 70% of the total variation in fish species richness

(Mastrorillo *et al.* 1998). Physical conditions (e.g. depth, width and velocity) that vary with river discharge affect the performance (birth, growth, feeding, movement and death rates) of organisms or trophic groups, e.g. biomass of invertebrates and fish increased with floodplain width (Power *et al.* 1995). Fish fecundity, potential size, maximum age and reproductive factors increased from headwater to plain reaches (Santoul *et al.* 2005). Our previous findings also linked fish biodiversity mainly with stream morphology (slope, altitude and maximum depth) and substrata (Springe *et al.* 2006). This study revealed that EFI in high-quality sites is influenced mainly by stream width and distance from the source (Table 2), which agrees with the results of other researchers.

A summary of the biological and hydrological data from high quality or reference sites highlighted the direct or indirect role of natural environmental factors in the formation of different biological indices characterizing stream biological quality. Our findings acknowledge the role of the following hydromorphological and hydrological factors to biological quality indices: altitude (TDI), distance to source (TDI, EFI), width (EFI), depth (SI, TDI) and substrate (SI). TDI_S has the greatest affect on hydromorphological factors, followed by SI. This confirms the results of our previous study (Springe *et al.* 2006), which were that environmental factors have a greater effect on small-bodied organisms (benthic diatoms and macroinvertebrates) than on large-bodied organisms (macrophytes and fish).

CONCLUSIONS

1. Biological indices (MTR, IBMR, TDI and SI for benthic invertebrates and EFI for fish) are highly variable in high-quality sites, but the environmental characteristics of sampled reaches varied more compared to biological indices.
2. Of the investigated biological indices, SI (based on benthic macroinvertebrates) is correlated with stream depth as well as substrate composition. A negative relationship exists between TDI on soft substratum and altitude as well as a positive correlation with distance to the source and depth. In high-quality sites, EFI is mainly influenced by stream width and distance from the source.

3. Significant correlations were not found between macrophyte trophic indices and environmental factors connected with stream hydrological conditions.
4. In high-quality or reference sites, a direct or indirect role of natural hydromorphological and hydrological factors is evident in the formation of different biological indices. Measurements of hydrological and hydromorphological factors are therefore important in the assessment of stream ecological quality.

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