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PRIMARY RESEARCH PAPER

The effect of channelization on the biological quality of lowland streams using macroinvertebrates as proxies

K. Käiro · M. Haldna · H. Timm · T. Virro

Abstract We studied whether and how channelization affects macroinvertebrate communities and biological quality in lowland streams of Estonia (Northern Europe). Two datasets of semi-quantitative samples (collected during 2001–2010) were used: (1) pairwise data (natural sites located upstream of the channelized sites; 22 streams, 24 pairs), and (2) background data (73 natural sites from 62 streams, 73 channelized sites from 62 streams). The mean stream order in both datasets was 3. Channelization had no significant effects on physicochemical parameters or on macroinvertebrates in the pairwise dataset where channelization was done decades earlier. However, it had several negative effects on macroinvertebrates in the background dataset where several areas had probably been maintained more recently. Richness of sensitive data, Shannon diversity, mean sensitivity, organic pollution index, and multimetric quality were significantly lower for the modified sites than for the natural sites. Only total taxon richness and score of hydromorphology were not significantly affected by channelization. Thus, several macroinvertebrate metrics that indicate water pollution, proved to be sensitive to channelization as well. The recovery conditions (such as stream type, channelization season, recovering duration, etc.) have been poorly studied and would deserve further attention.

Keywords Macroinvertebrates · Channelization · Anthropogenic impact · Lowland streams

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Introduction

Alteration of physical habitats by channelization is the most significant threat to biodiversity and rivers worldwide (Rosenberg et al., 2000; Nakamura & Yamada, 2005). After channelization, the slope of the river channel will increase (Lewczuk & Burandt, 2011) resulting in a temporary increase of flow velocity, which in turn facilitates channel and bank erosion (Julien, 2010). Significant changes take place in the thermal regime and water chemistry (Dewson et al., 2007; Yoshimura, 2012). Channel straightening decreases water depth and wetted channel width. Removal of the bankside vegetation, which is usually accompanied by channelization, increases solar

radiation input to the stream which then leads to higher water temperature (Karr & Schlosser, 1978; Quinn et al., 1992; Maxted et al., 2000) and can cause a reduction in allochthonous organic matter input (Brooker, 1985). Natural pool–riffle sequences, which provide shelter for fish and macroinvertebrates for high- and low-flow velocities in channelized streams, are lost (Brookes, 1987). These streams have little or no stable structure in the channel (except for macrophytes), have few or no meanders or pools, and have no native riparian vegetation to shade the channel and buffer the stream from adjacent cultural practices (Maxted et al., 2000; Nakano et al., 2008).

Cumulatively, these changes in hydrology, geomorphology, nutrient cycling, and sediment dynamics often lead to degradation in stream communities (Quinn et al., 1992; Rohasliney & Jackson, 2008; Smiley & Dibble, 2008; Blann et al., 2009; Horsák et al., 2009; Pliuraite & Kesminas, 2011; Wooster et al., 2013). Both food web size and number of links per species are negatively related to mean intensity of bed disturbance (Townsend et al., 1998). In addition, hydromorphologically degraded sites are significantly prone to invasion by nonindigenous species (Frueh et al., 2012).

Construction of drainage ditches in the current territory of Estonia is known from the seventeenth century. Draining and channelizing works intensified at the end of the nineteenth century and particularly in the 1950s–1960 s (EE, 1990). Many small streams were straightened and/or dredged. In excessively wet areas (e.g., NE Estonia), approximately 80% of all streambeds were modified (Tuulmets & Aasalo, 1980).

According to the European Water Framework Directive (2000), the Member States must protect and improve the biological quality of streams. Macroinvertebrates are considered to be an important quality element for the classification of their ecological status. In comparison with studies of hydrochemical pollution and flow regulation, surveys describing relationships between the macroinvertebrate fauna and channelization are relatively scarce. However, as channelization is the most common hydromorphological human impact on streams in Estonia (if not the most common human impact in general), its influences to diversity and sensitivity of macroinvertebrates should be determined.

We assumed that biological quality should be lower in channelized stream sections than in natural sections, due to initial disturbance and subsequent potential loss in habitat heterogeneity. Hence, we predicted that channelization affects the macroinvertebrate communities in Estonian streams and that the effects can be detected using biological quality indices.

## Materials and methods

Study area

Estonia is a small country (area 45,200 km^2) with a flat landscape (mean altitude 50 m above sea level), situated on the eastern shore of the Baltic Sea (Fig. 1). Together with Latvia and Lithuania, it forms the Baltic ecoregion in the sense of the Water Framework Directive, with a prevailing altitude lower than 200 m. Estonia belongs to the area of mixed forests of the temperate zone, bordering the taiga. In comparison with the other European areas, it is characterized by a large proportion of raised bogs and forests (Raukas & Rõuk, 1995).

Macroinvertebrate sampling

Sampling sites were distributed throughout the mainland territory (Fig. 1). A standard hand net (mesh size 500 μm, European Committee, 1994) was used. Each sample consisted of a semiquantitative part and a qualitative part. Five kicks or sweeps (with an area of 0.25 m^2) were taken from the prevailing bottom type. The qualitative sample was collected from all different habitats available at the study site (Ministry of Environment, 2009). Macroinvertebrates were placed in plastic jars and preserved with 95% ethanol, together with sieved debris. In the laboratory, the animals were identified to the species or genus level, according to Johnson's (1999) list with some modifications. Taxa requiring higher magnification (e.g., oligochaetes, chironomids, water mites) were not determined further than family or order level.

We used two independent datasets. In the pairwise set, we compared macroinvertebrate metrics and physicochemical parameters of two sites at the same stream: (1) modified (channelized) site, (2) natural (unchannelized) site. To avoid possible disturbances during initial excavation or later maintenance works of

Fig. 1 Study area.
A Pairwise study,
B background study. *Dark diamonds* modified sites, *gray circles* natural sites
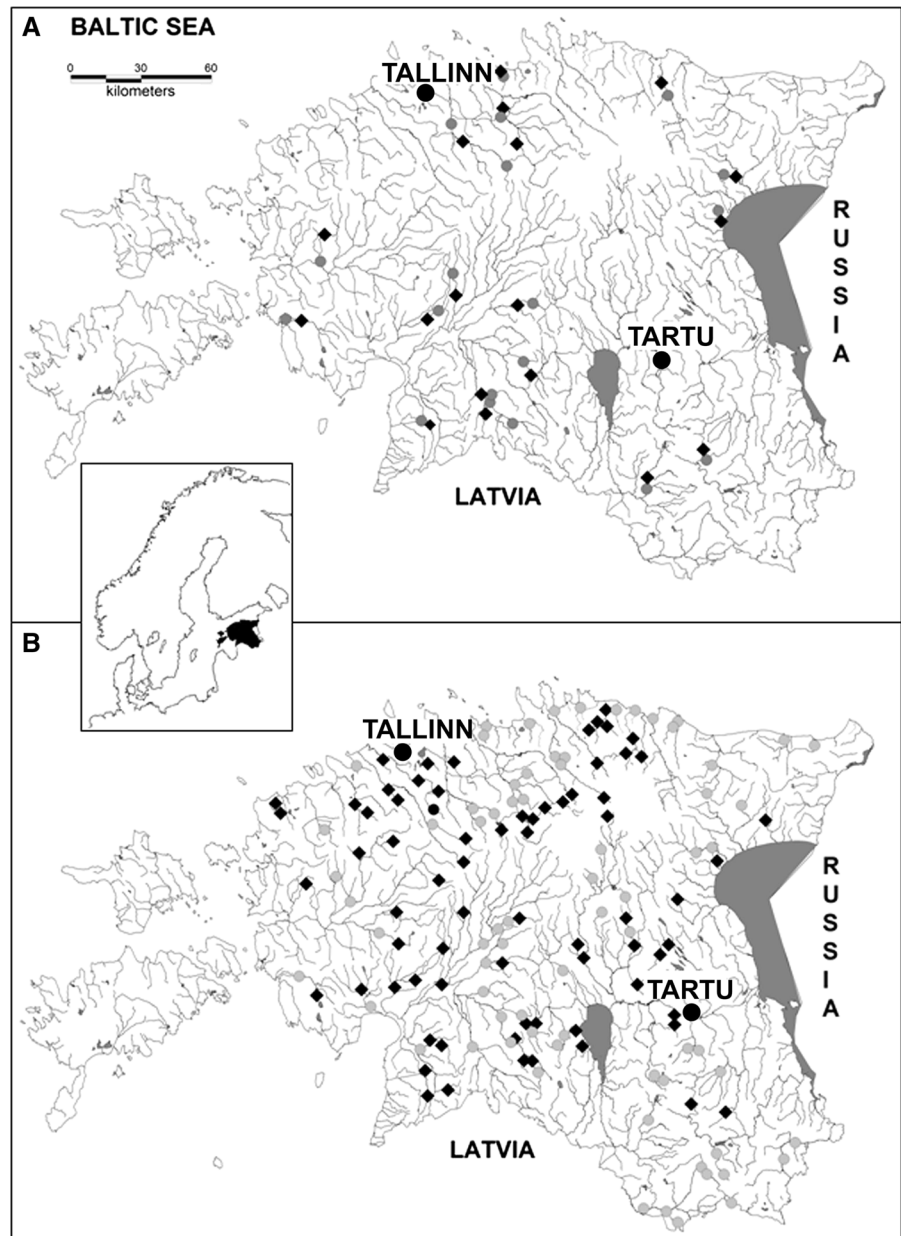
channelized sections, the natural sites were situated upstream of the modified sites. There were no disturbed areas in the upstream vicinity of the natural sites. In each pair, the sites belonged to the same Strahler stream order. In total, 24 pairs from 22 streams were compared. The samples were taken in May 2009 and in September–October 2010; the related pairs were collected on the same day. Channelization in the studied sections had been done more than 30 years prior to sampling in most cases. Thus,

we compared natural sections and sections straightened long ago rather than estimating the effect of recent excavations. The riparian canopy, if destroyed during channelization, was often recovered, consisting mostly of deciduous bush (*Alnus incana*, *Salix* spp.).

The background dataset originates from the database of the Estonian University of Life Sciences, collected during 2000–2010 (the sites used in the pairwise dataset were not included here). These samples include 73 different modified sites from 62

streams and 73 different natural sites from 62 streams. Among them, several areas had probably been maintained more recently compared with those in the pairwise dataset (but not during the last 1–2 years). The riparian canopy at the modified sites was often absent. Sampling time was spring (April or May). Most physical and chemical data for these samples were not measured. The background dataset had the benefit of much larger number of measurements, as well as more contrasting habitats compared with the pairwise set. Hydrochemically polluted sites and dammed areas were excluded from both datasets. The mean stream order for the modified and the natural sites was 3.

Physical, chemical, and hydromorphological measurements

In the pairwise study, water temperature (°C), dissolved oxygen (mg l^{-1}), oxygen saturation (%), pH and conductivity (μS cm^{-1}) were measured in the field, in autumn 2010. In the background study, only temperature data were available. In both cases, flow velocity and the composition of bottom substrate were estimated visually using the following scale: 0—no flow and/or muddy bottom, 1—slow flow (< 0.2 m s^{-1}) and sandy bottom, 2—fast flow (> 0.2 m s^{-1}) and sandy-stony bottom, 3—very fast flow ($\gg 0.2$ m s^{-1}) and stony bottom. Bottom was mostly stony or gravelly both at the modified and natural sites (Table 1).

Biological quality based on macroinvertebrate metrics

To characterize biological quality, five macroinvertebrate indices used in the national guide (Ministry of Environment, 2009) were calculated for each sampling site: total taxon richness T (taxa identified according to Johnson's (1999) list, modified for local conditions); Shannon diversity H' (Johnson, 1999); sensitive (Ephemeroptera, Plecoptera, and Trichoptera) taxon richness EPT (Lenat, 1988); mean sensitivity index or Average Score Per Taxon (ASPT; Armitage et al., 1983); and Danish Stream Fauna Index (DSFI), estimating organic pollution level (Skriver et al., 2000) (Table 1). Higher values indicate higher quality. For most metrics, the whole compound sample (five replicates plus one qualitative sample) was used, only H' was calculated

without the qualitative sample. The metrics were subsequently scored accordingly: all values of high quality were assigned five points, the values of good quality, four points, the values of moderate quality, two points, and the values of poor and bad quality, zero points. The difference between good level and moderate level was intentionally emphasized in order to underline the principal difference between them in terms of the Water Framework Directive. Multimetric quality (MMQ) was then calculated by adding up the corresponding points. Hence, the sum for the five indices 23–25 was considered to indicate high quality, 18–22, good, 10–17, moderate, 6–9, poor and <6, bad quality.

The values of all indices and the estimates of multimetric quality were then divided by their corresponding reference values resulting in Ecological Quality Ratios (EQR). The corresponding quality levels were established according to the results of an earlier intercalibration of running waters in Europe where the acceptable range for high/good quality was 0.84–0.94 and for good/moderate quality, 0.64–0.75 (van de Bund, 2009). In Estonian streams, these ranges were classified as follows: high > 0.9, good 0.7–0.9, moderate 0.4–0.7, poor and bad < 0.4 (Ministry of Environment, 2009).

To assess possible hydromorphological changes on the basis of macroinvertebrates, we used the Macroinvertebrates in Estonia: Score of Hydromorphology (MESH) index. The MESH is an average score based on the affinities of selected indicator taxa to flow velocity and substrate type. Individual MESH scores for macroinvertebrates range from 0 to 3, higher scores indicating harder bottom substrate (Timm et al., 2011).

Statistical analyses

Statistical analyses were performed using R 3.1.2 (R Core Team, 2014). We used Indicator Species Analysis (ISA; Dufrêne & Legendre, 1997) to detect indicatory species for the modified and natural stream sections. ISA calculates an indicator value i for each species in different habitats (j), using relative abundances of species and the presence–occurrence. The Indicator Value$_{ij}$ in Dufrêne & Legendre (1997) is multiplied by 100.

The Indicator Value$_{ij}$ in Dufrêne & Legendre (1997) is multiplied by 100. Indicator value index is a combination of two components, A and B:

Table 1 Arithmetic means of physical, chemical and hydromorphological parameters, and of macroinvertebrate metrics for the studied habitats

Parameter	Habitat		n
	Modified	Natural	
Pairwise			
Temperature (°C)	12.77 (10.6–15.8)	12.53 (10.5–15.4)	18
O$_2$ (mg l^{-1})	9.52 (7.2–11.6)	9.53 (7.1–10.8)	18
O%	89.45 (67–116)	89.05 (66–106)	18
pH	7.99 (7.8–8.22)	7.95 (7.74–8.18)	18
Conductivity (μS cm^{-1})	399 (237–565)	408 (312–572)	18
Flow velocity	1.17 (1–2)	1.78 (1–2)	18
Bottom substrate	1.67 (1–3)	2.22 (1–3)	18
T	40.2 (22–70)	41.3 (26–60)	18
H'	3.28 (1.7–4.36)	3.50 (2.3–4.45)	18
ASPT	5.92 (5.16–6.82)	6.12 (5.65–6.71)	18
EPT	15.2 (8–23)	17.2 (12–23)	18
DSFI	5.89 (4–7)	6.5 (5–7)	18
Background			
Temperature (°C)	9.38 (5–14)	10.08 (4–16)	73
Flow velocity	1.85 (1–3)	2.04 (1–3)	73
Bottom substrate	2.12 (0–3)	2.01 (1–3)	73
T	28.2 (13–47)	33.0 (17–55)	73
H'	2.29 (0.34–4.14)	2.98 (1–4.09)	73
ASPT	5.42 (4.18–6.91)	6.14 (4.78–7.2)	73
EPT	11.9 (2–27)	15.61 (7–26)	73
DSFI	5.51 (4–7)	6.53 (5–7)	73

T total taxon richness, *ASPT* Average Score Per Taxon, *EPT* taxon richness of Ephemeroptera, Plecoptera and Trichoptera, *DSFI* Danish Stream Fauna Index, H' Shannon diversity, n number of measurements

Minimum and maximum values are given in the brackets

$$\text{Indicator value}_{ij} = A_{ij} \times B_{ij},$$

where A is the probability of the studied site to belong to the target group where the species was found and B is the probability to find the species at sites belonging to the site group. An indicator value of 1 indicates perfect indication (i.e., individuals of species were observed at all sites of only one site group). The Indicator Value$_{ij}$ in Dufrêne & Legendre (1997) is multiplied by 100. However, this calculation was not performed in our analysis. Furthermore, species present in less than 10% of the samples were excluded prior to ISA.

The effects of channelization on the physical and chemical parameters and on the macroinvertebrate metrics described above were assessed using one-way Analysis of Variance. The parameters and metrics that did not meet the normal distribution requirement according to Shapiro–Wilk's test were $\log_{10} (x + 1)$ transformed. The Danish Stream Fauna Index, which is a categorical variable, was examined by the nonparametric Mann–Whitney U test. The significance of the indicator species was tested using the Monte Carlo test of 999 permutations. Due to multiple comparisons, the critical Bonferroni P value was adjusted to 0.007 (in the case of seven macroinvertebrate metrics), or to 0.01 (in the case of five physicochemical parameters). The χ^2 test was used to compare flow velocity (values 1, 2, 3) and bottom substrate (values 1, 2, 3) for the natural and modified sites at the 0.05 significance level.

Results

Physical and chemical parameters

The mean values of the physical and chemical parameters are presented in Table 1. No statistical differences between the modified and natural sites were found in water temperature (one-way ANOVA, df = 1, $F = 0.054$, $P > 0.05$), O$_2$ (one-way ANOVA,

df $= 1$, $F = 0.104$, $P > 0.05$), O% (one-way ANOVA, df $= 1$, $F = 0.032$, $P > 0.05$) pH (one-way ANOVA, df $= 1$, $F = 0.006$, $P > 0.05$) or conductivity (one-way ANOVA, df $= 1$, $F = 0.126$, $P > 0.05$). According to the Chi square test, the natural streams had significantly higher flow velocity and harder bottom substrate compared to the modified streams in the pairwise study ($\chi^2 = 11.15$, df $= 1$, $P = 0.0008$; $\chi^2 = 6.32$, df $= 2$, $P = 0.04$, respectively). In the background dataset, neither flow velocity nor composition of the bottom substrate was significantly different between the modified and natural sites.

Taxonomic composition and analysis
of the indicator species

In the pairwise dataset, 187 taxa were recorded (Online Appendix). Total taxon richness at the modified sites (149) did not differ significantly ($P > 0.05$) from that at the natural sites (151). The highest number of taxa per sample was 70 at the modified sites (the Pirita Stream, N Estonia) and 60 in the natural sites (the Jägala Stream, N Estonia). The most frequent taxon at the modified and natural sites was Chironomidae, occurring in 95 and 99% of the samples, respectively.

In the background dataset, the number of samples, and hence the total taxon richness, was higher compared to the pairwise dataset. A total of 252 taxa were recorded—among them 206 at the modified sites and 212 at the natural sites, the difference being statistically nonsignificant. The highest number of taxa per sample at the modified sites was 47 (Elbu Stream, W Estonia) and 55 at the natural sites (the Kasari Stream, W Estonia). The most frequent taxon both at the channelized and natural sites was once

more Chironomidae, occurring in 97 and 99% of the samples, respectively.

According to the indicator species analysis, the pairwise study revealed 4 taxa associated significantly ($P < 0.05$) with natural sites: the beetle *Elmis aenea*, the mayfly *Heptagenia sulphurea*, and two caddisflies *Cheumatopsyche lepida* and *Rhyacophila* sp. Two taxa, *Limnephilus* sp. and *Glossiphonia complanata* were significant indicators of the modified sites (Table 2).

The background dataset revealed 9 taxa associated significantly ($P < 0.05$) with natural sites. There were four significant indicators for the modified sites revealed (Ceratopogonidae, *Limnephilus flavicornis*, *Ironoquia dubia*, and *Limnephilus lunatus*). In both cases, most indicators belonged largely to the order Trichoptera (Table 3).

Biological quality

According to the pairwise study, channelization had no significant effect on macroinvertebrate metrics. However, most metrics had slightly higher arithmethic mean values for the natural sites compared to the modified sites. The results of the background study revealed some significant differences. Most single metrics and multimetric quality (EQR-MMQ) were significantly higher for the natural sites than for the modified sites (Table 4). Multimetric quality varied more for the modified sites than for the natural sites (Fig. 2). The quality classes of the modified sites ranged from "bad" to "high", with the median value "good". The quality classes of the natural sites varied from "good" to "high", with the median value "high". No significant differences were observed in total taxon richness (EQR-T) or in MESH between the modified and the natural sites.

Table 2 Results of indicator species analysis, pairwise study

	Indicator value	
	Natural sites	Modified sites
Elmis aenea (Müller)	0.815	
Heptagenia sulphurea (Müller)	0.742	
Cheumatopsyche lepida (Pictet)	0.527	
Rhyacophila sp.	0.527	
Limnephilus sp.		0.754
Glossiphonia complanata (L.)		0.609

Only significant indicator taxa ($P < 0.05$) are presented

Table 3 Results of indicator species analysis, background study

	Indicator value	
	Natural sites	Modified sites
Hydropsyche pellucidula (Curtis)	0.576	
Sericostoma personatum (Spence)	0.736	
Lepidostoma hirtum (Fabricius)	0.503	
Orectochilus villosus (Dejean)	0.403	
Cheumatopsyche lepida (Pictet)	0.384	
Ithytrichia lamellaris (Eaton)	0.343	
Odontocerum albicorne (Scopoli)	0.310	
Antocha sp.	0.310	
Hydropsyche siltalai (Döhler)	0.309	
Ceratopogonidae Gen. sp.		0.669
Limnephilus flavicornis (Fabricius)		0.467
Ironoquia dubia (Stephens)		0.369
Limnephilus lunatus (Curtis)		0.358

Only significant indicator taxa ($P < 0.05$) are presented

Table 4 Comparison of the macroinvertebrate metrics according to one-way ANOVA

Index	Modified sites	Natural sites	F	P value
Pairwise dataset				
EQRT	1.33	1.33	0.029	n.s
EQRH′	1.13	1.19	0.777	n.s
EQRASPT	0.87	0.91	2.781	n.s
EQRDSFI[a]	0.84	0.98	–	n.s
EQREPT	1.01	1.17	3.278	n.s
EQRMMQ	0.86	0.96	7.341	n.s
MESH	2.2	2.43	6.003	n.s
Background dataset				
EQRT	1.02	1.09	2.012	n.s
EQRH′	0.89	1.04	9.609	0.0002
EQRASPT	0.83	0.9	31.65	<0.0001
EQRDSFI[a]	0.79	0.91	–	<0.0001
EQREPT	0.93	1.07	15.05	0.0002
EQRMMQ	0.75	0.88	18.39	<0.0001
MESH	2.54	2.64	5.387	n.s

EQR environmental quality ratio, *T* total taxon richness, *ASPT* average score per taxon, *EPT* taxon richness of Ephemeroptera, Plecoptera and Trichoptera, *DSFI* Danish Stream Fauna Index, *H′* Shannon diversity, *MMQ* multimetric quality. *MESH* score of hydromorphology, *n.s.* not significant

[a] Estimation was made by nonparametric *U* test

Discussion

Total taxon richness

Among the macroinvertebrate metrics, total taxon richness was the most tolerant to channelization, being very similar for the modified and natural sites (in both datasets). Probably, natural species had been successfully replaced through stream drift, during the long recovery time. Similarly, hydromorphological alteration was not followed by changes in whole-community diversity in several streams of Netherlands, Germany and Poland, where ecologically similar species had replaced those lost through environmental changes (Feld et al., 2014). In an earlier study, there were no significant differences in the species richness of macroinvertebrates between the channelized and unchannelized sections, either (Hortle & Lake, 1982). However, several authors have reported that channelization leads to lower taxon
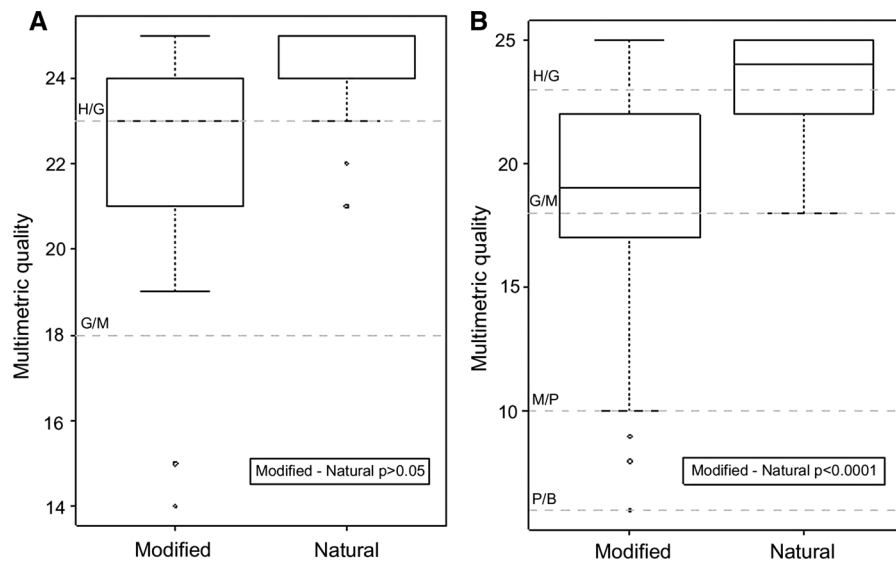
Fig. 2 Plots of multimetric quality index comparing the modified and natural sites. **A** Pairwise study, **B** background study. *Lines inside the boxes* indicate the median values, *boxes* indicate the 25 and 75% percentiles, and *whiskers* indicate the minimum and maximum values. *Dashed lines* denote the boundaries between the quality classes: *H/G* high and good, *G/M* good and moderate, *M/P* moderate and poor, and *P/B* poor and bad

richness of macroinvertebrates (Duvel & Volkmar, 1976; Quinn et al., 1992; Bis et al., 2000; Negishi et al., 2002; Rohasliney & Jackson, 2008; Horsák et al., 2009; Pliuraite & Kesminas, 2011).

Response to flow and bottom type

In the pairwise dataset, stream flow was unexpectedly significantly faster, and bottom substrate was significantly harder at the natural than at the modified sites. We speculate that channelization might have been concentrated in areas with a lower slope compared to that of typical natural areas. At the same time, MESH index, which characterizes both flow conditions and bottom type on the basis of the macroinvertebrate fauna, did not differ significantly between the modified and natural sites either in the pairwise or in the background dataset.

Sensitivity indices

Total taxon richness and MESH (which was basically designed to reveal the effects of damming) appeared to be tolerant to channelization in both datasets. The other indices of biological quality (H', ASPT, DSFI, EPT, and MMQ) were all sensitive to channelization

in the background dataset but neither of them was sensitive to channelization in the pairwise dataset. The contrast between the two datasets indicates that channelization done decades earlier, and being now discernible only by the shape of the stream channel, could lose its major influence on the macroinvertebrate fauna (like in the case of the pairwise dataset). Moreover, the channelized sections in the pairwise dataset were located downstream of natural sections in all cases, which could have restored the initial situation before long by stream drift.

When habitat heterogeneity and substratum stability for modified streams becomes similar to that noted prior to channelization, macroinvertebrate diversity can recover (Hortle & Lake, 1982; Smiley & Dibble, 2008). In the case of channel alterations, several metrics may also respond in the direction opposite to the expected response. Changes may also favor organism groups living on stony bottom (Ofenböck et al., 2004).

In the background dataset in which contrasts between the modified and the natural habitats were greater, the effects of channelization on the macroinvertebrate indices proved to be significant. Also Rabeni (2000) considered diversity indices to be the most sensitive to habitat changes. However, Hortle &

Lake ([1982]) obtained no consistent results supporting the ability of diversity and evenness to distinguish between modified and unmodified sites.

Not unlike our study, ASPT index was correlated negatively to channel modification in other studies (Davy-Bowker & Furse, [2006]; Friberg et al., [2009]). The DSFI (being significantly lower for the modified than for the natural sites in our study) was originally designed to estimate the effects of organic pollution (Skriver et al., [2000]). Horsák et al. ([2009]) did not find significant differences in the values of another index of organic pollution (Saprobic) between modified and unmodified sites.

In the present study, the mean total number of EPT taxa was significantly lower in the disturbed streams (4.1) compared to the undisturbed streams (7.0) (Pedersen & Friberg, [2009]). At the same time, taxa associated with stable substrata, such as *Leuctra* sp. and *Baetis* sp., declined in abundance by approximately 50% at the disturbed sites. There were no significant statistical differences for total richness of Ephemeroptera and Trichoptera between the natural and the channelized sites (Pliuraite & Kesminas, [2011]). In channelized sections, taxa that favored cool water and low periphyton abundance (e.g., Plecoptera) decreased in density, whereas the densities of taxa favored by the abundance of periphyton (e.g., Chironomidae) increased (Quinn et al., [1992]).

Multimetric indices to estimate hydrochemical pollution and general degradation of streams have been developed in many countries (Barbour & Yoder, [2000]; Camargo et al., [2004]; Dahl & Johnson, [2004]; Ofenböck et al., [2004]; Pinto et al., [2004]; Vlek et al., [2004]; Munne & Prat, [2009]; Gabriels et al., [2010]; Oliveira et al., [2011]; Couceiro et al., [2012]; Jun et al., [2012]; Mondy et al., [2012]; Helson & Williams, [2013]; Hong et al., [2014]). Yet only few of them (Balestrini et al., [2004]; Lorenz et al., [2004]) are focused on hydromorphological changes. Although hydromorphological impairments are highly frequent, the corresponding indication systems are mostly not available. It is noteworthy, that the indices that have proved to be useful in estimation of hydrochemical changes are often successfully used to estimate hydromorphological effects.

In the current study, the Estonian national multimetric index (Ministry of Environment, [2009]), expressed as the Environmental Quality Ratio, was used. It indicated a significant difference between the channelized and the natural sites in the larger (background) dataset. Thus, as predicted, channelization affected significantly the macroinvertebrate communities in Estonian streams and the effects could be reliably detected using biological quality indices. The indices of biological quality forming the national multimetric index have effectively characterized all major disturbances in Estonian streams: organic pollution (Timm et al., [2001]), damming (Käiro et al., [2011], [2012]) and channelization (this study).

We believe that the observed differences of macroinvertebrates between natural and channelized sites may indicate significant disturbances also on whole-stream level. Even if water quality does not change significantly, the elements of freshwater biota (such as invertebrates, fishes, macrophytes, phytobenthos, etc.) that need time to recover or to re-immigrate, probably become all more or less disturbed. However, the longer is the interval between channelization works and hydrobiological sampling, the higher is the probability to meet recovered conditions. On the other hand, several species that settle in the channelized areas probably did not inhabit these reaches before channel alteration, thus complementing the original species list.

As shown above, the channelization didn't always have significant effects on macroinvertebrates, however, the shape of the channel and bottom substrates would be as predicted after such alteration. In this cases, the biota (unlike the channel) was probably already recovered, either by stream drift, wind, flying insects, or by other dispersal mechanisms. However, the effects of channelization and the degree of recovery are poorly studied and would deserve further attention under different conditions (e.g., different stream types, seasons, etc.). We hope that our results are relevant for hydrobiologists, land and freshwater managers at least in European Baltic Ecoregion, as well as elsewhere in the world.

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