

**Comparison between  
Multiple-channel and Single-channel Stream Sections**

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**Hydromorphology and Benthic Macroinvertebrates**

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## General Introduction

Rivers and streams can be described as lifelines of regions, defining geography, ecology, national boundaries, and economy, human development, and well-being is intimately associated with them. Since the Middle Ages, rivers have been confronted with human demands for multiple purposes and they have faced progressive deterioration due to anthropogenic pollution, eutrophication, bank fixation, disengagement of floodplains, alteration of hydrology and loss of aquatic and riparian biodiversity.

In response to these problems in Europe, the European Commission developed the Water Framework Directive (WFD; EC, 2000). In 2000 this comprehensive set of regulations went into effect in all EU member states. The goals of the WFD require that all water bodies achieve a "good ecological status" by the year 2015. After several years of surveying the status of the European rivers, the disastrous situation became clear, with up to 90% of the rivers being at risk of not reaching this goal (e.g. BMU, 2005; ICPDR, 2005; ICPR, 2005). In Central Europe, poor hydromorphology has been identified as the main problem, while severe pollution and effects from toxic substances or acidification were dealt with quite successfully in past decades (Brookes, 1987; Verdonshot and Nijboer, 2002). Thus, presently there is a strong demand for stream restoration, but restoring streams is a slow process and has only recently started (Küster, 1999; Gurnell and Petts, 2002; Nollkaemper, 2005).

Another reason for growing interest in stream restoration arises from global climate change. Changing weather patterns are becoming more and more evident, followed by effects on water resources: severe flooding, dikes breaking, or rivers drying out. The German Environmental Agency reports an increase of winter precipitation between 1971 and 2000 of 34%, accompanied by a winter temperature increase of 2.3°C, compared to a yearly mean increase of 1.1°C (Schönwiese *et al.*, 2005). Besides the rising temperature, a more extreme and more variable hydrological cycle is predicted on the basis of higher precipitation (IPCC, 2001; IPCC, 2007). The Intergovernmental Panel on Climate Change (IPCC) considers these the result of various causes, such as more frequent rain periods in winter, increased storm intensity, and more frequent and more intense rain events (IPCC, 2001; IPCC, 2007). Especially the distribution of precipitation will vary regionally, although on average an increase

in precipitation is expected. The intensity and impacts of flooding events is predicted to increase, as surface area degradation from additional urbanisation or deforestation progresses.

Giving streams and rivers more room to cope with the new circumstances of a more extreme water supply situation and re-creating natural retention space is thus considered an appropriate measure to reduce flooding impacts. A larger retention space and complex channel form, including riparian vegetation or wetlands, will buffer floods by offsetting flood water release (Committee on Riparian Zone Functioning and Strategies for Management, 2002). Downstream areas then face less severe flood peaks (Hooijer *et al.*, 2004). This can reduce damage to infrastructure and lower the threat to human livelihood (LFU Bavaria, 1999), while at the same time meeting the requirements set by the WFD.

Both the WFD regulations and the challenges posed by climate change are predicted to lead to more restoration measures in the future. These will aim at changing, reducing or abandoning floodplain use for flood risk reasons, and at establishing a more dynamic stream environment, which reduces flood risk and is assumed to enhance biodiversity (Ward *et al.*, 1999; Jungwirth *et al.*, 2002; Pedrolí *et al.*, 2002).

Any restoration aim or measure should be defined according to "reference conditions" or the "potentially natural situation", which is derived from the natural or near-natural condition of a stream (Thorne *et al.*, 1997; USEPA, 2000; LUA NRW, 2001a; Palmer *et al.*, 2005). The considerable regional differences in stream characteristics are codified in the WFD and are in Germany reflected by 24 acknowledged stream types (LAWA, 2004). A primary differentiating parameter of hydromorphology under reference conditions is the longitudinal stream course, which is either straight, multiple-channel (braided) or meandering. The different stream shapes result from discharge patterns, channel slope and dominant substrates (Rosen, 1994). It is increasingly recognised that unimpaired streams in the lower mountainous areas of Central Europe would show a multiple-channel pattern characterised by large gravel banks, shallow transverse profiles, differently vegetated island stages, and a high sediment dynamic (Träbing, 1996; Knighton, 1998; LUA NRW, 2001b; Gurnell and Petts, 2002). Yet today, multiple-channel stream sections are restricted to very short sections in remote regions. Bank fixation and flow regulation prevent lateral migration of most streams and restrict the channel to a narrow stretch of the former floodplain, impeding multiple-channel development. For these streams, restoration measures aiming to restore reference conditions target the development of multiple-channel patterns. A common approach is to remove bank fixation along the shoreline or bottom fixation to allow the river channel to broaden (Rohde *et al.*, 2005) or to initiate new hydromorphological features. What happens after restoration is

thus conceptually clear: due to the increasing morphological diversity and the re-instating of processes aquatic-terrestrial connections are re-established, thereby promoting a biodiversity increase. This process can be modified by factors acting from within or around the system. However, with some exceptions, hydromorphology of multiple-channel streams is not well investigated and difficult to classify due to its complex structure (Thorne *et al.*, 1997). To judge the success of restoration measures, such data are nevertheless required, particularly since morphological diversity is often assumed to be positively correlated to species and functional diversity (Brosse *et al.*, 2003; Townsend *et al.*, 2003). Re-establishing these latter types of diversity are important aims of most restoration measures (Kern, 1994; Knighton, 1998; Rabeni, 2000). Furthermore, the WFD requires the use of different organism groups such as benthic diatoms, macrophytes, benthic invertebrates and fish to assess the ecological status of water bodies. Apart from their particularly long history as aquatic bioindicators (Kolkwitz and Marson, 1909) benthic macroinvertebrates are seen as suitable organisms to explore biodiversity issues in streams. Their distribution within a streams is influenced by various factors, acting at different scales. A sites' community can be seen as the result of ongoing processes of selection, where ecoregion and catchment parameters (climate, geology, land use) and small-scale parameters (velocity, substrates, and species-related processes) interact (Malmqvist, 2002). Due to their life cycle characteristics, a reasonably quick response to restoration measures should be discernible.

A detailed comparison of hydromorphological and biological characteristics of single- and multiple-channel streams in German lower mountainous areas has not yet been conducted, but literature sources on restoration and conservation (Ward *et al.*, 1999; Beisel *et al.*, 2000; Muotka *et al.*, 2002; Richards *et al.*, 2002; Robinson *et al.*, 2002) suggest the following hypothesis: multiple-channel sections differ from anthropogenic single-channel sections in various morphological and biological parameters, including

- an increased width-depth variance,
- a higher diversity of hydromorphological features,
- a higher variability of current velocity and depth,
- a higher substrate diversity,
- an increased rate of processes, testified by material relocated during flood events,
- and thus a higher habitat diversity, which results in a more diverse fauna.

Quantitative aspects of the development of multiple-channel systems from straightened single-channels are still largely unknown, leaving two questions unanswered: (1) What are the

qualitative and quantitative effects of restoration measures on hydromorphology? (2) What are its effects on biological diversity?

### ***Scope of this thesis***

The objective of this thesis is to expand the scientific basis on the effectiveness of stream restoration measures, which aim at re-braiding of streams in the lower mountainous areas of Germany. The theoretical framework on multiple-channel streams and according restoration has been established some time ago (Leopold *et al.*, 1964; Kern, 1994), but concepts on multiple-channel streams have rarely been applied in restoration projects. Knowledge on specific details about their characteristics, which could guide or evaluate restoration measures are scarce. If bank and bottom fixations are removed locally, corresponding structures start to re-establish instantly (Patt and Städtler, 2000; Peter, 2003; Marti and Bezzola, 2004; Aufleger *et al.*, 2005). Only few stream sections in the German Federal States Hesse, North Rhine-Westphalia and Rhineland-Palatinate show such multiple-channel patterns. Hydromorphological characteristics and benthic macroinvertebrate communities of these stream sections were investigated and compared to single-channel sections. Records of changes in hydromorphological characteristics of the stream channel and surrounding floodplains are the basis of this comparison (Chapter 1 and 2). The response of macroinvertebrates to changes in stream morphology build the second central part (Chapter 3 and 4). In detail, the following hypotheses are tested:

*(1) In multiple-channel sections hydromorphological characteristics at all scales are more diverse and variable than in single-channel sections.*

Multiple-channel sections are characterised by a higher number of channel features, e.g. several active channels, standing water bodies, bars and islands. Shore length and mean width are increased, and substrate, velocity and depth show higher variability (Chapter 1).

*(2) Higher substrate dynamics will be observable within the multiple-channel sections.*

In multiple-channel streams sediment is continuously relocated, vegetation cleared, and deposited sediment re-vegetated and colonised to a varying degree. This dynamic is reflected in changes of stream cross-section or relocation of bars and islands. The effects from erosion or sedimentation processes or restructuring from flood events are much more prominent in the multiple-channel sections (Chapter 2).

*(3) The diversified habitat situation at the multiple-channel sections will affect macroinvertebrate communities at the micro-scale, leading to higher alpha-diversity in similar substrates.*

Comparable aquatic habitats host a more diverse macroinvertebrate community in the multiple-channel sections due to more variable colonisation possibilities and an overall more diverse macroinvertebrate community (Chapter 3).

*(4) Overall macroinvertebrate diversity of multiple-channel sections will be increased and community traits are changed.*

According to an increased number and more varied arrangement of aquatic habitats, multiple-channel stream sections have a higher overall macroinvertebrate diversity. Community traits, such as habitat preferences, current preferences, or feeding type composition are influenced, too, by the more diverse environment (Chapter 4).

Each chapter of this thesis focuses on one of the above hypotheses and has its own introduction, description of material and methods, results and discussion. Overall conclusions and a summary integrate the findings.

This thesis aims to quantify the differences between single-channel sections and restored or natural multiple-channel sections of streams in German lower mountainous areas and is thus helpful for planning, implementing and monitoring success of restoration projects.

# Glossary

The basis of this thesis are pairs of single- and multiple-channel stream sections and several key terms occur throughout the text, which are illustrated and explained in their context below (Table I to III).

The term **site** refers to such a pair. The term **section** is reserved for either a single- or the multiple-channel section of a site. **Multiple-channel** describes a stream section which has naturally or from restoration measures at least one secondary channel besides the main channel, separated by an island or midchannel bar; usually floodplain areas, standing water bodies, and bars are present as well. **Single-channel** sections are characterised by their singular main channel, which is usually fixed at the banks, without variability.

**Table I.** Key terms used in this thesis.

Macro-scale	Macro- / Meso-scale	Meso-scale	Micro-scale
Site	Single-channel section (Affix "1")	<u>Channel features</u> (Table II) main channel embankment . . .	 Lahn-W (Foto S. Jähnig)
	Multiple-channel section (Affix "2")	<u>Channel features</u> (Table II) main channel island midchannel bar secondary channel . . .	 Lahn-LH (Foto A. Lorenz)

Aquatic habitat  
substrate (Table III)  
depth  
velocity

Aquatic habitat  
substrate (Table III)  
depth  
velocity

The terms macro-, meso- und micro-scale are used sensu latu Newson and Newson (2000) and describe the spatial extent of habitat features. **Macro-scale** applies to the site or section. **Meso-scale** applies to channel features within a section, and **micro-scale** is related to characteristics within features, here related to the aquatic habitat of macroinvertebrates.

**Channel features** are the readily distinguishable habitat elements within a stream section (Table II).

**Table II.** Recorded channel features; modified from Raven *et al.* (1997).

Channel features	Abbreviation	Description
Main channel	mc	Hydrologically dynamic water bodies, most important runoff channel
Secondary channel	sc	Hydrologically dynamic water bodies, connected with the main channel at both ends, less water runoff
Connected sidearm	con	Water bodies lacking unidirectional current, connected only at the downstream end
Disconnected sidearm	dis	No connectivity with the main channel
Permanent standing water body	perm	On the floodplains, fed by high water levels and groundwater, no signs of drying
Temporary standing water body	temp	On the floodplains, fed by high water levels, will dry out quite shortly, puddle-like
Side bar	sideb	Unvegetated gravel bar either at the floodplain or at an island
Midchannel bar	midb	Unvegetated gravel bar in the middle of main or secondary channel
Island (vegetated)	isl	Vegetated large bar, separating main and secondary channel(s)
Embankment	emb	Artificially created bank, e.g. with trapezoidal or rectangular profile, confines bankfull discharge area
Bank	bank	Aquatic-terrestrial transient zone, not bar or embankment
Floodplain area	fp	Within bankfull discharge area, area prone to flooding

Substrate is aside of current velocity and water depth the main descriptor of aquatic habitat relevant to benthic macroinvertebrates. The following substrates were recorded (Table III).

**Table III.** Recorded substrates; according to multi-habitat sampling protocol (Hering *et al.*, 2003).

Substrate	Abbreviation	Description	Type	Grainsize (mm)
Blocks [Macrolithal]	block	Large cobbles, boulders and blocks, bedrock; coarse blocks, head-sized cobbles, with a variable percentages of cobble, gravel and sand	mineral	>200
Cobbles [Mesolithal]	cobble	Fist to hand-sized cobbles with a variable percentage of gravel and sand	mineral	>60–200
Coarse gravel [Microlithal]	c-gravel	Coarse gravel (size of a pigeon egg to child's fist) with variable percentages of medium to fine gravel	mineral	>20–60
Fine gravel [Akal]	f-gravel	Fine to medium-sized gravel	mineral	>2–20
Sand [Psammal]	sand	Sand	mineral	>0.006–2
Loam [Argyllal]	loam	Silt, loam, clay (inorganic)	mineral	<0.006
Algae	algae	Filamentous algae, algal tufts	biotic	
Submerged macrophytes	subm	Floating stands or mats of macrophytes	biotic	
Living parts of terrestrial plants	lptp	Fine roots, floating riparian vegetation	biotic	
Large wood [Xylal]	wood	Tree trunks, dead wood, branches, roots	biotic	
Coarse particulate organic matter	cpom	Deposits of coarse particulate organic matter, e.g. fallen leaves	biotic	
Organic mud	mud	Mud and sludge (organic)	biotic	

### Further Abbreviations

asl	above sea level
MQ	Mean annual discharge ( $\text{m}^3 \text{s}^{-1}$ )
MHQ	Mean high discharge ( $\text{m}^3 \text{s}^{-1}$ )
SDI	Spatial-Diversity-Index
SWI	Shannon-Wiener-Index
WFD	Water Framework Directive

# 1 Hydromorphological Diversity in Multiple-channel Sections

## 1.1 *Abstract*

Despite a growing number of stream restoration projects in Central Europe targeting hydromorphological improvements, it is still uncommon to evaluate the effects of restoration. Hydromorphological diversity between straightened single-channel sections and restored or naturally developed multiple-channel sections in German mountain streams were studied to identify parameters and derive metrics suitable for evaluating hydromorphological diversity. Seven multiple-channel sections were compared to nearby straightened single-channel sections. Six hydromorphological parameters at macro-, meso- and micro-scales were recorded with transect point protocols, amongst others aquatic, terrestrial and transient areas and width of channel features (main and secondary channels, sidearms, standing water bodies, bars, banks, floodplains and embankments). Depth, current velocity and substrate type were measured at 400 points per stream section. With this data 12 metrics were calculated, to provide comparison between the sections. All macro- and meso-scale metrics were well differentiated between single-channel and multiple-channel sections: mean channel width and shore line length increased by factors of 2.1 and 2.4, respectively. The mean number of channel feature types increased from two to ten per section. Micro-scale metrics, such as current velocity and depth variance, were significantly different between single-channel sections and most multiple-channel sections. Substrate composition was more diverse in the restored sections; the share of the major substrate was on average reduced from 75% to 62%. The Spatial-Diversity-Index described differences in substrate patterns best. The individual metrics correlated only within, but rarely between scales. Rapid assessment of hydromorphological diversity is possible by combining simple macro- and meso-scale metrics, e.g. overall width or transient areas, and presence or absence of bars and islands. Aquatic area and diversity of habitats are the most suited micro-scale metrics required to evaluate habitat suitability for aquatic organisms. For depth and current velocity data, variance should be analysed.

## 1.2 Introduction

Central European watercourses and their floodplains have been used and modified since the Middle Ages (around 1000 AD; Küster, 1999; Nollkaemper, 2005). Multiple uses, such as water supply, irrigation, flood protection, transportation, wastewater discharge, and hydropower generation, have variously created pollution, caused eutrophication, flooding problems, and loss of aquatic and riparian biodiversity. While point source pollution problems have almost been controlled during the last 20 years, hydromorphological degradation, caused by straightening, dam construction, and disconnection of streams from their floodplains represents the biggest impact to stream systems. Almost 80% of the total water discharge of the main European rivers is affected by flow regulation measures (Dynesius and Nilsson, 1994), whilst 90% of the original floodplain area has been reclaimed (EC, 1995; Pedroli *et al.*, 2002).

In Germany, a recent nationwide study to assess stream hydromorphology revealed that: 3% rated "unimpaired", 19% "slightly" or "moderately changed", while 78% were ranked in the four poorer classes "distinctly / obviously / strongly / completely" changed (LAWA, 2002). To protect and enhance the biodiversity of Central European streams and rivers, conservation of the few remaining near-natural stretches is not sufficient; restoration of degraded stream sections is also required. Physical restoration of streams has frequently been attempted since the 1970s and recently such measures have become more popular in response to European legislation demands for "good ecological status" of water bodies and recognition of the beneficial role of natural floodplain areas to control floods (EC, 2000; Austrian Federal Ministry of Agriculture, Environment and Water Management, 2001). Restoration goals can be defined according to "reference conditions" or the "potentially natural situation", which are oriented at the natural or near-natural condition (Thorne *et al.*, 1997; USEPA, 2000; LUA NRW, 2001a; Palmer *et al.*, 2005). A primary typological parameter for determining hydromorphology under reference conditions and thus, defining restoration goals, is longitudinal stream course, because differences in discharge, channel slope and dominant bed materials generate either straight, braided (multiple-channel) or meandering channel courses (Lane, 1957; Leopold and Wolman 1957; Schumm, 1977; Rosgen, 1994).

Many streams in the mountainous regions of Central Europe would doubtless develop multiple channels patterns in the absence of bank reinforcements. Indeed, up to the 19th century, multiple-channel sections were abundant in lower mountainous areas of Germany (Kilian, 1997; LUA NRW, 2001b; Sommerhäuser and Pottgiesser, 2005).

Today, only very short sections of multiple-channel reaches remain, mainly in remote regions of Central Europe, because bank fixations and flow regulation prevent lateral migration and

restrict the channel to a narrow stretch of the former floodplain (Kern, 1994; Knighton, 1998). Therefore, to restore near-natural conditions in mountain streams, multiple-channel patterns should be allowed to redevelop.

Widening of riverbeds is an increasingly used method to develop multiple-channels and to better connect the river and its floodplain (Rohde *et al.*, 2004). For monitoring restoration measures and defining conservation goals, a variety of data on hydromorphology and biodiversity of multiple-channel streams are required (Kemp *et al.*, 1999; Verdonschot and Nijboer, 2002). Especially, multiple-channel streams are not well investigated or understood, due to their complexity and rarity (Thorne *et al.*, 1997). In particular, quantitative data on the redevelopment of multiple-channel patterns are missing, leaving two questions: (1) What are the direct qualitative and quantitative effects of restoration measures on hydromorphology? (2) What are the indirect effects on biological diversity?

In this study, the hydromorphology of single- and multiple-channel sections is compared, based on the hypothesis that multiple-channel sections are characterised by a higher diversity of hydromorphological features and aquatic habitats, defined by current velocity, depth, substrate. The aim of the study is to suggest useful parameters and derive metrics for monitoring restoration measures and defining conservation goals.

### **1.3 Material and Methods**

#### **1.3.1 Study sites**

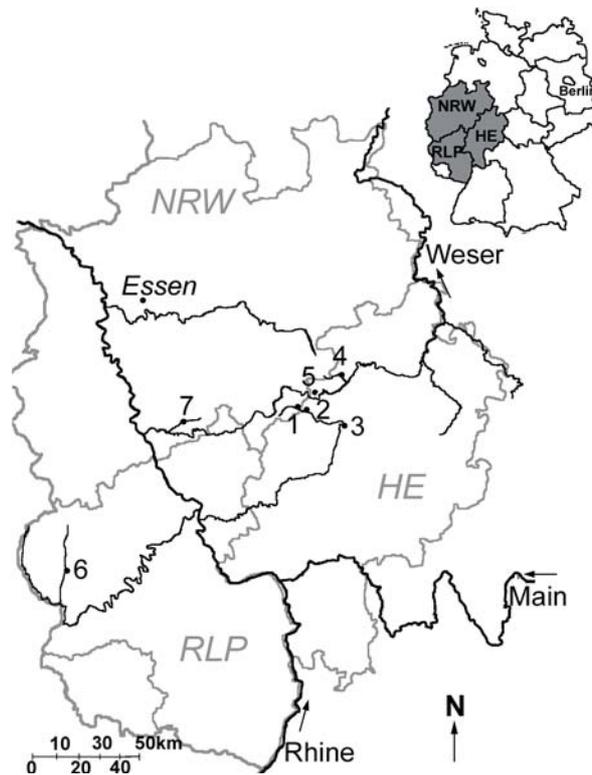
In a paired-site study, seven multiple-channel sections were compared to nearby straightened single-channel sections. Each pair is similar in terms of catchment geology, land use, and discharge characteristics. The streams are located in lower mountainous regions of Western Germany at altitudes between 200 and 400 m. Catchment size at the sampling sites ranges from 180 to 650 km<sup>2</sup> (Table 1-1; Figure 1-1). According to slope and discharge, all but one paired stream sections would be expected to develop multiple-channel patterns under near-natural conditions (LAWA, 2004). The channel of site Lahn-C is in the transition to a meandering pattern.

The multiple-channel sections either resulted from restoration measures or developed without interference in less intensively used floodplain sections. The sites Lahn-W and Lahn-LH have been restored by excavation to the stream bottom level (Hessische Gesellschaft für Ornithologie und Naturschutz, 2002). At site Lahn-C, the bank fixation was removed to initiate bankside erosion with the intent of creating a constant sediment supply for downstream

parts of the stream, which otherwise would start scouring. The channel patterns developed after substantial side erosion during floods. The multiple-channel sections at the Orke, Eder, Nims and Bröl developed naturally in the absence of bank fixations and the abandonment of bank maintenance. Besides Orke and Bröl, all multiple-channel sections have been generated in the year 2000 or later.

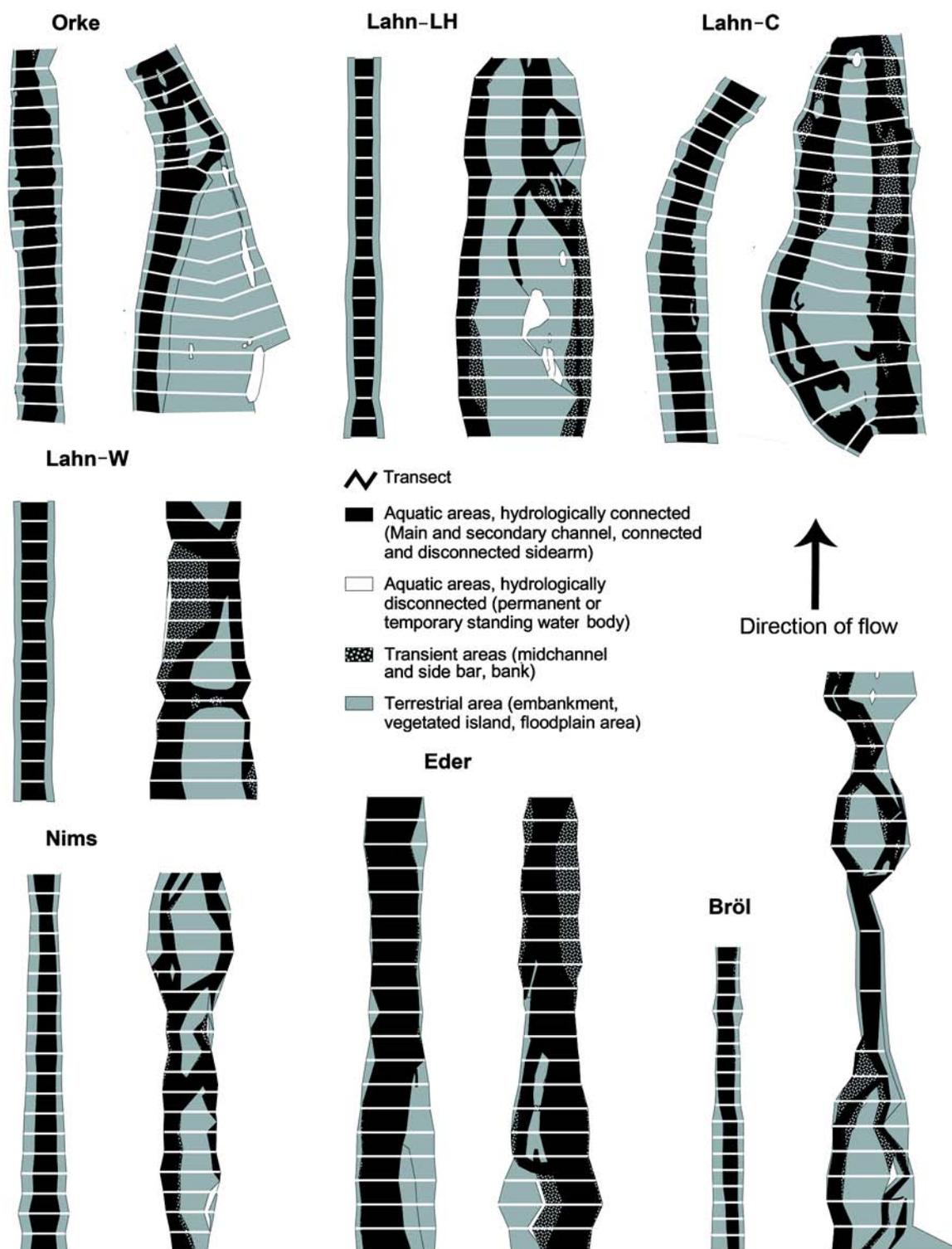
**Table 1-1.** Site characteristics. Information is valid for both single- and multiple-channel sections, as they are located some 100 meters away from each other.

Site name	Lahn-W	Lahn-LH	Lahn-C	Orke	Eder	Nims	Bröl
Stream	Lahn	Lahn	Lahn	Orke	Eder	Nims	Bröl
Location	Wallau	Ludwigshütte	Coelbe	Niederorke	Dodenau	Birtlingen	Waldbröl
Latitude (N)	50°55'37"	50°55'29"	50°51'47"	51°9'8"	51°1'38"	49°56'48"	50°49'36"
Longitude (E)	8°29'20"	8°29'59"	8°47'25"	8°50'37"	8°34'21"	6°29'3"	7°22'58"
Catchment size (km <sup>2</sup> )	278	288	650	289	480	222	181
Section area (ha)	0.29	0.31	0.48	0.43	0.73	0.35	0.45
(single- vs. multiple-channel)	— 0.62	— 1.14	— 1.24	— 0.92	— 0.74	— 0.55	— 1.04
Altitude (m asl)	300	300	190	300	300	240	104
Catchment geology	100% acid rock (schist)	40:60% acid : carbonate rock	100% acid rock (schist)				
Restoration year	2001	2002	2000	n.a. (natural)	n.a. (natural start ~ 2000)	n.a. (natural start ~ 2000)	n.a. (natural)
Investigation date	26.05.2004	28.06.2004	24.05.2004	13.05.2004	15.06.2004	19.07.2004	08.08.2004
Mean discharge (m <sup>3</sup> s <sup>-1</sup> )	5.1	5.2	8.3	6.3	10.5	2.8	3.4
Bankfull discharge (m <sup>3</sup> s <sup>-1</sup> )	45	45	90	65	131	49	46
Local channel slope (m km <sup>-1</sup> )	0.21	0.40	0.20	0.45	0.20	0.48	0.60



**Figure 1-1.** Location of sampling sites. German Federal States: NRW = North Rhine-Westphalia; HE = Hesse, RLP = Rhineland Palatinate (in grey). Site names: 1 = Lahn-W, 2 = Lahn-LH, 3 = Lahn-C, 4 = Orke, 5 = Eder, 6 = Nims, 7 = Bröl.

Figure 1-2 displays the major features of the stream section pairs. All multiple-channel sections are characterised by a large main channel, one or more vegetated islands, which divert at least one secondary channel, and oxbows still connected or already disconnected from the channels. Side and midchannel bars without vegetation occur as well. Some sections feature extensive floodplain areas with temporary or permanent pools. The right and left edges are usually (still) delineated by manmade embankments. The stream sections have a thalweg length of around 200 m and lateral extensions of up to 60 m.



**Figure 1-2.** Distribution of channel features at single- (left) and multiple-channel (right) sections. Analyses were standardised to length of single-channel section.

### 1.3.2 *Hydromorphological measurements*

Six parameters were recorded at macro-, meso- and micro-scales (sensu Newson and Newson, 2000) and from these data 12 metrics were calculated (Table 1-2). A stretch of approximately 200 m was investigated at each stream section. Along 20 equidistant transects running between the left and right edge of the embankments the width of channel features was measured (Table II). The channel features were categorised according to their position within the floodplain and their hydrological connectivity to the main river into six aquatic features (main channel, secondary channel, connected and disconnected side arm and permanent and temporary standing water body), three transient features (bank, mid-channel bar and side bar) and three terrestrial features (embankment, vegetated islands and floodplain area). They were modified from the River Habitat Survey protocol (Raven *et al.*, 1997). At 20 points along each transect current velocity, water depth and submerged substrate types (Table III) were recorded. Thus, a total of 400 point data were generated per section at the micro-scale. At the site Lahn-W investigations were limited to 16 transects per section, as access to the riverbed was restricted by very steep, densely vegetated embankments, block fixed banks and water depth.

The surveys were carried out in the low flow season from May to August 2004, always after several days without precipitation as otherwise submergent substrates would have been unidentifiable. Single- and multiple-channel sections were always investigated at two consecutive days. Thus, discharge may have differed between the sites but not within the pairs.

### 1.3.3 *Data analyses*

To characterise the sections several metrics and indices were calculated (Table 1-2; formulas in Appendix 1). The Braiding-Index (Brice, 1960) measures the degree of ramification, which is 0 for single-channel sections. A value from 0 to 1 indicates the presence of a few braiding structures; values depend on size and number of islands and bars.

The Shannon-Wiener-Index (Shannon and Weaver, 1949), a measure of diversity, was calculated with channel feature data and substrate data. This index considers the number of channel features or substrates and the proportion of each feature or substrate at a section. Additionally, the number of different channel features was counted for each section.

The Spatial-Diversity-Index (Fortin *et al.*, 1999) was calculated only for substrate data. In addition to the Shannon-Wiener-Index it considers the spatial arrangement of substrates along the transects.

The coefficient of variation was calculated for depth and current velocity data. Substrate area in the aquatic part of each transect was calculated from transect width and substrate point recordings. The area covered by each substrate type was computed from the distance between points, considering the increased width at the multiple-channel sections.

To identify metrics suitable for judging hydromorphological diversity, e.g. to estimate conservation value or restoration success, the coherence of parameters at different scales was investigated. For selected parameter pairs the Pearson Product Moment Correlation Coefficient ( $r$ ) (Pearson, 1896) was calculated and converted to r-squared ( $r^2$ ).

**Table 1-2.** Parameters measured in the field and related calculated metrics.

Scale	Field measurement	Metric
Macro-scale	Bankfull width (m)	Mean width Shore length (calculated with ArcView) Braiding Index (Brice, 1960)
Meso-scale	Aquatic / transient / terrestrial width (m) Channel feature width (m) <sup>a</sup>	Mean aquatic / transient / terrestrial width (m) Number of channel features Mean channel feature width (m) Shannon-Wiener-Index (channel feature diversity) (Shannon and Weaver, 1949)
Micro-scale	Water depth (m) <sup>b</sup> Current velocity ( $m\ s^{-1}$ ) <sup>c</sup> Substrate type <sup>d</sup>	Median velocity and median depth Coefficient of variation of current velocity and depth Substrate area Shannon-Wiener-Index (substrate diversity) Spatial-Diversity-Index (substrate diversity) (Fortin <i>et al.</i> , 1999)

a) Channel features modified from River Habitat Survey (Raven *et al.*, 1997).

b) Water depth was measured with a 2-m-long rule, fixed to a surveying pole; measuring accuracy was to the centimeter. Accessibility was limited to 140 cm; greater water depth values were standardised to 145 cm.

c) Current velocity was measured at 0.6 of the water depth using a Schiltknecht MiniAir2 device with MiniWater20 Mini water sensor, which automatically calculates a 6-second mean from 0.5-second values in a measurement range from 0.02–5  $m\ s^{-1}$ .

d) According to multi-habitat sampling protocol (Hering *et al.*, 2003).

## 1.4 Results

### 1.4.1 Macro-scale

Differences between single- and multiple-channel sections are well reflected by comparison of shore length, Braiding-Index, and mean bankfull width (Figure 1-2, Table 1-3). The Braiding-Index is 0 for all single-channel sections and for multiple-channel sections ranges between 0.47 (Eder) and 3.2 (Lahn-C).

**Table 1-3.** Macro- and meso-scale metric results. Shore length, Braiding-Index, mean width and Shannon-Wiener-Index for channel feature diversity at single- and multiple-channel sections.

Site	Shore length (m)		Braiding-Index	Mean width (m)		Shannon-Wiener-Index (channel features)	
	single	multiple		single	multiple	single	multiple
Lahn-W	301	735	1.56	20.4	41.0	0.68	1.82
Lahn-LH	380	1272	2.70	17.6	59.3	0.69	2.02
Lahn-C	432	1408	3.20	25.5	57.8	0.99	1.79
Orke	415	785	0.76	22.9	49.2	1.04	1.56
Eder	480	734	0.47	31.6	34.6	1.10	2.02
Nims	382	815	1.30	18.2	29.2	0.69	2.18
Bröl	402	1050	1.49	22.4	57.0	0.84	2.24
Mean	399	971	1.64	22.6	46.9	0.68	1.82

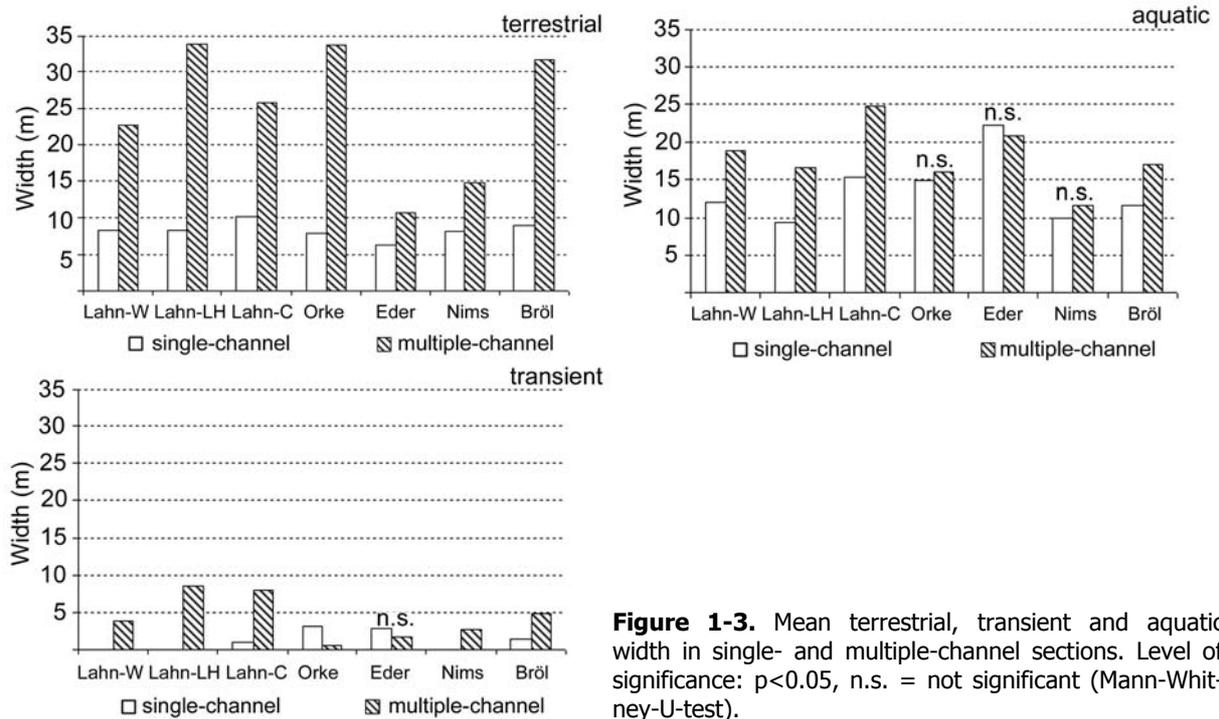
#### 1.4.2 Meso-scale

The mean width of aquatic, terrestrial, and transient areas increases in the multiple-channel sections (Figure 1-3). While terrestrial and aquatic features occur at both single- and multiple-channel sections, transient parts are mainly restricted to the latter. Three out of seven single-channel sections (Lahn-W, Lahn-LH and Nims) have no transient areas. In multiple-channel sections, the mean width of meso-scale features increases by a factor of 2.96 (terrestrial parts), 1.37 (aquatic parts) and 5.93 (transient parts).

The number of channel features increases at the multiple-channel sections, although they differ widely between the various sections (Figure 1-4). The maximum difference was observed at the Bröl (10 features), while the multiple-channel section at Lahn-C has eight features compared to four features at the single-channel section. Some features do not occur at single-channel sections, these are secondary channels, vegetated islands, disconnected sidearms, permanent and temporary standing water bodies. Side bars and connected sidearms occur only occasionally.

Differences of the Shannon-Wiener-Index (diversity of channel features) support the previous results (Table 1-3). On average this index calculates to 0.8 for single-channel sections and 1.95 at the multiple-channel sections.

The sites Eder and Nims show only small scale changes in terms of shore length, width, and width of channel features (Table 1-3, Figure 1-3, Figure 1-4). Nevertheless, the multiple-channel sections are characterised by an increase of the Shannon-Wiener-Index comparable to sites with much larger absolute differences.



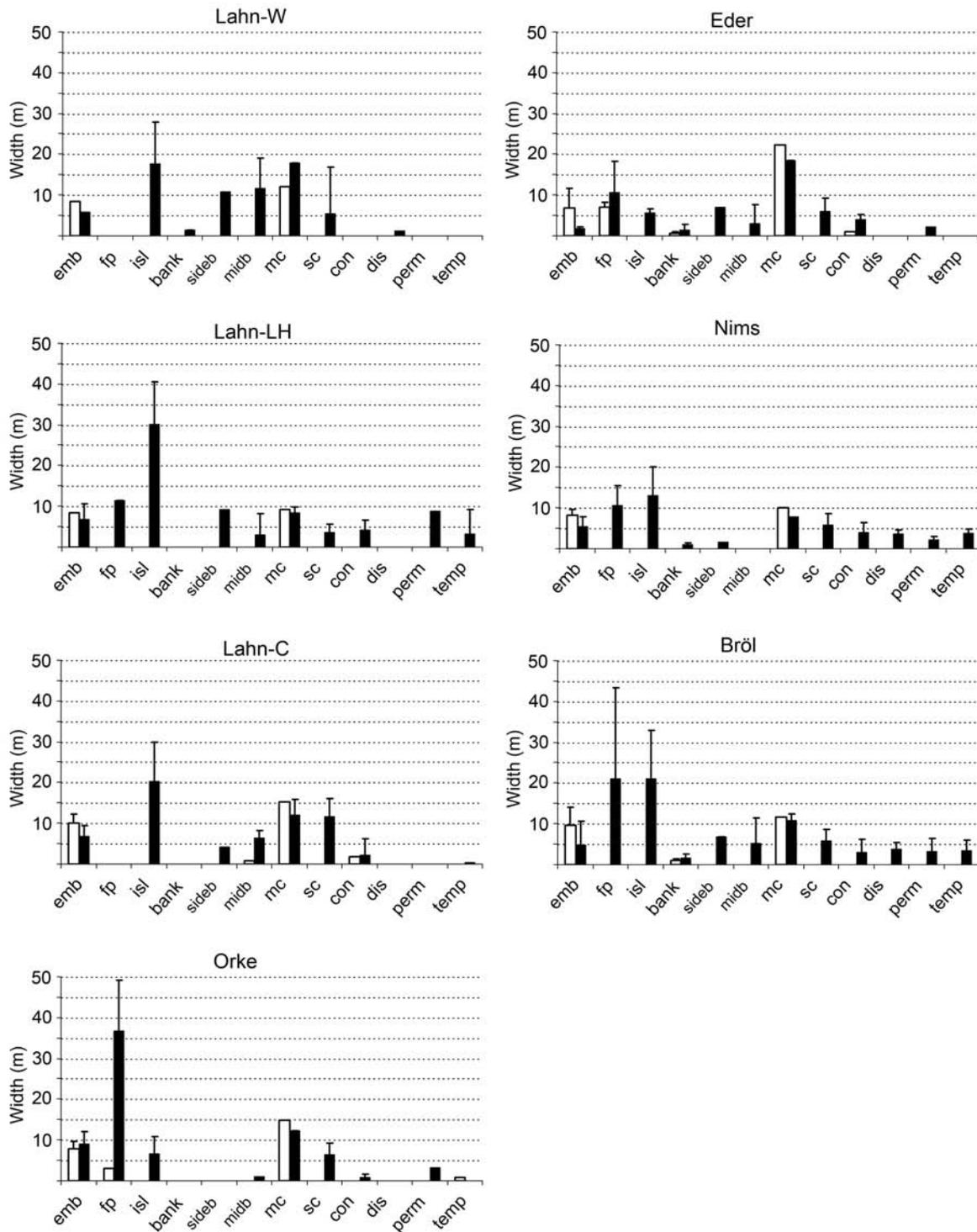
**Figure 1-3.** Mean terrestrial, transient and aquatic width in single- and multiple-channel sections. Level of significance:  $p < 0.05$ , n.s. = not significant (Mann-Whitney-U-test).

### 1.4.3 Micro-scale

Minimum current velocity is the same for single- and multiple-channel sections, i.e. 'zero' current. However, the range increases at all multiple-channel sections with maximum values always being higher. Maximum current velocity at all single-channel sections is less than  $1 \text{ m s}^{-1}$ , while multiple-channel sections have current velocities of up to  $1.8 \text{ m s}^{-1}$ .

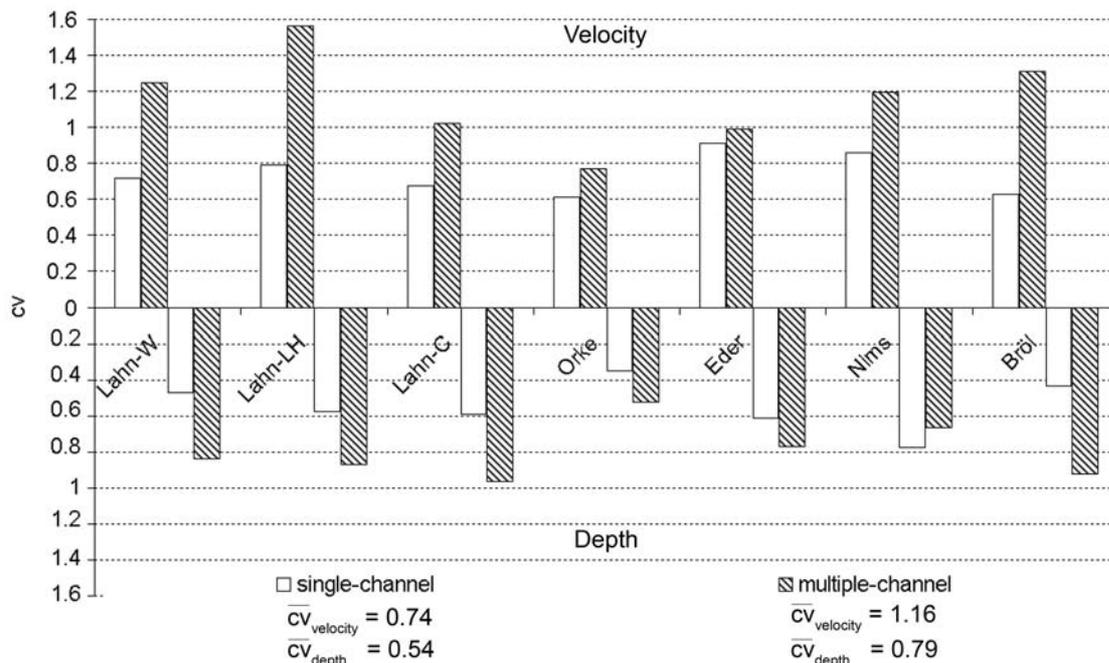
Water depth shows similar patterns: the lowest values are a few centimeters throughout all sections, with a much increased maximum depth at the multiple-channel sections. The interquartile range does not necessarily increase, indicating an inconsistent pattern.

In general, median values of depth and current velocity are lower at the multiple-channel sections, with the exception of median velocity at the Orke and Eder sections (Figure not shown).



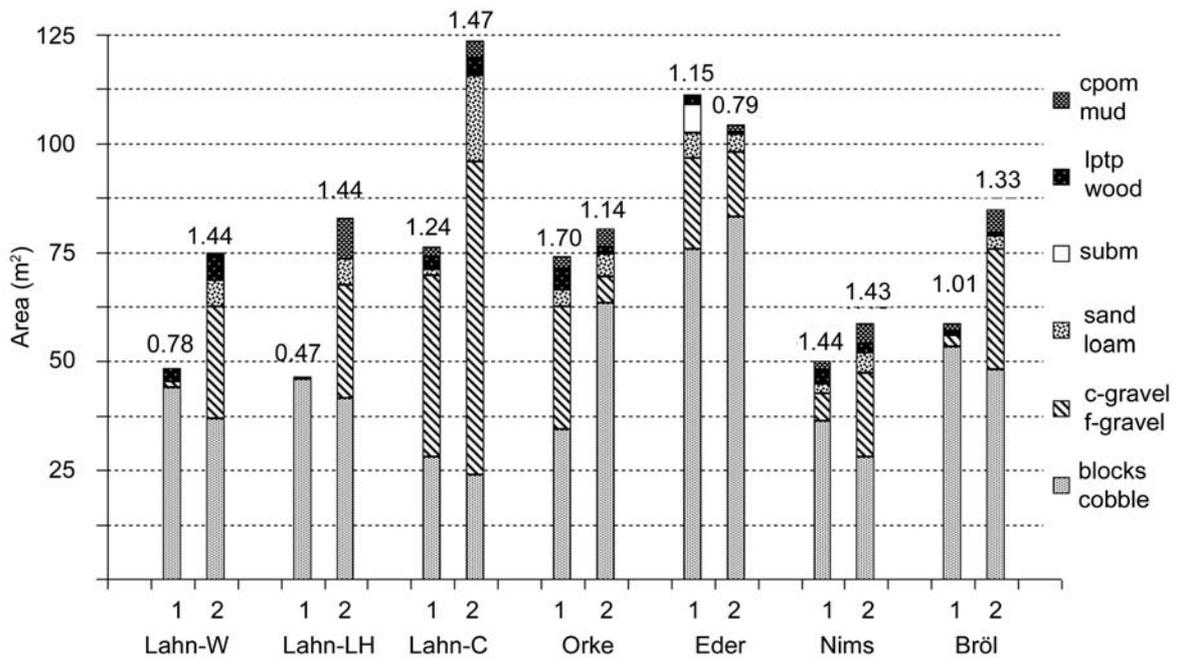
**Figure 1-4.** Channel feature width at single- (white) and multiple-channel (black) stream sections. emb = embankment, fp = floodplain, isl = island (vegetated), sideb = side bar, midb = midchannel bar, mc = main channel, sc = secondary channel, con = connected sidearm, dis = disconnected sidearm, perm = permanent standing water body, temp = temporary standing water body.

The coefficient of variation (cv) of current velocity and depth is generally higher at the multiple-channel sections (Figure 1-5). Coefficient of variation of current velocity increases the most at Lahn-LH from 0.79 to more than 1.5. The maximum increase in depth cv is from 0.43 to 0.92 (Bröl), while at one site (Nims) cv of depth decreases at the multiple-channel sections.

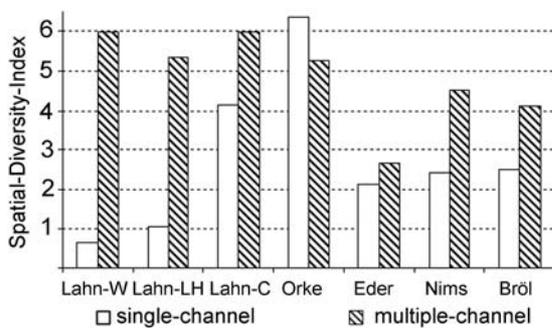


**Figure 1-5.** Coefficient of variation for parameters current velocity and depth at single- and multiple-channel sections.

Substrate diversity was analysed in terms of composition, local distribution and diversity metrics. While all single-channel sections are dominated by one substrate or substrate group, the composition is much more diverse at the multiple-channel sections (Figure 1-6). Larger amounts of smaller mineral grain sizes (coarse gravel, fine gravel, sand and loam) and organic substrates are almost exclusive to the multiple-channel sections. The share of the dominant substrate is on average reduced from 75% to 62%. For example, at the site Lahn-LH, the coverage of the cobbles drops from 84% at the single-channel section to 46% at the multiple-channel section. In three out of seven sites, substrate diversity (Shannon-Wiener-Index) is higher at the single-channel sections (Figure 1-6). However, this does not sufficiently reflect the spatial distribution of substrate types, which is much more complex at the multiple-channel sections (Appendix 2). The distribution is better reflected by the Spatial-Diversity-Index, which increases at all but one (Orke) of the multiple-channel sections (Figure 1-7).



**Figure 1-6.** Substrate composition and diversity. Estimated overall substrate area at single- (1) and multiple-channel (2) sections. Shannon-Wiener-Index based on relative substrate composition; substrate abbreviations see Table III.



**Figure 1-7.** Spatial-Diversity-Index at single- and multiple-channel sections.

### 1.4.4 Correlation of metrics

The correlation coefficients reveal the coherence of patterns of the investigated parameters at different scales (Table 1-4). Macro-scale metrics are highly correlated with each other, while there is less correlation of macro- with micro-scale metrics. Micro-scale metrics do not correlate with each other. The Spatial-Diversity-Index is not correlated to any other metric. Therefore, the description of spatial diversity requires two sets of metrics including both a selection of macro- or meso-scale and micro-scale metrics. Metrics from different scales do not substitute each other.

**Table 1-4.** Correlation matrix of nine hydromorphological metrics. R-squared values from Pearson Product Moment Correlation Coefficient (r); asterisk indicates level of significance: \*  $p < 0.05$ ;  $n = 14$ , seven single- and seven multiple-channel sections.

	MW	SL	TL	CF	EA	SDI	SU	CVV	CVD
Mean width (MW)									
Shore length (SL)	0.86*								
Transient width (TL)	0.65*	0.77*							
SWI <sup>a</sup> channel features (CF)	0.61*	0.67*	0.42*						
Estimated area (EA)	0.42*	0.37*	0.37*	0.25					
SDI <sup>b</sup> substrate (SDI)	0.18	0.19	0.05	0.16	0.00				
SWI <sup>a</sup> substrate (SU)	0.61*	0.59*	0.31*	0.79*	0.34*	0.27			
cv <sup>c</sup> current velocity (CVV)	0.45*	0.25	0.10	0.28	0.05	0.01	0.23		
cv <sup>c</sup> depth (CVD)	0.28	0.22	0.10	0.49*	0.21	0.01	0.44*	0.28	

a) Shannon-Wiener-Index

b) Spatial-Diversity-Index

c) Coefficient of variation

## 1.5 Discussion

### 1.5.1 Metric response to increased hydromorphological diversity

Hydromorphology of seven single- and seven multiple-channel sections was compared to quantify differences on macro-, meso- and micro-scales. The results support the hypothesis of multiple-channel sections being characterised by a higher diversity of hydromorphological features and aquatic habitats, defined by current velocity, depth, substrate. In the multiple-channel sections, morphological diversity increases at macro-, meso- and micro-scales; however, the magnitude of the effects varies largely between metrics and metrics groups. Historic development of individual sites and the impact of upstream and downstream reaches partly explain these differences and the weak correlation of metrics between scales. The results suggest that a combination of metrics from different scales is required for an overall understanding of the changes and that metrics can not substitute each other across scales.

In all cases, the paired sections differed in terms of mean width and aquatic width (Table 1-3, Figure 1-3). Both metrics also reflect the catchment size, where at the multiple-channel sections catchment size is more regularly reflected by width than at the single-channel sections. For all sites, more channel features were recorded in the multiple-channel sections despite differences in sampling season and, thus, vegetation cover, which may obstruct individual features (Bridge, 1993). Also, differences in the origin of the multiple-channel sections and in the impact of upstream sections, e.g. due to dams which trap sediments, do not obscure the overall pattern. In general terms, the presence of additional channel features at the multiple-channel sections is a result of the absence of bank fixation and more open space for the stream.

Differing results at the micro-scale (depth and current variability) can partly be explained by site characteristics. A relatively high diversity of depth and current velocity values at the single-channel sections of Lahn-W and Nims can be attributed to weirs located downstream of the investigated sections. These impound the water and lead to a "diverse" range of depth and current velocity values. At the Eder, the overall width of the multiple-channel section is only slightly increased (Table 1-3) along with a decreased aquatic width (Figure 1-3). As a consequence, current velocity and depth variance decreased in the narrowing middle part of the channel.

Substrate distribution seems to be most strongly impacted by bank and stream bed fixations, which are present at all single-channel sections. Due to different stages of removal, substrates at multiple-channel sections still include a considerable part of fixation material, which restricts substrate diversity. The material is mainly classified as cobbles, which is not easily eroded and replaced.

The analysed metrics thus reflect the differences between single- and multiple-channel sections but differ according to resolution of time and spatial scale. Site specific adjustments of an applied monitoring design and subsequent analyses are required, e.g. considering the origin of the multiple-channel sections, influences from the catchment such as land use pressure and the sites' potential for lateral development. Differences between single- and multiple-channel sections are best indicated by the metrics, which incorporate and summarise the increase in hydromorphological diversity, such as Shannon-Wiener-Index on all levels or Spatial-Diversity-Index for substrate data.

### *1.5.2 Effects from multiple-channel origin*

Restored multiple-channel sections differ in certain metrics and in magnitude of change from those having developed without human interference. Restored stream sections (Lahn-W, Lahn-LH, Lahn-C) display more distinct differences at all scales compared to naturally developed stream sections (Orke, Eder, Nims, Bröl). Lepori (2005) found a similar structure, when comparing restored, still channelised and best available reference sections. Structural heterogeneity was substantially higher in the restored stream sections with consistent results across the spatial scales considered, while the reference stream sections took an intermediate position.

At the Lahn sites restoration included the artificial generation of a secondary channel; thus, differences are high at all scales. The Eder, where the multiple-channel section developed naturally, displays weakest differences between single- and multiple-channel sections (Table 1-3, Figure 1-4, Figure 1-5).

"Restored" or "naturally developed" stream sections show no difference in the meso-scale channel feature composition. At the multiple-channel section the former single-channel acts now as a "main channel", which is accompanied by other aquatic channel features of much lower area (Figure 1-4). Thus, the relative coverage of the former main channel is still high, and meso-scale metrics differ only slightly between single- and multiple-channel sections.

Micro-scale metrics are not only influenced by the type of restoration measure, but by site specific characteristics. Substrate composition might be influenced by remnants of former bank fixation, and thus increases substrate diversity compared to natural stretches. The insignificance of the differences between multiple-channel origin may be explained by influences at larger scales and affecting both, single- and multiple-channel sections. In-stream habitats are determined by interactions of channel morphology, substrate, and discharge; hydraulic patterns are affected by channel cross-section shape, clast size, bed roughness and bed slope. Metrics at larger scales are related to channel morphology, geomorphic processes, and valley geometry, which determine the type and distribution of floodplain habitats and their connectivity. Nested hierarchical models of stream systems demonstrate the importance of coupling larger scales information with small scale characteristics. For example, morphology and dynamics of a stream are determined and controlled by the surrounding catchment (Thomson *et al.*, 2001; Molnar *et al.*, 2002). Restoring a short stream section does not restore stream hydrology and other large scale parameters, which are decisive for the development of natural channel patterns at smaller scales.

For the naturally developed multiple-channel sections, in this study characterised by the Orke, which resemble their single-channel counterparts, an additional explanation might be appropriate. The streams investigated are located in Western Germany, which is characterised by high land use pressure. The development of multiple-channel sections is a result of less intense floodplain land use, which operates at a larger scale and thus influences both sections. The single-channel section of the Orke is quite similar to its multiple-channel section counterpart in terms of depth, current velocity and substrate diversity. It might, therefore, be in the transition to a multiple-channel section, which may develop in the future.

Although the studied sites are small (maximum 1 ha) compared, for example, to Swiss stream widening projects of 5 ha (Rohde *et al.*, 2004), macro-scale parameters show clear distinction between single- and multiple-channel sections. Rohde *et al.* (2004) used habitat types in the floodplain, vegetation cover and height to determine differences between restored, straightened, and near-natural sections. Their results are comparable with this study,

with few structures at the regulated stream sections but much higher morphological diversity at the restored and near-natural stream sections.

The investigated stream sections are not only comparatively small in area, but also the time since restoration is relatively short. However, restoration measures accelerate the recovery process in comparison to unmanaged sections, e.g. differences are larger for the (restored) Lahn sections, compared to Eder and Nims. According to Parsons and Gilvear (2002) abandonment of flood embankment and land use change leads to a recovery in the medium term, which is defined as "less than 50 years". This is much longer than the time span since the development of the investigated German sections.

### 1.5.3 Suitability of metrics for assessing hydromorphological diversity

Data on habitat diversity and dynamics is the basis to better understand drivers of riverine biodiversity (Ward and Voelz, 1998; Arscott *et al.*, 2000). Recently, the scale of restoration schemes changed from rather opportunistic habitat enhancement to projects that restructure channel morphology up to several hundred meters. However, only limited information on the effects of such modifications is available (Sear *et al.*, 1998). Metrics of hydromorphological diversity for assessing conservation value and the success of restoration should reflect the high spatio-temporal heterogeneity and thus the potential for a high biodiversity of natural riverine floodplains, and they should differentiate between sections.

High spatio-temporal heterogeneity – one major goal of conservation and restoration efforts – is formed by fluvial dynamics and results in lentic, lotic, and semi-aquatic habitats (Ward *et al.*, 1999). Semi-aquatic (transient) parts might be defined as ecotones, which generally occur at various scales: floodplains themselves may be defined as ecotones between river channels and the upland, but ecotones are also present between habitat patches. The number of channel features of a section is a good approximation of habitat diversity. Certain channel features are suitable indicators for the restoration or conservation goal "to establish a site that is self-regulating and integrated within its landscape" (Middleton, 1999). For example, islands occur only under (semi) natural flood regime and sediment supply, unconstrained channels and are supported by the presence of large wood in the stream. Island abundance, distribution, and turnover, provide an indicator for the stream corridor status. To "protect the ecological processes that form and destroy islands" is therefore an important conservation goal (Ward *et al.*, 2001). An earlier stage of multiple-channel development is indicated by the presence of midchannel and side bars, secondary channels, connected sidearms, and floodplain area.

Habitat diversity can be best assessed with metrics regarding depth, current velocity and substrate. The relative substrate composition is suitable as a first approximation of aquatic habitat diversity. Additionally, the increase of (aquatic) habitat area is a well suited proxy for the development of morphological diversity. The Spatial-Diversity-Index and metrics related to habitat number reflect morphological diversity even better. Depth and current velocity variability are good indicators of varying habitat conditions, while mean, minimum and maximum values might obscure differences. The correlation analyses indicated that metrics frequently correlated within but rarely between scales; thus, metrics of all scales should be included into a set of parameters for assessing hydromorphological diversity.

A further consideration is to choose metrics which reflect habitat suitability for organisms. Island and floodplain areas provide additional habitat for terrestrial and semi-terrestrial organisms. Depth and current velocity variance and a broader range of substrates improve aquatic habitat availability, while an enlarged habitat area supports a higher aquatic and riparian biodiversity (Maddock, 1999; Beisel *et al.*, 2000; Rabeni, 2000; Amoros, 2001; Inoue and Nunokawa, 2002). Substrate, current velocity and depth have frequently been shown to influence biota on a micro-scale (Boyero, 2003; Harrison *et al.*, 2004; Beauger *et al.*, 2006). However, fish and macroinvertebrate communities are influenced by factors at different scales, supporting the approach to include all scales into monitoring programs (Inoue and Nunokawa, 2002; Boyero, 2003; Brooks *et al.*, 2005; Hering *et al.*, 2006).

#### *1.5.4 Conclusions and implications*

Multiple-channel sections differed at macro-, meso-, and micro-scale from their straightened single-channel counterparts, but differences are hardly to generalise and strongly influenced by the sites' history and large scale conditions. Major reasons are the short section-length in comparison to stream-size and the generation of multiple-channel sections only a few years ago. Metrics that are (partly) independent of these factors are best suited to evaluate hydromorphological diversity.

While hydromorphological diversity is one element of conservation value or useful for monitoring, the ecological relevance of it will be tested in two other chapters of this thesis.

## **2 Multiple-channel Sections Revisited: Quantifying Annual Changes**

### **2.1 Abstract**

Hydromorphological differences and relative annual changes between single-channel and multiple-channel sections were investigated for seven sites in German lower mountainous areas. In 2004 and 2005 six hydromorphological parameters at macro-, meso- and micro-scales were recorded along 20 stream transects, including shore length and width of channel features (main and secondary channels, side arms, standing water bodies, bars, islands, floodplains and embankments). Along each transect, depth, current velocity and substrate type were measured at 20 points, for a total of 400 points per stream section. With these data, 12 metrics were calculated to compare single-channel and multiple-channel sections within each year and across years within each section. In both years all metrics differentiated well between single-channel and multiple-channel sections. Analyses comparing data across years confirmed changes in riparian features, like width and depth profiles. Multiple-channel sections showed more changes over time than single-channel sections. Width of aquatic channels changed 10% in the single-channel sections and 30% in the multiple-channel sections, while depth profiles changed 31% and 45%, respectively. The highest changes were observed for areas of bars, islands and floodplains. The mean ratio of increase for selected hydromorphological metrics in multiple-channel sections was 1.99, and was significantly higher for restored sites compared to natural sites (ratio of 2.54 and 1.57, respectively). Similarly, changes over time (mean and standard variation) were higher in restored than in natural multiple-channel sections. In contrary, all single-channel sections changed to a similar degree. The results indicate higher dynamics in the multiple-channel sections, independent of the origin or age of the features. In fact, there is no succession but a year to year large turnover rate, without "section aging". Although the multiple-channel sections studied were only short, and land use was unchanged, rejuvenation and restructuring in the multiple-channel sections clearly do occur, and positive ecological effects are predicted. The year-to-year change is more prominent in restored than in natural multiple-channel sections.

## 2.2 Introduction

Hydromorphological dynamics typical for unimpaired streams create a shifting mosaic of habitat patches, where channel features are repeatedly rejuvenated by flooding, and sediment erosion and deposition (Ward *et al.*, 2002b). Typical for such dynamisms are different stream channels, standing water bodies within vegetated floodplains, and riparian vegetation supplying large wood to the stream, not only acting as a more natural bank fixation. A constant development of islands and bars, which disappear elsewhere in exchange, is also characteristic. Gurnell and Petts (2002) have collected evidence that islands were once a common, even dominant feature of riverine landscapes in forest regions of the world. Maps of European rivers prior to modern river regulation from Austria, France, Germany, Italy, Netherlands, Switzerland, and the UK provide evidence of multiple-channel reaches with wooded islands (see Gurnell and Petts, 2002 for list and references).

Human alterations of floodplains and river regulations have a long history, with major changes starting in the Medieval Ages around 1000 BP (Steiger *et al.*, 2005). As a consequence most streams and rivers within industrialised regions, such as Europe, have experienced drastic habitat deterioration and minimisation of riverine dynamics. To the present day this results in a reduced rate of turnover of the fluvial landscape, reduced rates of ecosystem change, reductions of channel and ecosystem dynamics, and an unvaried habitat mosaic. Habitat diversity becomes lower as age diversity of structures or vegetation is unified (Richards *et al.*, 2002).

More recently, the importance and benefit of a good ecological status of streams has been realised and in Europe legally anchored by the Water Framework Directive (WFD; EC, 2000). The abiotic aspect of the ecological quality of streams is determined by three major components: water quality, water quantity, and geomorphology (Chovanec *et al.*, 2000; Logan and Furse, 2002; Newson, 2002). In this context geomorphology subsumes macro- to micro-scale features, including ecoregion, catchment, stream sections, and habitat characteristics. The results from the first European river basin inventory in the course of the WFD implementation revealed: for example in the German Federal State of Hesse almost 80% of the streams are at risk of failing the WFD requirements due to poor hydromorphology (HLUG, 2004). Similar results were obtained for analyses of trans-European river basins, of the Rhine or Danube (ICPDR, 2005; ICPR, 2005). Specifications of reference conditions, which build the basis to assess the ecological condition as required by the WFD, suggest higher morphological diversity than is currently the case in many areas (e.g. LUA NRW, 2001a; LUA NRW, 2001b). Stream restoration measures are required to achieve this.

Despite an increasing number of such restoration projects aiming at re-establishing ecological condition and integrity (Rohde *et al.*, 2006), the restoration of dynamic processes is particularly challenging in agriculturally-used and urbanised river valleys (Piégay, 2003). The two major obstacles are flow regulation and bank fixations which truncate and impede the cycle of patch development (Marston *et al.*, 1995). Several studies (Arscott *et al.*, 2002; Richards *et al.*, 2002; Hering *et al.*, 2004; Hohensinner *et al.*, 2005) emphasise the high turnover rates and fluvial dynamics, but investigations of dynamic features at restoration projects of multiple-channel streams are scarce.

Following the idea of a 'shifting mosaic steady state' (Arscott *et al.*, 2002; Ward *et al.*, 2002a; Stanford *et al.*, 2005), it is not necessary to know exactly how much of an island or midchannel bar is reshaped within a stream reach, but a relatively constant ratio of habitat proportions can be assumed. It is important to know, however, whether (1) certain morphological features are available and (2) whether certain dynamics are occurring over the course of the stream or within a section, which restructure the section and rework the land-water boundary conditions. This reworking will then allow the development of different stages of vegetation and other habitats, and might promote the desired biodiversity, which corresponds to the potential natural situation of these streams.

Although the multiple-channel sections studied here comprise maximum 2% of the stream length in contrast to a potential 25–75%, the results from Chapter 1 and field visits from 2003 to 2005 stimulate the idea that the multiple-channel sections show a higher morphological dynamic than the single-channel sections (Figure 2-1 and 2-2, Table 2-1). Further notice had been taken on different degrees of changes between natural and restored multiple-channel sections. The latter seemed more easily erodible and more susceptible to the stream's power, because of removed bank fixations and cleared vegetation from floodplain areas.

The objective of this chapter is to quantify parameters that are both suitable to reflect dynamic behavior between single- and multiple-channel sections, and meaningful for the riverine ecosystem. The following hypotheses were tested:

- Hydromorphological differences between single- and multiple-channel sections are similar for two independent years.
- Hydromorphological changes due to recent dynamic processes that have occurred within the course of the year will be more pronounced in the multiple-channel sections.
- Hydromorphological changes due to recent dynamic processes are different between multiple-channel sections of natural and restoration origin.

## 2.3 *Material and Methods*

### 2.3.1 *Study sites*

The study sites have been described in Chapter 1 (Table 1-1, Figure 1-1) and only key information will be given here (Table 2-1). Seven sites in the lower mountainous areas of the German federal states of Hesse, North Rhine-Westphalia, and Rhineland-Palatinate were studied. The sites comprise the upper parts of the streams Lahn, Eder, and tributaries to the Sieg and Mosel, being Rhine and Weser tributaries. The streams catchment areas range from 180 to 650 km<sup>2</sup>. The catchment geology is mostly comprised of acid rock (schist). Land use in the study catchments consists of up to 60% forest, around 30% pasture, and 10% urban areas (Corine land cover data, 2000).

**Table 2-1.** Study sites and catchment characteristics.

	Lahn-W	Lahn-LH	Lahn-C	Orke	Eder	Nims	Bröl
Catchment area (km <sup>2</sup> )	278	288	650	289	480	222	181
Stream length (distance to source) (km)	25	26	50	31	74	44	30
Length of all multiple-channel sections up to site (m)	200	400	1000	200	250	200	600
Proportion of multiple-channel sections compared to stream length (%)	0.8	1.5	2	0.6	0.6	0.3	2
Potential length of multiple-channel sections estimated from stream type length (m)	6000	7000	36000	15500	40000	17000	11800
Potential proportion of multiple-channel sections compared to stream length (%)	24	27	72	50	54	39	39

A paired site study was set up where in the spring and summer 2004 and 2005 seven multiple-channel sections were compared to nearby straightened single-channel sections for differences in hydromorphology and aquatic macroinvertebrates. Each pair is comparable in terms of catchment geology, catchment land use, and discharge characteristics. The multiple-channel patterns either resulted from restoration measures or developed in less intensively maintained floodplain sections (Table 1-1). They are single outstanding stream sections within an otherwise largely uniform single-channel stream course.

Table 2-2 summarises discharge key data for the sites. Discharge on the days of investigation was mostly well below mean discharge (MQ), with the exception of the Orke in 2004, which resulted in a large discharge difference for the two years. Bankfull discharge occurred at all sites in the winter 2004/05 (Figure 2-3).



(A) Lahn-C; view upstream  
Feb. 2003; Photo A. Lorenz



(B) Lahn-C; view upstream  
Feb. 2004; Photo S. Jähnig



(C) Lahn-C; view downstream  
June 2005; Photo S. Jähnig

**Figure 2-1.** Multiple-channel section (main channel) of Lahn-C in different years. Red arrows indicate similar location within the stream section.



(A) Lahn-LH, April 2004; Photo S. Jähnig

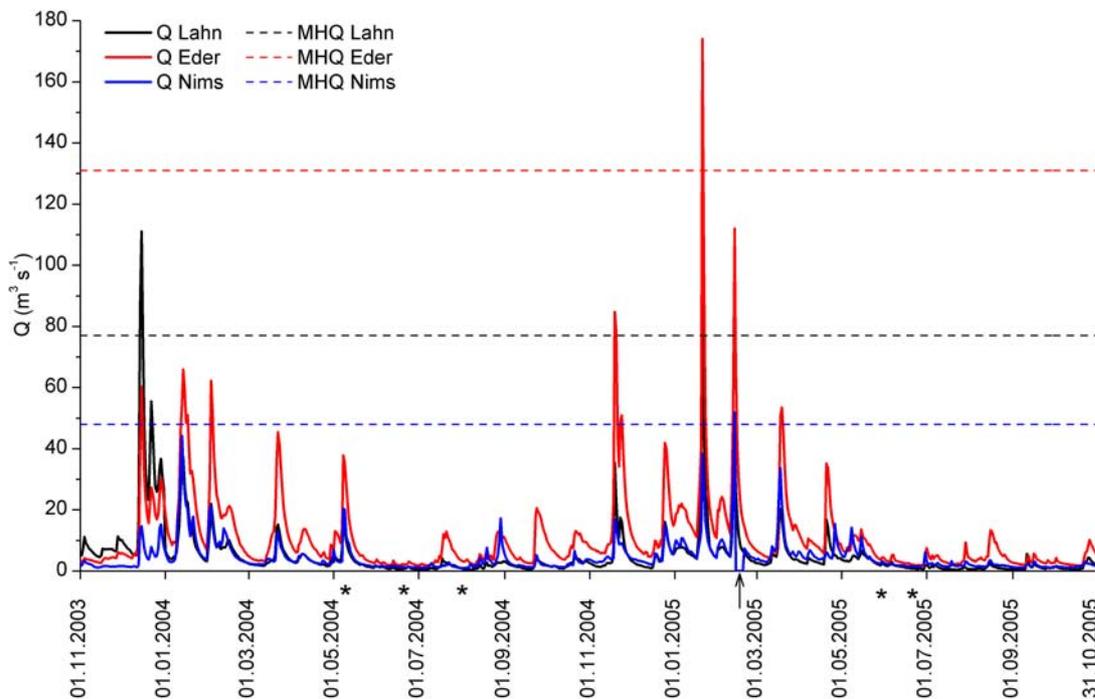


(B) Lahn-LH, May 2005; Photo A. Lorenz

**Figure 2-2.** Multiple-channel section of Lahn-LH in different years. Nearby gauge at Biedenkopf (Hesse): Discharge  $Q_{2004} = 6 \text{ m}^3 \text{ s}^{-1}$ ,  $Q_{2005} = 3.8 \text{ m}^3 \text{ s}^{-1}$ . Red arrows indicate similar location within stream section.

**Table 2-2.** Discharge key data. Mean discharge (MQ) and discharge (Q) at respective investigation days in 2004 and 2005, in relation to highest flood in-between ( $Q_{max}$ ) and mean high flow (MHQ) ( $m^3 s^{-1}$ ).

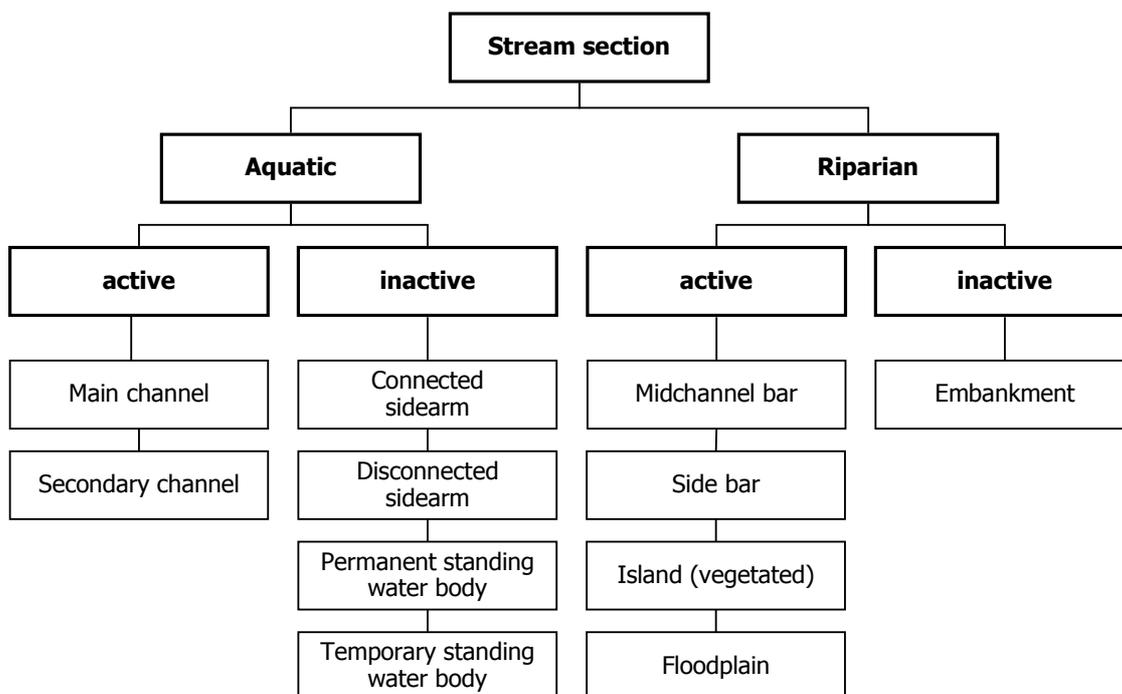
Site	2004			2005		Flood events	
	MQ	Date	Q	Date	Q	$Q_{max}$ 2004/05	MHQ
Lahn-W	5.1	26.05.2004	1.3	08.06.2005	1.7	15	8
Lahn-LH	5.2	28.06.2004	0.6	09.06.2005	1.6	15	8
Lahn-C	8.3	24.05.2004	2.3	17.06.2005	1.7	105	77
Orke	6.3	13.05.2004	5.1	23.06.2005	0.4	48	47
Eder	10.5	15.06.2004	1.9	22.06.2006	1.8	174	131
Nims	2.8	19.07.2004	2.0	05.07.2005	2.6	52	48
Bröl	3.4	08.08.2004	0.4	27.06.2005	0.3	31	30

**Figure 2-3.** Hydrographs of three representative gauge stations. Q = discharge (raw data); MHQ = mean bank-full discharge. Maximum discharge at the Lahn in Winter 2004/2005 has been confirmed to  $137 m^3 s^{-1}$ . Asterisks indicate months of field work. Arrow indicates failing of gauge station due to high discharge.

### 2.3.2 Hydromorphological measurements

Morphological measurements were conducted during low flow season as the investigated streams are otherwise not accessible by wading. A stretch of approximately 200 m was investigated at each stream section. The width of channel features was measured along 20 equidistant transects running between the left and right edge of the embankments. Eleven channel features, being either aquatic or riparian habitat, were distinguished and recorded (Figure 2-4). According to their hydrological characteristics the channel features are divided into: hydrologically active aquatic features, i.e. directly influenced by discharge (main and secondary channels) and hydro-

logically inactive features, which are indirectly influenced from discharge (connected and disconnected sidearms, and permanent and temporary standing water bodies). Riparian habitats were further divided into active features, which are flood-prone areas susceptible to changes (bars, islands, floodplain areas) and inactive features (rather stable embankments).



**Figure 2-4.** Classification of channel features. Explanation for channel features see Table II.

Along the transects at 20 points (limited to the aquatic areas) current velocity, water depth and substrate type according to substrate types used in multi-habitat sampling procedure (Hering *et al.*, 2003) were recorded, to determine each section's relative substrate composition. Thus, a total of 400 point data were generated per stream section. At the site Lahn-W investigations were limited to 16 transects, due to limited access to the riverbed. Water depth was measured with a 2-m-long rule fixed to a surveying pole; measuring accuracy was to the centimeter. Stream accessibility was limited to 140 cm; greater water depth values were standardised to 145 cm. Current velocity was measured using a Schiltknecht MiniAir2 device with a MiniWater20 current velocity sensor, which automatically calculates a 6-second mean from 0.5-second values in a measurement range from 0.02–5 m s<sup>-1</sup>. In 2004 a full set of data was recorded, consisting of width measurements of channel feature and substrate, depth, and current velocity recordings along 20 transects per stream section. In 2005 recordings were downsized and consisted of width measurement for channel features and substrate recordings along 20 transects. Depth and current velocity measurements were made for every second transect only.

### 2.3.3 Data analyses: Differences within years

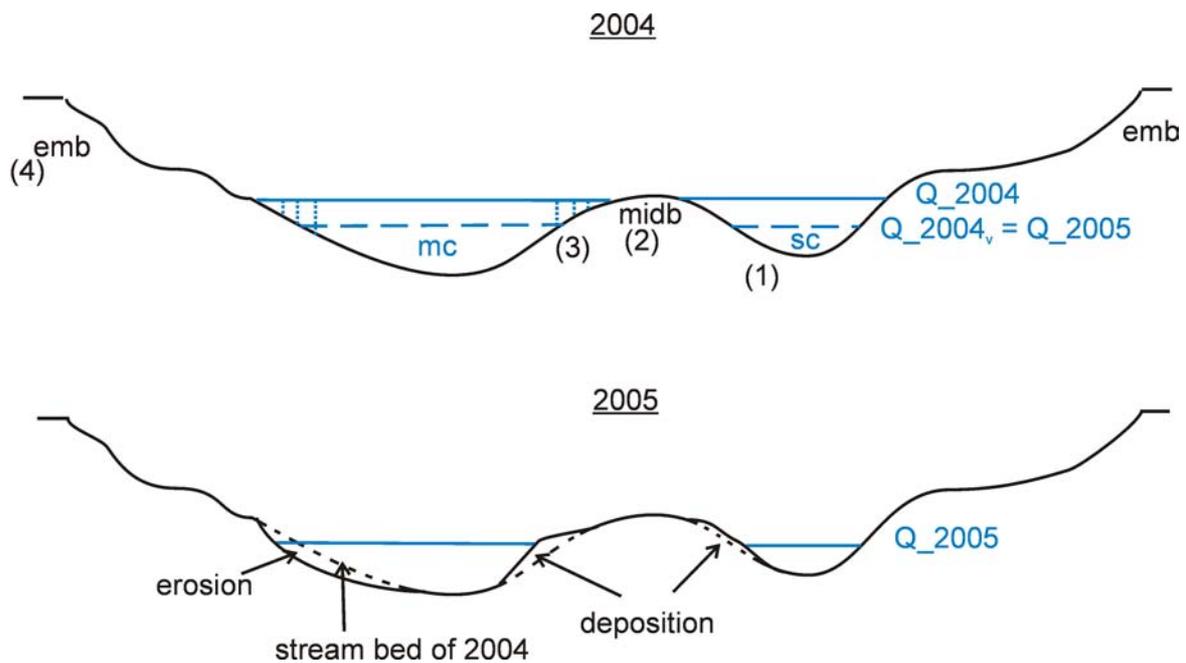
Analyses of annual changes are handicapped by the different water level at the investigations days and might require adjustment (see 2.3.4). The analyses between stream sections (within one year) are less sensitive to this. Morphological metrics which use relative width or number in relation to each other, and are thus less impaired by water level, were chosen to compare single- and multiple-channel sections within one year. Of the twelve morphological metrics described in Chapter 1, seven metrics were considered, indicating various aspects of habitat diversity:

- Number of channel features within one stream section: includes meso-scale habitat diversity, e.g. bars, islands or standing water bodies.
- Shannon-Wiener-Index of channel features: considers number and width of channel features.
- Number of substrates: indicates aquatic habitat diversity, relevant to macroinvertebrates.
- Shannon-Wiener-Index of substrates: considers number and substrate composition of a section; indicates aquatic habitat diversity.
- Spatial-Diversity-Index (Fortin *et al.*, 1999): additionally includes spatial aspects of substrate distribution.
- Coefficient of variation for depth and current velocity: takes into account the other two important elements of aquatic habitat aside from substrate.

Detailed information on the metrics can be found in Chapter 1. For each year and each metric the mean proportion between single- and multiple-channel sections was calculated. The results were pooled for all stream sections.

### 2.3.4 Data analyses: Annual changes

To evaluate the effects of sedimentation and erosion processes, adjustment of different discharges between the years is required. Without this adjustment, differences in the widths of channel features cannot be attributed to sedimentation or erosion that have occurred, but might rather be due to different water level (Figure 2-5).



**Figure 2-5.** Water level scheme. Discharge ( $Q$ ) differs in 2004 and 2005 ( $Q_{2004} > Q_{2005}$ ), resulting in different water levels and hence, influencing width measurements. The water level of 2005 in the stream bed of 2004 is  $Q_{2004,v}$  ( $v$ =virtual water level). The stream bed characteristics of 2004, and 2005 were compared for width and depth differences, indicating morphological changes. mc = main channel, sc = secondary channel, midb = midchannel bar, emb = embankment; further explanation to numbers (1–4) in text.

The data were thus adjusted prior to evaluating the morphological changes from year to year; this was done using an Excel macro (hereafter referred to as 'virtual flow macro', which was devised for this purpose). This macro was used to compare the actual measured water level based on the actual discharge of 2005, with a virtual water level in 2004, which would have been present under the discharge conditions in 2004, presuming the floodplain morphology of 2004. Following the adjustment, the modifications due to flood events and continuing erosion between both years were able to be calculated and quantified. Data sets were compared regarding water depth, the widths of active and inactive channel features, and cross-sections.

The following assumptions for calculating the virtual water level were made (numbers in Figure 2-5):

- (1) Only main and secondary channel contribute, i.e. sidearms and standing water bodies are inactive in terms of discharge.
- (2) Active riparian areas are non-submerged areas of midchannel bars, side bars, islands and floodplain area.
- (3) The mean gradient of riparian areas was extrapolated from the first and last three adjacent depth measurements; the height of riparian areas above the measured water level was deliberately limited to 100 cm.

(4) Embankments restrict the floodplain area on both sides. Their height is irrelevant for the calculation as I was not interested in calculating bankfull discharge or flood events; the gradients of the embankments were deliberately assumed to be 45° in all cases.

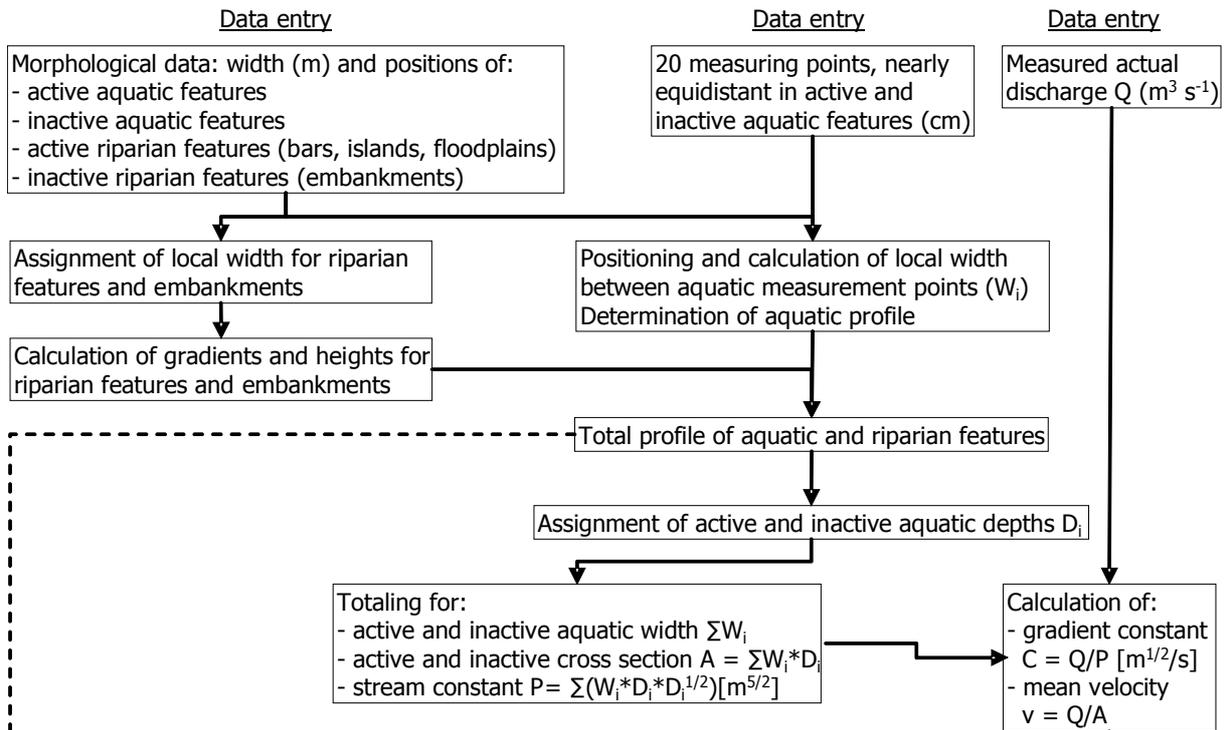
The various active channels in the floodplain for each transect were considered as conduits having the same water head, same gradient and roughness respectively. Roughness at channel bottoms was assumed to be large, so turbulent flow (Reynolds number larger than 1000) was assumed. Iteratively a new depth increment (positive or negative) was added to the actual measured depth values, to yield the virtual depth values. These were tested until the virtual discharge of the first year matched the actual discharge in the second year.

Table 2-3 summarises and explains the investigated parameters. The principle data flow and processing is shown in Figure 2-6.

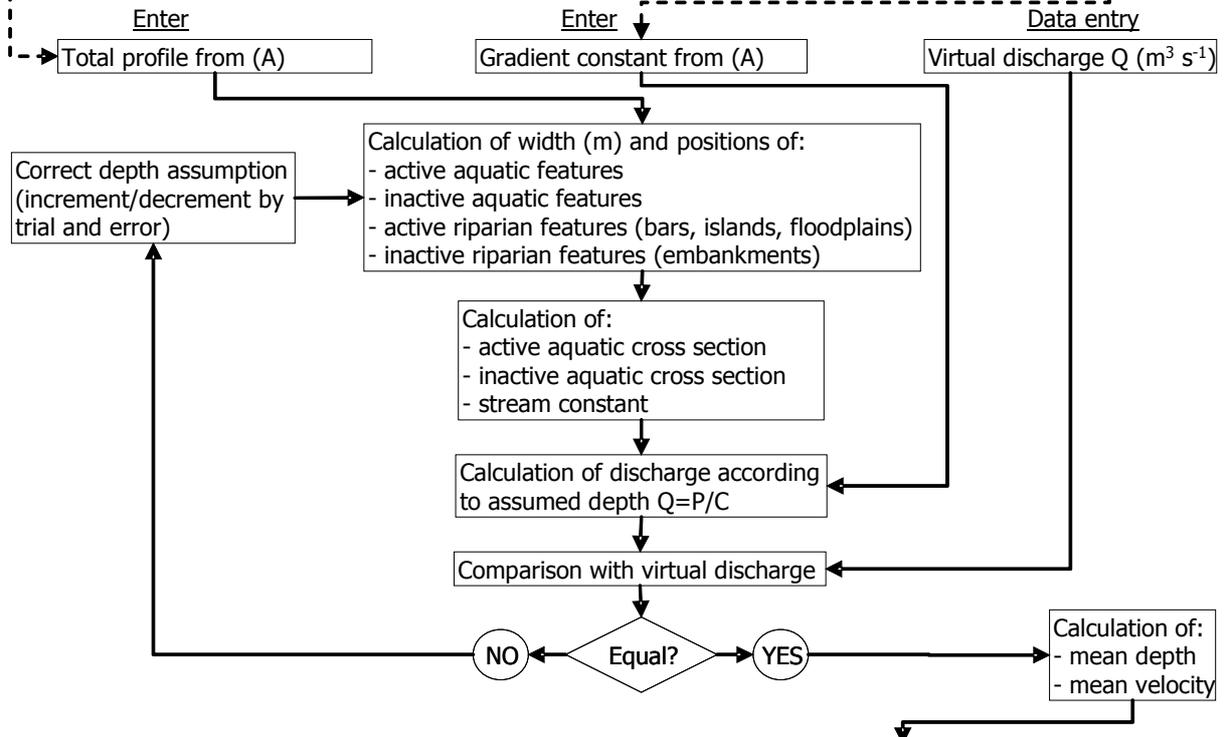
**Table 2-3.** Hydromorphological metrics processed in virtual flow macro.

Parameter	Abbreviation	Explanation
Discharge	$Q$ ( $\text{m}^3 \text{s}^{-1}$ )	Taken from a nearby gauge (Table 2-2).
Mean active depth	$D_i$ (cm)	Calculated from up to 20 point depth measurements in the aquatic parts, corrected for an integral number of equal widths between points starting and ending always 0.1 m from land-water edges for all active and inactive water bodies of a transect.
Active aquatic width	$W_{\text{active}}$ (m)	Calculated from transect measurements, only of active aquatic features; for virtual discharge, the width is corrected according to bank gradient and change of depth.
Inactive aquatic width	$W_{\text{inactive}}$ (m)	Calculated from transect measurements, only of inactive aquatic features; for virtual discharge, the width is corrected according to bank gradient and change of depth.
Active riparian width	$W_{\text{riparian}}$ (m)	Includes the width of bars, islands and floodplain areas; calculated from transect measurements; for virtual discharge the width is corrected according to bank gradient and change of depth.
Active aquatic cross-section	$A_{\text{active}}$ ( $\text{m}^2$ )	Calculated as sum of products of active depth and of the active aquatic widths.
Inactive aquatic cross-section	$A_{\text{inactive}}$ ( $\text{m}^2$ )	Calculated as sum of products of the inactive depth and inactive aquatic widths.
Mean current velocity	$v$ ( $\text{m s}^{-1}$ )	Is calculated: $v = Q / A_{\text{active}}$

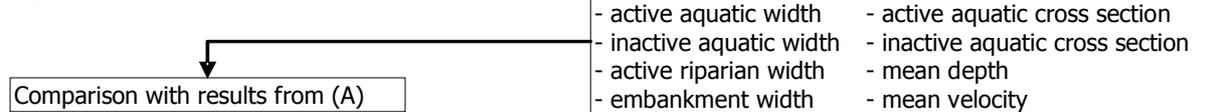
**(A) Calculation for actual profile and actual discharge**



**(B) Calculation for actual profile and virtual discharge**



**(C) Comparison of profiles**



**Figure 2-6.** Main processes and data flow in virtual flow macro.

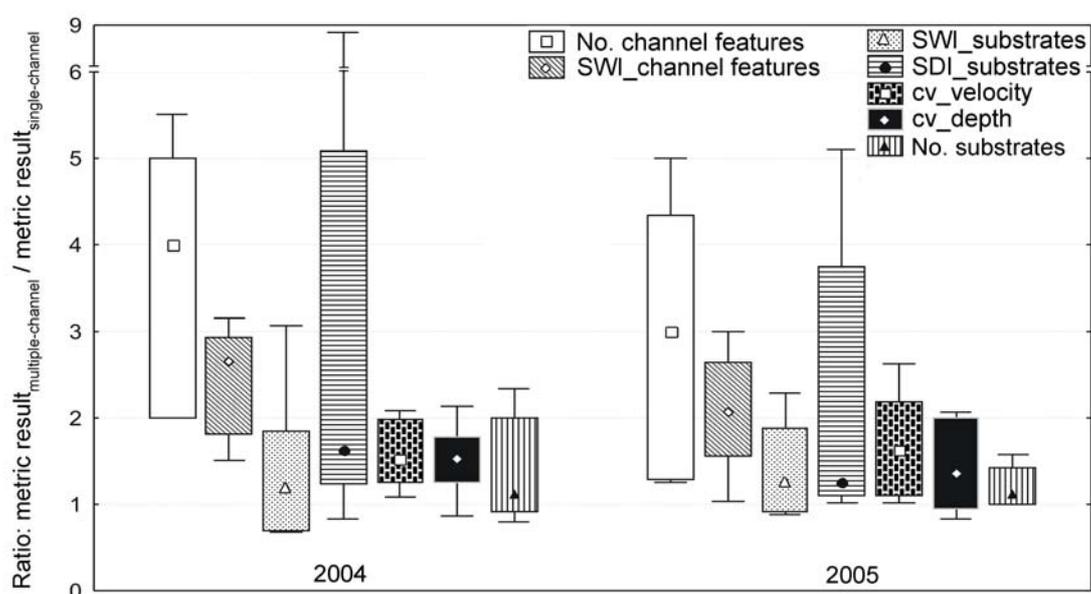
For ten transects at each stream section (eight in the case of Lahn-W), the mean changes and variation for parameters listed in Table 2-3 between the years 2004 and 2005 were compared. t-tests were performed for absolute values as otherwise averaging of negative and positive changes will obliterate the results. Furthermore, the ratio of change was calculated.

Following the hypotheses separate analyses concerned the restored sites Lahn-W, Lahn-LH and Lahn-C, and the natural-developed sites Eder, Nims and Bröl. Due to the high discharge differences in consecutive years the Orke site was not considered in these analyses.

## 2.4 Results

### 2.4.1 Hydromorphological differences within years

Figure 2-7 condenses the results for hydromorphological metrics (Table 2-4) by comparing the ratio for selected seven metrics between single- and multiple-channel sections for both survey years. Most metrics increase from single- to multiple-channel sections in both years, decreasing values (i.e. a ratio below 1) occur in 8% of the cases. The ratio remains approximately the same for the metrics in the two years. It is largest for the number of channel features and the Spatial-Diversity-Index, both of these values in the multiple-channel sections exceed those of the single-channel sections by factors of up to nine. Metrics associated with habitat characteristics, such as habitat diversity (Shannon-Wiener-Index) or the coefficient of variation of depth and current velocity increase by lower factors, especially in the stream sections of Orke, Eder and Nims in both years.



**Figure 2-7.** Ratio (multiple- / single-channel section) of selected hydromorphological metrics. Median; Box: 25%-75%; Whisker: Min-Max; n=7. SWI = Shannon-Wiener-Index, SDI = Spatial-Diversity-Index, cv = coefficient of variation.

**Table 2-4.** Hydromorphological metric results in 2004 and 2005. First line: result from 2004; second line: result from 2005. SWI = Shannon-Wiener-Index; SDI = Spatial-Diversity-Index; cv = coefficient of variation.

	Lahn-W		Lahn-LH		Lahn-C		Orke		Eder		Nims		Bröl	
	single	multiple	single	multiple	single	multiple	single	multiple	single	multiple	single	multiple	single	multiple
Shore length (m)	301	735	380	1272	432	1408	415	785	480	734	382	815	402	1050
	301	1001	381	1605	397	1623	440	760	509	715	382	862	403	1021
Mean width (m)	20.4	41.0	17.6	59.3	25.5	57.8	22.9	49.2	31.6	34.6	18.2	29.2	22.4	57.0
	18.5	56.0	15.8	67.3	23.0	59.7	22.1	47.0	34.6	39.3	17.9	31.4	19.0	54.2
Number of channel features	2	8	2	10	4	8	4	8	5	10	2	11	3	13
	2	10	4	12	5	12	8	10	7	9	3	10	3	13
SWI channel features	0.68	1.82	0.69	2.02	0.99	1.79	1.04	1.56	1.10	2.02	0.69	2.18	0.84	2.24
	0.65	1.95	1.04	2.15	1.18	2.28	1.67	1.72	1.23	1.91	0.89	2.05	0.82	2.17
SWI substrates	0.78	1.44	0.47	1.44	1.24	1.47	1.70	1.14	1.15	0.79	1.44	1.43	1.01	1.33
	0.80	1.50	0.76	1.74	0.91	1.51	1.24	1.13	1.06	0.94	1.18	1.16	0.95	1.19
SDI substrates	0.67	5.97	1.05	5.34	4.14	5.98	6.38	5.28	2.14	2.66	2.41	4.50	2.52	4.12
	0.99	5.05	1.91	5.94	1.41	5.29	4.33	4.44	2.74	3.38	2.60	3.28	2.93	3.22
cv_current velocity	0.72	1.25	0.79	1.56	0.67	1.02	0.61	0.77	0.91	0.99	0.86	1.19	0.63	1.31
	0.46	1.21	0.63	1.38	0.66	1.08	0.86	0.99	0.99	1.00	0.96	1.06	0.67	1.09
cv_depth	0.47	0.84	0.57	0.87	0.59	0.97	0.35	0.52	0.61	0.77	0.77	0.66	0.43	0.92
	0.44	0.69	0.41	0.85	0.65	0.88	0.61	0.58	0.69	0.71	0.81	0.67	0.45	0.90
Number of substrates	5	10	3	7	8	11	11	10	10	8	10	11	8	9
	7	10	7	11	9	10	8	8	8	9	10	10	8	9

Differences for single- and multiple-channel sections were compared, keeping the restored and natural multiple-channel sections separate (Table 2-5). The mean ratio of metric results is significantly higher for restored sites. The metrics related to channel features and to the coefficient of variation of depth are not different for restored and natural stream sections. The substrate-related metric ratios are significantly higher for the restored stream sections.

**Table 2-5.** Mean ratios (multiple- / single-channel section) of selected hydromorphological metrics. Restored sites: Lahn-W, Lahn-LH, Lahn-C; natural sites: Orke, Eder, Nims, Bröl. Asterisks indicate level of significance: \*\*  $p < 0.05$ ; n.s. = not significant (Mann-Whitney-U-test).

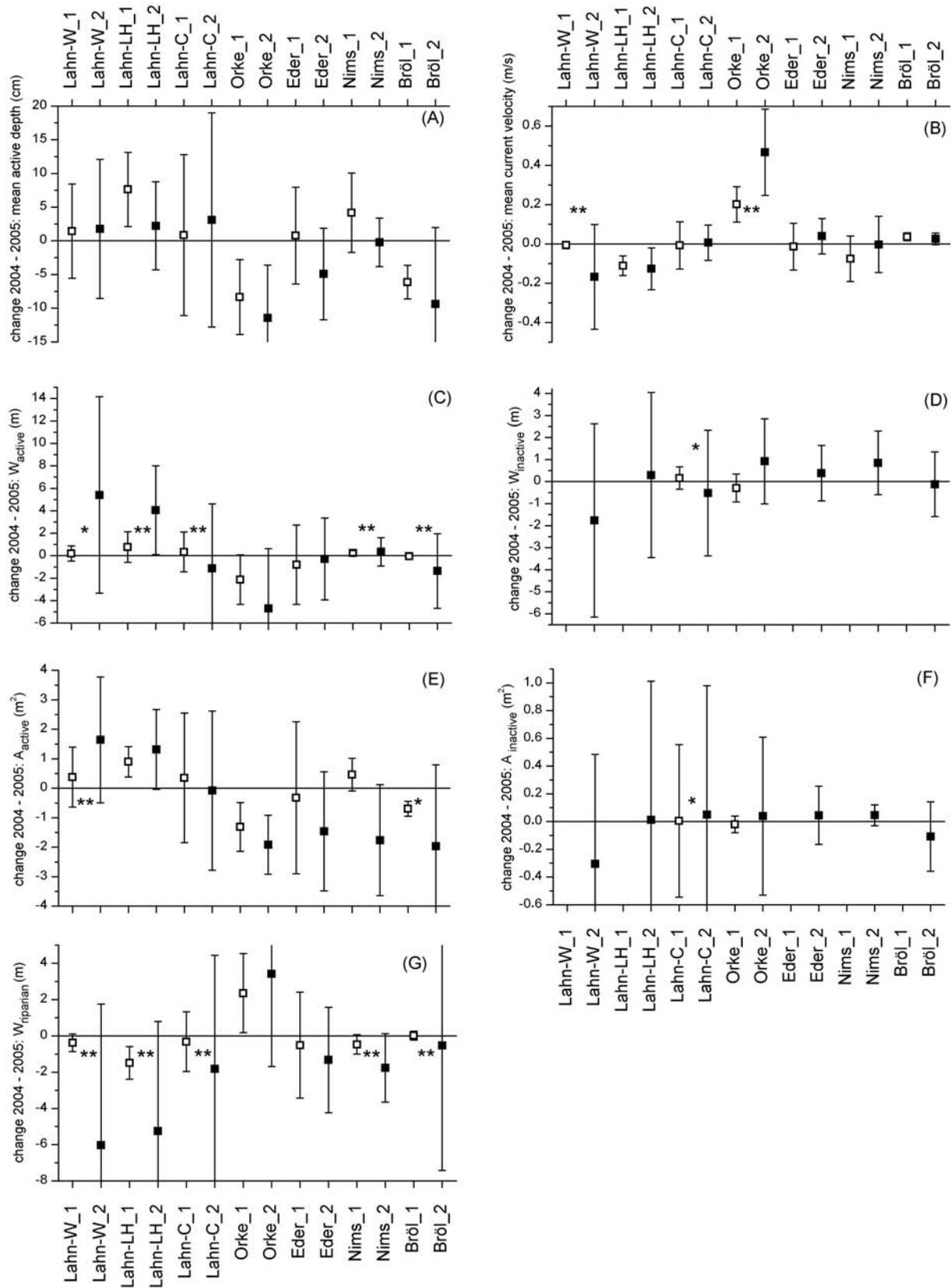
	Restored sections	n	Natural sections	n	p
Number of channel features	3.6	6	3.0	8	n.s.
Shannon-Wiener-Index channel features	2.4	6	2.1	8	n.s.
Number of substrates	1.6	6	1.0	8	**
Shannon-Wiener-Index substrates	2.0	6	1.0	8	**
Spatial-Diversity-Index substrates	4.6	6	1.3	8	**
Coefficient of variation current velocity	1.9	6	1.3	8	**
Coefficient of variation depth	1.7	6	1.3	8	n.s.
Overall mean	2.5	42	1.6	56	**

#### 2.4.2 Annual changes of hydromorphology

Water depths and the widths of all aquatic features, of all riparian features, and of the waterside margins of the embankments have been modified by the streams over the course of the year. Figure 2-8 displays the mean changes and standard deviations of 10 transects for each stream section between 2004 and 2005.

Mean active depth (A) shows no discrete pattern for annual changes, both increases and decreases appear. Mean active depth interacts with aquatic width (C, D), cross-section (E, F) and current velocity (B): for the same discharge it is imperative that as the cross-section (depth\*width) is increased, the velocity is decreased, and vice versa. This is exemplified for the single-channel sections of Lahn-W and Lahn-LH, which show a decreased depth, a decreased cross-section and an increased current velocity. At the Orke the reverse features are displayed, i.e. increasing depth, increasing cross-section and decreasing current velocity.

The active aquatic width (C) shows the most pronounced changes in the multiple-channel sections of Lahn-W and Lahn-LH. Lahn-C shows an increased width, which is associated with a decreased depth, resulting in an overall unchanged cross-section. Multiple-channel sections develop largely laterally, while single-channel sections remain unchanged. The single-channel sections at the Orke and Eder show the largest variations in aquatic width of all single-channel sections.



**Figure 2-8.** Annual changes of hydromorphology. Mean changes (difference between 2004 and 2005) and standard deviations for 10 transects of single- (1 / white) and multiple-channel (2 / black) sections. Asterisks indicate level of significance: \*\* p < 0.05; \* p < 0.1 (t-test with absolute values). Abbreviations see Table 2-3.

Single-channel sections lack inactive channel features, i.e. sidearms and standing water bodies (D, F). At the multiple-channel sections the mean annual changes are close to zero, but variations are pronounced, with the largest differences occurring at the Lahn sites.

Active and inactive aquatic cross-sections (E, F) differ in their displayed pattern: while inactive area shows low mean changes and a very high variability, the active cross-sections show actual (significant) changes.

The active riparian width (G) shows almost no change over the year in the single-channel sections. The multiple-channel sections show mainly an increasing width of riparian features, which often (but not always) occurs at the expense of embankment margins (not shown). However, variation is large, especially at the sites Lahn-W, Lahn-LH and Lahn-C. The Orke is characterised by decreasing riparian widths, but also highly variable.

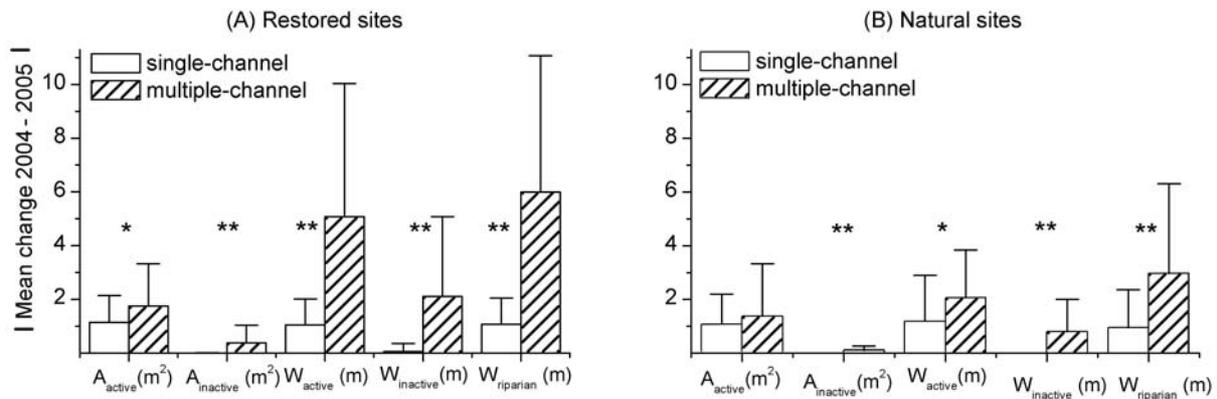
On a year-to-year basis the multiple-channel sections show more changes compared to the single-channel sections (Table 2-6). For all parameters the mean change is higher in the multiple-channel sections. In the single-channel sections changes occur, too, but to a lesser degree. This is especially true for the active width (10% change), compared to changes of over 32% in the multiple-channel sections. Changes in inactive aquatic cross-section and width are large (167% and 85% respectively) for the multiple-channel sections.

**Table 2-6.** Percentages of annual changes. Mean ratio of absolute values of annual changes (2004-2005) to values at first investigation (2004) (%). Asterisks indicate level of significance: \*\*  $p < 0.05$ ; \*  $p < 0.1$ ; n.s. = not significant (t-test with absolute values).

	Single-channel section		Multiple-channel section		p
	Mean annual change (%)	n	Mean annual change (%)	n	
Mean active depth	31	68	45	68	n.s.
Mean current velocity	31	68	44	68	**
Width <sub>active</sub>	10	68	32	68	**
Width <sub>inactive</sub>	n.a.	n.a.	85	28	**
Width <sub>riparian</sub>	185	38	53	68	*
Cross-section <sub>active</sub>	40	68	74	68	*
Cross-section <sub>inactive</sub>	n.a.	n.a.	167	28	**

In relation to Table 2-5, analyses of section changes resemble findings for differences between single- and multiple-channel sections depending on multiple-channel origin (Figure 2-9). The restored sites show much higher changes (mean and standard variation) compared to the sites of natural origin. The differences are either significant or highly significant for changes between single- and multiple-channels in each case. Cross-over analyses of single- and multiple-

channel sites yield no significant difference for the single-channel changes, but natural and restored multiple-channel sections differ significantly.



**Figure 2-9.** Annual changes of hydromorphology depending on multiple-channel origin. Mean and standard deviation of hydromorphological metrics for restored (Lahn-W, Lahn-LH and Lahn-C) and natural sites (Eder, Nims, Bröl). The Orke was not considered because of high discharge differences. Asterisks indicate level of significance: \*\*  $p < 0.05$ ; \*  $p < 0.1$ . Changes for restored and natural multiple-channel sections are significantly different with  $p < 0.1$ ; single-channel sections are not significantly different.

## 2.5 Discussion

### 2.5.1 Hydromorphological differences within years

Hydromorphological diversity is increased in the multiple-channel sections, compared to the single-channel sections. The results from 2005 resemble those from 2004 (Figure 2-7). Thus, a greater morphological change is discernible in the multiple-channel sections than in the single-channel sections. Especially the number of channel features and aquatic micro-habitat diversity (Spatial-Diversity-Index and Shannon-Wiener-Index) are strongly reduced in single-channel sections. These results demonstrate how successful water engineers were in taming rivers. Hydromorphological differences between more natural and anthropogenically altered sections have been reported elsewhere (Rohde *et al.*, 2004; Lepori *et al.*, 2005), and the obtained results are in the same range in terms of increased habitat feature number. Thus, the hypothesis "hydromorphological differences between single- and multiple-channel sections are similar for two independent years" is supported by the data. It must be noted, however, the records of the status quo do not yield information on temporal dynamics, which are seen as a central element of natural stream morphology (Pringle *et al.*, 1988; Robinson *et al.*, 2002; Wohl *et al.*, 2005). With so few features available in the single-channel sections, a system following the concept of a 'shifting mosaic steady state' is barely imaginable.

### 2.5.2 Annual changes of hydromorphology

The results confirmed the assumption that single- and multiple-channel sections differ in their degree of hydromorphological change. The multiple-channel sections were significantly changed, while the single-channel sections remained largely unaffected in consecutive years. The second hypothesis is thus also supported by the data. Still, the discharge events of the winter 2004/05 (Figure 2-3) had enough power to change a few parameters of some single-channel sections as well. The single-channel sections of Lahn-LH and Orke were affected by changes of mean active depth and cross-section area (Figure 2-8, A, E). These effects can be attributed to erosion or deposition of bed material, but not to changes of aquatic width, which is constrained by fixed banks and only slightly changed (Figure 2-8, C). At the Lahn, recorded discharges 100 times higher than on the investigation days may serve as explanation. The Orke is an exception to the pattern of unchanged width in the single-channel sections. One possible reason is the large discharge difference between the investigation days in 2004 and 2005 (Table 2-2). The virtual flow macro might be limited in such extreme application, as assumptions, especially regarding bank gradients, will be violated. The second reason is the comparatively natural status of the single-channel section, which has bottom and banks that are relatively less fixed, allowing more dynamics than at the other single-channel sections. In contrary, the Eder site shows very few changes in both stream sections. The largest differences originate from the increased availability of riparian areas in the multiple-channel sections. Again, this is attributed to the site itself: the multiple-channel section at the Eder developed recently (starting in about the year 2000) and since then has created the features itself, i.e. neither excavators "supported" it as at the Lahn sites, nor has time had the chance to shape the features as is the case at the Bröl and Orke. In comparison to the Nims, with a similar development date, the availability of large wood as a main source of habitat diversity is much reduced. The Eder flows through floodplains, subject to agricultural use, with stream banks almost totally cleared, thus bankside trees are scarce. The Nims has completely vegetated margins, and in case of the multiple-channel section, trees are allowed to fall into the stream and, most importantly, allowed to remain there. Additionally, the Nims is not as wide, so large wood has a greater effect on stream flow and can more easily create new channel features than in the Eder.

These findings correspond to the general effects attributed to vegetation and its affects on hydrology, erosion, sediment transport and deposition processes (Gurnell, 1997; Tabacchi *et al.*, 2000). Channel dynamics that renew habitat and succession processes, and the ecological dynamics related to it are interdependent: succession depends on sedimentation, which is accelerated by the presence of vegetation – and in-stream large wood causes erosion and

channel avulsion (starting new succession areas) (Richards *et al.*, 2002). Large wood is an especially important determinant of channel morphology: it forms pools, regulates transport of sediment and particulate organic matter, and provides habitat and cover for fish and other biota (Edwards *et al.*, 1999; Naiman *et al.*, 2000; Piégay, 2003).

The change of riparian active features widths (bars, islands and floodplains) are clearly different for single- and multiple-channel sections. These areas are highly variable in the multiple-channel sections, while mean changes remain low. A high turnover of elements is suggested, fulfilling the dynamics paradigm for more natural sites. On a larger scale, the relative abundance of landscape elements or channel features in a natural river corridor may remain relatively constant over longer time (Ward *et al.*, 2002b). However, the studied stream sections are too short to conclude this. The stream sections with a mean clearly different from zero (Lahn-W, Lahn-LH and Nims) suggest an imbalance in the section's sediment budget, maybe due to lack of supply. Sources and sinks are available up and downstream of any site (Thorne *et al.*, 1997), but their investigation was beyond the scope of this study. The sites studied here will likely not approach a steady state in the near future, as they are unique stream sections in largely confined catchments.

### 2.5.3 Annual changes in restored and natural multiple-channel sections

Different stages of development following restoration measures are revealed when comparing the year-to-year changes of restored and natural multiple-channel sections. The data support the hypothesis of different large changes at restored and naturally developed stream sections (Figure 2-8). The mean ratio of hydromorphological metrics between single- and multiple-channel sections (Table 2-5) already distinguishes between restored and natural sites. The processes causing these differences are reflected by significant changes of cross-section, aquatic width and width of active riparian features. The active aquatic cross-section is changed in single- and multiple-channel sections, which is due to changes in depth (by erosion or deposition), occurring at either section. Multiple-channel sections are better characterised by change in width and inactive features. In the natural sections these changes are more subtle, while restoration measures entail large changes when stream sections are struck by comparable flood events. The large changes in the restored stream sections are due to the margins and banks lacking vegetation, following the removal of fixing bankside vegetation or excavation works. Aufleger *et al.* (2005) report high dynamics and high rates of erosion and widening after fixation deconstruction, which later adjusts to stream morphological characteristics, such as grain size, discharge, slope and sediment load.

Contrary to what might be expected, the naturally developed multiple-channel sections usually still have fixation material somewhere. For example, the main channel at the multiple-channel section of the Orke is, for about half of the stream section, still fixed by large blocks. Natural sites miss another typical restoration measure which consists of excavating the alluvial clay down to the gravel layer, creating a better workspace for the stream. The Nims (natural multiple-channel section) is restricted in that respect, as it flows deeply within the cohesive clay. Processes will thus take much longer and smaller changes will continue until more erodible layers are reached.

#### *2.5.4 Conclusion and implications*

The findings imply higher dynamics in the multiple-channel sections, primarily independent of the origin or age of the features. Despite more channel features or a higher number of habitats, it is possible to gain certainty about dynamics occurring in the multiple-channel sections, which is one of the central targets of restoration efforts. The obtained results cannot be generalised, as the stream sections are short, and overall estimation of sources and sinks of sediment has not been conducted. There seems to be no succession but a large annual amount of turnover or dynamic taking place without "section aging". Despite short stream sections and land use remaining the same, rejuvenation and restructuring in the multiple-channel sections do occur, and positive ecological implications are assumed. Active riparian features such as banks and islands allow a high biodiversity of organisms, such as riparian arthropods (Boscaini *et al.*, 2000; Pätzold, 2004; Gacek and Hering, 2007), and positive effects have been reported for grasshoppers (Reich, 1991), and plants (Naiman and Decamps, 1997) as well. The dynamic interactions between water, sediment and aquatic-terrestrial landforms create and maintain riparian areas and control their characteristic functional processes and biodiversity patterns (Steiger *et al.*, 2005).

Recommendation for future research therefore includes the comparison of these results to longer stretches of either natural or restored sections in lower mountainous areas for evaluation of turnover rates and habitat in the 'shifting mosaic steady state'. Furthermore, revisiting multiple-channel sections in the next several years to follow up if they reach a more equilibrium state of turnover is also suggested.

Knowledge in habitat dynamics provides another set of criteria against which biotic reactions can be evaluated. It helps to understand hydromorphological monitoring results of restoration measures and can put effects of floods at restored sites in perspective.

### **3 Substrate-specific Macroinvertebrate Communities in Multiple-channel Sections**

#### **3.1 Abstract**

Most stream restoration measures aim at increasing habitat diversity on various scales. However, this does not necessarily have an effect on the aquatic macroinvertebrate communities. Seven single- and seven multiple-channel sections in German lower mountainous areas were compared in terms of aquatic habitat diversity and substrate-specific macroinvertebrate communities. The multiple-channel sections showed a considerable diversification of hydromorphological structures, i.e. increased shore length, higher channel feature and substrate diversity, and raised flow variability. Alpha- and beta-diversity and nestedness patterns were analysed for 199 substrate-specific macroinvertebrate samples. Taxa number, abundance, and evenness of communities found on multiple-channel substrates did not significantly differ from their single-channel section counterparts. However, ten Coleoptera and seven Trichoptera taxa were present exclusively on multiple-channel substrates, with the highest differences found for the fine mineral substrates such as loam or sand and for organic substrates such as living parts of terrestrial plants (LPTP), coarse particulate organic matter (CPOM) and large wood. The dominant substrates of two sites displayed no differences of macroinvertebrate communities in single- and multiple-channel sections either. Non-metric Multidimensional Scaling (NMS) showed that macroinvertebrate communities were substrate-specific (differentiating substrate groups of LPTP and wood, CPOM and mud, and mineral substrates), rather than section-specific. Nestedness was neither different from a section's perspective, i.e. single- and multiple-channel sections were equally nested, nor from a substrate's perspective, i.e. substrates from either section were equally nested. An exception were 25% of the samples, mostly organic ones. The findings imply that substrates at single- and multiple-channel sections have similar macroinvertebrate communities, thus alpha-diversity is not changed. Different substrates host different communities, so beta-diversity might be influenced. Hence, stream restoration projects aiming at a re-development of macroinvertebrate diversity should focus on the generation and availability of high quality habitats, such as large wood.

### 3.2 Introduction

Both large and small scale parameters are able to influence a macroinvertebrate community. Large scale influences stem from hydrological, physical, geomorphological and chemical processes. Small scale influences originate from the texture of single stones, substratum complexity, the spatial distribution of sand and leaf patches, and the mosaic heterogeneity around a habitat (Beisel *et al.*, 2000; Palmer *et al.*, 2000; Lepori *et al.*, 2005). In addition, factors of invertebrate life history, e.g. those related to oviposition sites, migration, and drift, play a role (Harper and Everard, 1998). At all spatial scales, the data largely support the idea that physical complexity promotes biological richness (Brosse *et al.*, 2003; Townsend *et al.*, 2003). Most consistent patterns of richness have been reported with substrate size, disturbance regime, annual temperature range and flow intermittency, followed by substrate heterogeneity, habitat type, and food availability, which are more equivocal in their effects (Vinson and Hawkins, 1998). According to the niche theory, the structural heterogeneity provides resource gradients along which functionally similar species can segregate and thereby coexist. As aquatic habitat composition changes from one dominant substrate at the single-channel sections to a more diversified composition in the multiple-channel sections, macroinvertebrate communities could potentially be influenced in two ways: (1) Macroinvertebrate communities of equal substrates differ in single- or multiple-channel section, thus alpha-diversity (within-habitat diversity) is dissimilar. (2) On the contrary, substrates might host different communities and by presence or absence of specific substrate types, beta-diversity (between-habitat diversity) is influenced. Besides alpha- and beta-diversity, the degree of nestedness is a valuable indicator of actual stream condition. Nestedness (Atmar and Patterson, 1993) describes the predictability of the species composition. A high degree of nestedness implies that a few common species tend to be ubiquitous; rare species tend to occur only at species rich sites. Nestedness analyses suggests which substrates might be valuable for conservation.

Today, most streams in Central Europe exhibit only remnants of their former hydromorphological and aquatic habitat diversity. The first river basin district analyses and characterisation of anthropogenic pressures conducted according to the European Water Framework Directive (WFD; EC, 2000) found 86% of the water bodies assessed in Germany to be at risk of failing the WFD objectives (BMU, 2005). Poor hydromorphology was the most often stated reason for this classification. Similar results were obtained for the Rhine and Danube basins thus, applying to large parts of Europe (ICPDR, 2005; ICPR, 2005). According to the WFD this status calls for improvement by stream restoration, to achieve a "good" ecological status by the year 2015.

Already a variety of restoration measures have been conducted across the country. Recently, stretches of larger streams with 100–1000 km<sup>2</sup> catchment area have been restored, trying to meet their stream type-specific reference conditions (LUA NRW, 2001a; LUA NRW, 2001b). Restoration measures of rivers and streams often aim at increasing habitat diversity on various scales, frequently linked to the general assumption of profound effects on macroinvertebrate communities. While physical changes might be achieved (Jähnig *et al.*, 2007a; Schlachta *et al.*, 2007), the biological implications, especially in terms of benthic macroinvertebrates used for stream assessment, remain unclear (Jähnig *et al.*, 2007b; Lorenz and Jähnig, 2007; van den Boom and Scharf, 2007).

Along the following questions and corresponding hypotheses this chapter aims at detecting diversity patterns in the aftermath of habitat diversification:

- Which differences regarding the benthic macroinvertebrate community are detectable on the same substrates at single- and multiple-channel sections?  
*Hypothesis: Similar substrates are colonised differently in single- and multiple-channel sections, meaning that alpha-diversity (diversity within habitat) is changed.*
- How large are the differences in the macroinvertebrate community between substrates?  
*Hypothesis: Beta-diversity is increased at the multiple-channel sections as substrate diversity is increased.*
- How does nestedness vary between single-channel and multiple-channel sections?  
*Hypothesis: Nestedness is higher in the single-channel sections, as the species pool is smaller and various substrates colonised similarly. Correspondingly it is hypothesised that nestedness is higher in the various substrates of multiple-channel sections, because a multiple-channel section is able to support a greater variety of species, therefore substrate-specific communities are more diverse among each other.*

Elucidating these answers will enable more effective planning of restoration measures, as the relative importance of certain habitats for the macroinvertebrate community can be estimated, and whether efforts in restoring in-stream habitat are sufficient.

### **3.3 Material and Methods**

#### **3.3.1 Study sites**

The sites have previously been described (Table 1-1, Figure 1-1) and information will be restricted to key information here. The study areas are located in the German Federal States of Hesse, North Rhine-Westphalia and Rhineland Palatinate. They comprise the upper parts of

the streams Lahn, Eder, and tributaries to the Sieg and Mosel, being Rhine and Weser tributaries. The stream catchments range from 180 to 650 km<sup>2</sup>. The catchment geology mostly comprises acid rock (schist). Land use in the study catchments consists of forest (60%), pasture and agriculture (30%), and around 10% urban areas (Corine land cover data Germany, 2000). The research design is comprised of a paired-site study. In the spring and summer of 2004 and 2005 seven multiple-channel sections were compared to nearby straightened single-channel sections for differences in hydromorphology and stream macroinvertebrate communities. The multiple-channel patterns either resulted from restoration measures (Lahn-W, Lahn-LH, Lahn-C) or developed without interference in floodplain sections less intensively maintained (Orke, Eder, Nims and Bröl). They are single outstanding stream sections within a largely uniform single-channel environment.

### 3.3.2 *Hydromorphological measurements and analyses*

A stretch of approximately 200 m was investigated at each stream section. Along 20 equidistant transects running between the left and right edge of the embankments the widths of channel features were measured (Table II). Along the transects at 20 points (limited to the aquatic features) current velocity, water depth and substrate types, according to substrate types used in multi-habitat sampling procedure (Hering *et al.*, 2003; Table III), were recorded, to determine each stream section's relative substrate composition. Thus, a total of 400 points of data were generated per stream section. At the site Lahn-W investigations were limited to 16 transects, due to limited access to the riverbed. Depth was measured with a 2-m-long rule, fixed to a surveying pole; measuring accuracy was to the centimetre. Accessibility was limited to 140 cm; greater water depth values were standardised to 145 cm. Current velocity was measured using a Schiltknecht MiniAir2 device with a MiniWater20 Mini water sensor, which automatically calculates a 6-second mean from 0.5-second values in a measurement range from 0.02–5 m s<sup>-1</sup>. With this data 12 metrics were calculated, to provide comparison between the stream sections (Table 1-2). A detailed description of the metrics can be found in Chapter 1. Relevant to this study were metrics related to aquatic habitat: depth and current velocity variability, number of substrates, Shannon-Wiener-Index, and Spatial-Diversity-Index (Fortin *et al.*, 1999).

### 3.3.3 *Macroinvertebrate sampling*

Altogether 199 macroinvertebrate samples were obtained in 2004 and 2005 using a shovel sampler (500 µm mesh size, 0.0625 m<sup>2</sup> sampling area). Each sample was kept separately and substrate, depth and current velocity were recorded prior to sampling. Generally each

available substrate was sampled no matter of it's frequency. This procedure considers important but area-limited habitats, which are usually downplayed by the dominance of widely occurring habitats when a strict multi-habitat sampling protocol is applied (Rabeni, 2000).

Two levels of detail were defined for macroinvertebrate sampling. In 2004 a more elaborate sampling design was used at the sites Lahn-C and Orke for circumstantial investigation of substrate-specific communities. Both were chosen as representatives for the two groups of multiple-channel sections: one having a restoration background (Lahn-C), one a natural background (Orke). The sampling involved the following procedure: the dominant substrate was sampled eight times, both in the single- and the multiple-channel section; every other substrate was sampled twice per stream section, with two exceptions due to availability. The other sites Lahn-W, Lahn-LH, Eder, Nims and Bröl were sampled in 2005, building on analyses of the above samples: each occurring substrate was sampled once in the single-channel section and once in the multiple-channel section. Substrates occurring only in the multiple-channel sections were sampled twice there. No substrate occurred solely in the single-channel section (Table 3-1).

**Table 3-1.** Number of substrate-specific macroinvertebrate samples taken. Samples of Lahn-C and Orke were taken in 2004, other samples in 2005. Substrate abbreviations see Table III.

	Lahn-C		Orke		Lahn-W		Lahn-LH		Eder		Nims		Bröl	
	single	multiple	single	multiple	single	multiple	single	multiple	single	multiple	single	multiple	single	multiple
Block	2	2	2	2	1	1	1	1	1	1	1	1	1	1
Cobble	2	2	8	8	1	1	1	1	1	1	1	1	1	1
C-gravel	8	8	2	2	1	1	1	1	1	1	1	1	-	2
F-gravel	-	2	2	2	-	2	1	1	-	2	1	1	1	1
Sand	-	2	2	2	-	2	1	1	-	2	1	1	1	1
Loam	1	2	1	2	1	1	-	-	-	-	1	1	-	2
Subm	-	-	-	-	-	-	-	2	1	1	-	-	-	-
LPTP	2	2	2	2	1	1	1	1	1	1	1	1	1	1
Wood	2	2	2	2	1	1		2	1	1	1	1	1	1
CPOM	2	2	2	2	1	1	1	1			1	1	-	2
Mud	2	2	2	2	1	1	-	2	1	1	1	1	1	1
Pool	-	2	-	2	-	-	-	-	-	-	-	-	-	-
Sum	21	28	25	28	8	12	7	13	7	11	10	10	7	13

Samples were preserved in 70% ethanol and transferred to the laboratory, where sorting took place following the RIVPACS sorting scheme (Murray-Bligh *et al.*, 1997). The organisms were identified to species level where possible, except Oligochaeta, which were recorded as such or identified to the family level, and Chironomidae, identified mostly to the family or

tribus level. Prior to data analyses, all taxa lists were corrected to the same taxonomic identification level. Taxa only found in one sample with one individual were omitted from further analyses; this applied to 19 taxa. Additionally samples from floodplain ponds and submergent macrophytes were excluded as they had been sampled at only two sites.

Conductivity ( $\mu\text{S cm}^{-1}$ ), temperature ( $^{\circ}\text{C}$ ), dissolved oxygen content ( $\text{mg l}^{-1}$  and %), and pH were measured at each stream section with WTW portable devices (Oxi-meter 197, Conductivity-meter 197 and pH-meter 197; Appendix 10).

### 3.3.4 Macroinvertebrate data analyses

Statistical analyses were conducted according to the different sampling programs (Table 3-2).

**Table 3-2.** Compendium of analyses undertaken. References and explanation in text.

Analyses for all samples, pooled for sections	Additional analyses for Lahn-C and Orke
Taxa number, abundance, evenness	Non-metric multidimensional scaling (NMS)
Nestedness	Multi-Response-Permutation-Procedures (MRPP): within substrate differences
	MEANSIM: between-group differences

Samples of Lahn-C and Orke were separately analysed for taxa number, abundance and evenness. Samples from these two sites were ranked using Non-metric Multidimensional Scaling (NMS) with Bray-Curtis dissimilarity as distance measure (PC-ORD, McCune and Meford, 1999). Dissimilarity was calculated with log-transformed abundance data. Differences within substrates were calculated using the Multi-Response Permutation Procedures (MRPP) of PC-ORD and focussed on single- and multiple-channel differences. Differences between groups were calculated using the MEANSIM-calculator of Van Sickle (1998). The calculated dissimilarity within and between groups was used as an estimate of the degree of differences both between and within substrates as well as between samples from single- and multiple-channel sections.

Substrate samples were then pooled, sorted into single- and multiple-channel sections and analysed together for taxa number, abundance, evenness.

Nestedness was calculated for samples of sections and substrates using the "nestedness calculator" (Atmar and Patterson, 1993). The nestedness calculator calculates the "temperature"  $T$ .  $T=0$  means a perfectly nested data set, i.e. taxa of species poor samples occur all in species rich samples;  $T=100$  is a maximally disordered data set. Generally, a higher  $T$  means less predictability. The nestedness calculator uses presence-absence data of

taxa, and analyses the probability of nestedness by a Monte Carlo permutation (500 runs per test), issuing  $T_{calc}$ : if  $T < T_{calc}$  the community can be stated nested.

### 3.4 Results

#### 3.4.1 Hydromorphological diversity

The multiple-channel sections show a considerable diversification of hydromorphological structures (detailed results for macro- and meso-scale parameters can be found throughout Chapter 1). The mean overall width is increased by a factor of 2.1. Shore length increases by a factor of 2.4 for comparable stream sections. The aquatic habitat diversity is increased as well (Table 3-3): the coefficient of variation of depth and current velocity is higher in the multiple-channel sections; the multiple-channel sections have usually more substrates and a more complex arrangement of substrates, which is reflected by greater values for the Spatial-Diversity-Index.

**Table 3-3.** Hydromorphological metrics at single- (1) and multiple-channel (2) sections. cv = coefficient of variation; SWI = Shannon-Wiener-Index; SDI = Spatial-Diversity-Index; higher values within a site are marked bold. Substrate abbreviations see Table III.

	cv			Substrate composition (%) (median rate of increase)											
	Current velocity	Depth	# Substrates	SWI	SDI	Blocks (0.3)	Cobble (1.2)	C-gravel (1.4)	F-gravel (8)	Sand (2)	Loam (5.3)	LPTP (1)	Wood (1)	CPOM (3)	Mud (1.6)
Lahn-W_1	0.72	0.47	5	0.78	0.67	<b>20.63</b>	<b>73.44</b>	1.25	0.00	0.00	0.94	0.94	0.63	0.31	<b>1.88</b>
Lahn-W_2	<b>1.25</b>	<b>0.84</b>	<b>10</b>	<b>1.44</b>	<b>5.97</b>	10.63	50.00	<b>21.88</b>	<b>5.31</b>	<b>5.94</b>	<b>1.25</b>	<b>3.13</b>	0.63	<b>0.94</b>	0.31
Lahn-LH_1	0.79	0.57	3	0.47	1.05	<b>22.06</b>	<b>73.68</b>	1.00	0.50	2.01	0.00	0.25	0.00	0.50	0.00
Lahn-LH_2	<b>1.56</b>	<b>0.87</b>	<b>11</b>	<b>1.44</b>	<b>5.34</b>	5.25	45.00	<b>22.25</b>	<b>5.25</b>	<b>3.75</b>	<b>4.00</b>	<b>2.00</b>	<b>0.50</b>	<b>2.75</b>	<b>5.75</b>
Lahn-C_1	0.67	0.59	8	1.24	4.14	<b>8.25</b>	<b>28.50</b>	54.00	0.50	0.00	1.75	<b>1.25</b>	2.50	0.25	3.00
Lahn-C_2	<b>1.02</b>	<b>0.97</b>	<b>10</b>	<b>1.47</b>	<b>5.98</b>	2.26	16.29	<b>55.14</b>	<b>4.01</b>	<b>4.76</b>	<b>12.03</b>	0.75	<b>1.50</b>	0.25	3.01
Orke_1	0.61	0.35	<b>11</b>	<b>1.7</b>	<b>6.38</b>	6.75	41.75	<b>13.75</b>	<b>22.00</b>	<b>4.25</b>	0.75	<b>3.75</b>	<b>3.50</b>	0.25	<b>3.00</b>
Orke_2	<b>0.77</b>	<b>0.52</b>	10	1.14	5.28	<b>9.25</b>	<b>71.00</b>	6.75	1.00	1.50	<b>4.00</b>	1.25	0.75	<b>3.00</b>	1.50
Eder_1	0.91	0.61	<b>10</b>	<b>1.15</b>	2.14	4.50	64.00	<b>7.00</b>	0.00	0.25	0.25	0.25	0.25	0.00	2.00
Eder_2	<b>0.99</b>	<b>0.77</b>	8	0.79	<b>2.66</b>	<b>9.00</b>	<b>75.50</b>	5.50	<b>0.50</b>	<b>0.75</b>	0.25	0.25	0.25	0.00	<b>3.25</b>
Nims_1	0.86	<b>0.77</b>	10	<b>1.44</b>	2.41	<b>30.25</b>	56.5	3.25	<b>1.25</b>	0.25	0.75	1.25	1.25	0.25	5.00
Nims_2	<b>1.19</b>	0.66	<b>11</b>	1.43	<b>4.50</b>	9.25	<b>68.0</b>	<b>4.50</b>	0.25	<b>0.50</b>	<b>3.75</b>	1.25	<b>1.50</b>	0.25	<b>10.75</b>
Bröl_1	0.63	0.43	8	1.01	2.52	<b>49.5</b>	45.25	0.25	1.25	<b>1.25</b>	0.00	<b>0.75</b>	0.25	0.00	1.50
Bröl_2	<b>1.31</b>	<b>0.92</b>	<b>9</b>	<b>1.33</b>	<b>4.12</b>	5.00	<b>68.5</b>	<b>9.00</b>	<b>2.75</b>	0.75	<b>2.50</b>	0.25	<b>2.25</b>	<b>1.00</b>	<b>8.00</b>

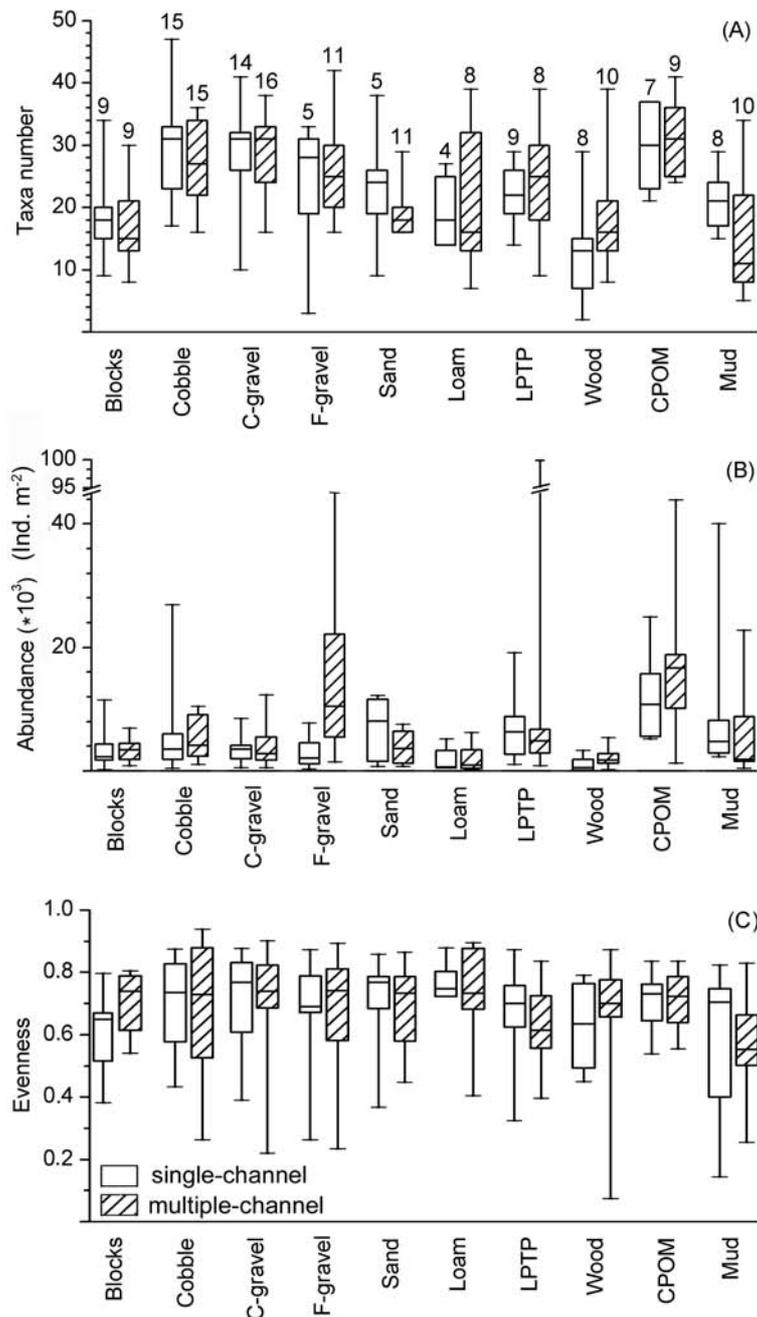
### 3.4.2 Overview of macroinvertebrates communities

In total 182 taxa were found at the 14 stream sections. This results in 163 taxa, when taxa only found in one sample with one individual are omitted – these data were used for further analyses; data are given in brackets. 48,947 individuals (extrapolated to 82,540 individuals from subsampling) in 69 (66) families were identified in the 199 samples. The mean density was 6,631 individuals  $m^{-2}$  (ranging from 113 to 100,720). The most diverse groups were Trichoptera [44 (40) taxa], Coleoptera [42 (36) taxa], Diptera [25 (21) taxa] and Ephemeroptera [23 (22) taxa]. The average number of taxa per sample was  $23.48 \pm 8.96$  (ranging from 2 to 47). All taxa lists are provided as Appendices 3–9.

29 taxa were found in only one or two of the samples (1% of the samples), and 105 taxa were found in less than 20 samples (10% of the samples). The dominant taxa were mainly Chironomidae and Crustacea, the ten most abundant taxa account for 73% of the individuals. These taxa were also very frequent in the samples.

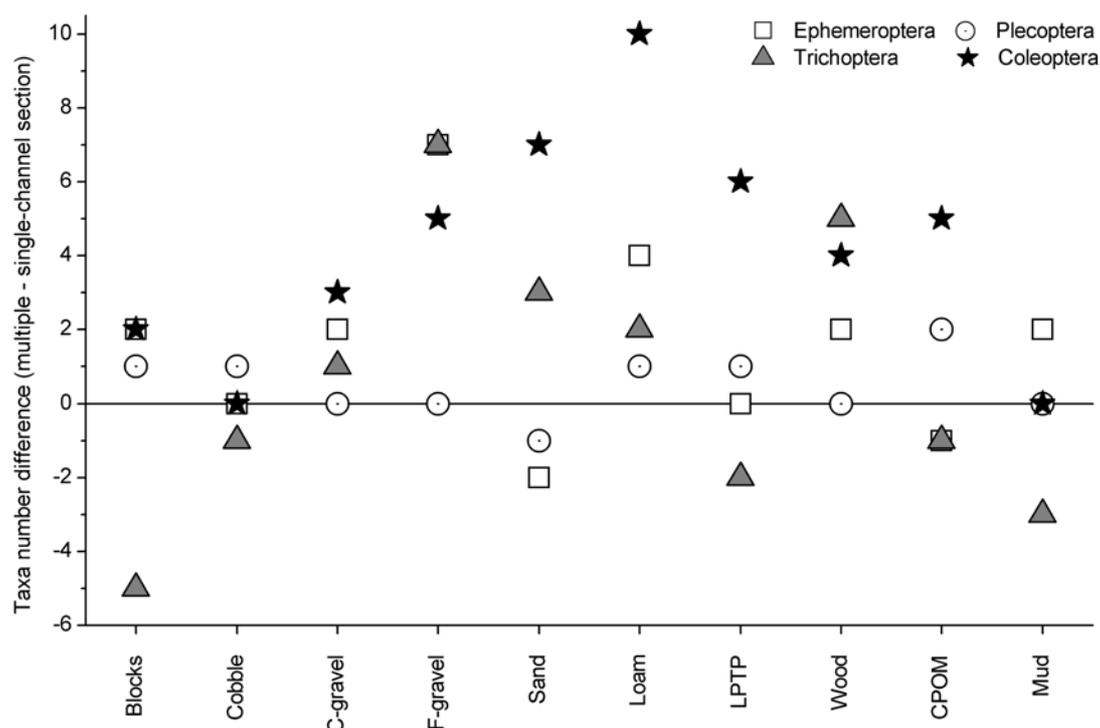
### 3.4.3 Substrate-specific communities

The lowest (mean) number of taxa can be found on wood and blocks (Figure 3-1, A). The highest number of taxa are found in the mineral substrates such cobbles, coarse and fine gravel, together with CPOM. Taxa numbers on substrates in multiple-channel sections do not significantly differ from their single-channel section counterparts. The abundances of the samples show a stochastic distribution (Figure 3-1, B). Highest abundances are found on fine gravel and CPOM of the multiple-channel sections. Despite the fact that fine mineral and organic substrates increase in the multiple-channel sections (Table 3-3), abundances do not differ for substrates sampled in different channel forms. Average evenness of all samples is 0.68 (Figure 3-1, C). Multiple-channel substrates have highest mean evenness in blocks, coarse gravel, loam and CPOM. The Mann-Whitney-U-test between single- and multiple-channel groups is not significant for any set.



**Figure 3-1.** Mean community metrics (taxa number, abundance, evenness) for substrates in single- and multiple-channel sections. Sample n for substrates indicated in (A) only and valid for (A), (B), (C).

Coleoptera and Trichoptera are the groups contributing the most to the few differences observed for taxa numbers (Figure 3-2). Coleoptera show highest dissimilarity, with up to ten additional taxa and never fewer taxa found in the multiple-channel sections. For Ephemeroptera up to seven additional taxa are found, with a mean of 1.6 additional taxa; in sand and CPOM fewer taxa were recorded. Trichoptera have up to seven more taxa in fine gravel, but otherwise more or fewer taxa occur equally. Plecoptera, the order with the overall fewest taxa, have only one or two taxa more in the multiple-channel sections.



**Figure 3-2.** Taxa number difference of four insect orders. Multiple-channel taxa number - single-channel section taxa number. Substrate abbreviations see Table III.

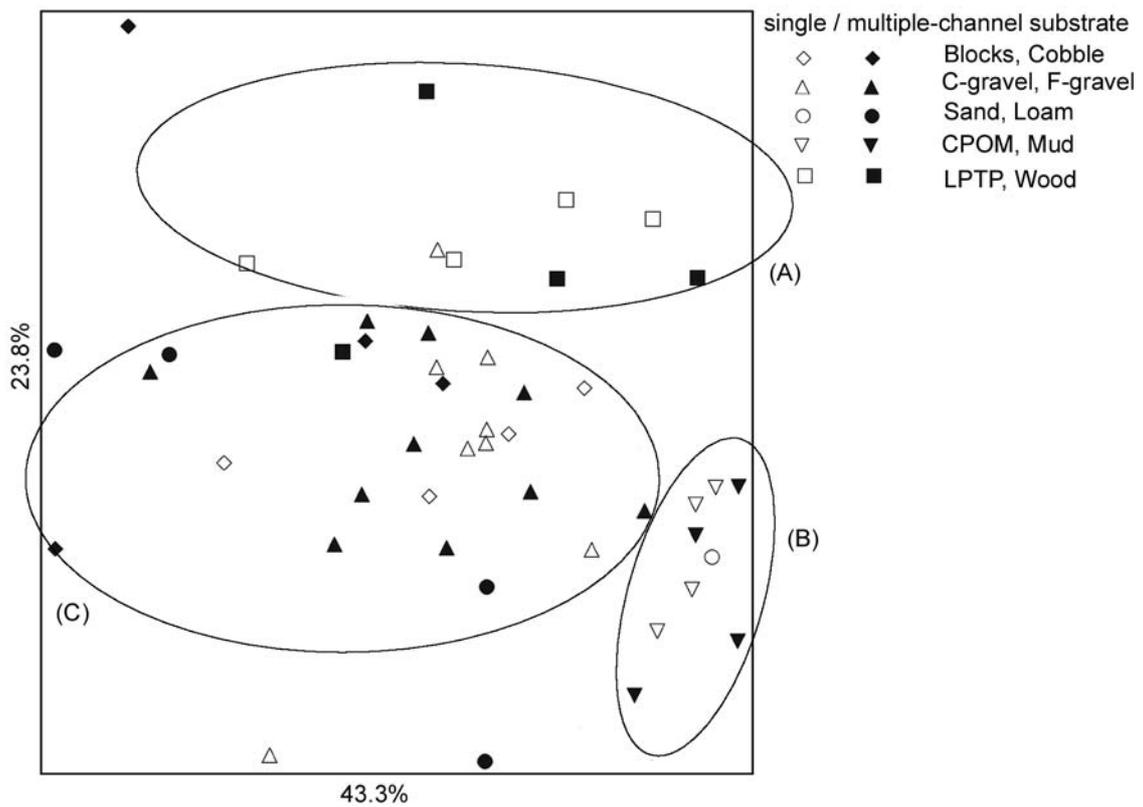
#### 3.4.4 Substrate-specific communities at single- and multiple-channel sections

For the sites Lahn-C and Orke the macroinvertebrate communities in the most dominant substrate – coarse gravel for Lahn-C and cobbles for Orke – do not differ between the single- and multiple-channel sections (Table 3-4). The mean dissimilarity between samples from single- and multiple-channel sections is less than 50% for both. When within- and between-stream section dissimilarities are compared, the Orke has a 3% higher mean between-group dissimilarity than within-group dissimilarity. This implies a small difference of the macroinvertebrate communities of different stream sections. Lahn-C shows no differences in that respect.

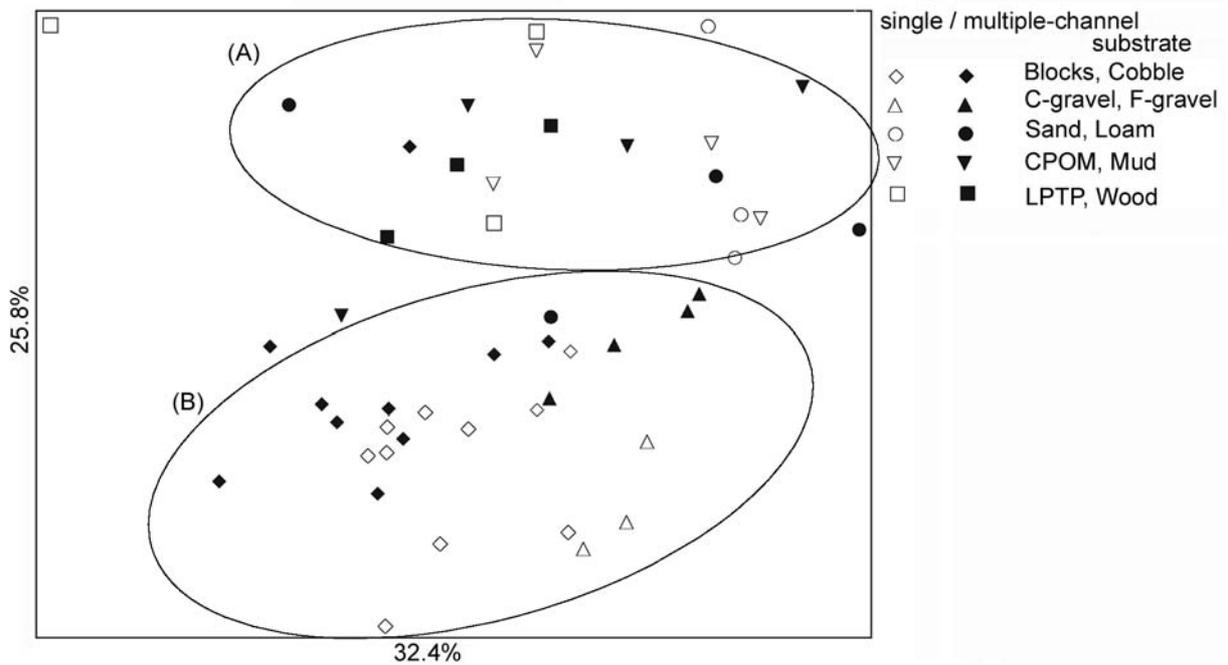
**Table 3-4.** Mean community metrics (taxa number, abundance, evenness, dissimilarity) in dominant substrates at Lahn-C and Orke. n=8; t-test not significant.

	Taxa number	p	Abundance (Ind. m <sup>-2</sup> )	p	Evenness	p	Between-group dissimilarity (Bray-Curtis Index)
Lahn-C single (c-gravel)	28.3		209.8		0.81		47.63
Lahn-C multiple (c-gravel)	26.1	n.s.	209.3	n.s.	0.78	n.s.	
Orke single (cobble)	31.5		381.8		0.71		49.11
Orke multiple (cobble)	24.8	n.s.	318.8	n.s.	0.68	n.s.	(p<0.1)

The results of the NMS-analyses of the Lahn-C and Orke samples are shown in Figure 3-3 and Figure 3-4. The ordination results suggest similar communities in substrates of single- and multiple-channel sections. For the sites two or three groups can be identified.



**Figure 3-3.** NMS graph of macroinvertebrate communities at site Lahn-C. Comparison of substrate groups in single- and multiple-channel section. Stress: 13.3; MRPP mean between-group dissimilarity: 61%.



**Figure 3-4.** NMS graph of macroinvertebrate communities at site Orke. Comparison of substrate groups in single- and multiple-channel section. Stress: 13.7. MRPP mean between-group dissimilarity: 66%.

The topmost part of Lahn-C (Figure 3-3) shows communities in the substrates living parts of terrestrial plants and large wood (Group A). In the lower right corner, communities of finer and lighter substrates such as organic mud and CPOM are displayed (Group B), and an intermediate part summarises various mineral substrates (Group C). For the Orke site (Figure 3-4), a group comprised of organic substrate samples (CPOM, mud, large wood and living parts of terrestrial plants; Group A), and a large group of mineral samples (Group B) can be identified. For both sites, substrates taken in the single- or multiple-channel section cannot be differentiated from one another. Analyses of within- and between-group dissimilarity for both streams distinguish between substrate groups with dissimilarities of 61 and 66% respectively. These results support the graphical assumptions, that substrates are colonised differently but difference between substrates of single- and multiple-channel sites are minor.

Analogous results are obtained from dissimilarity analyses of section-pooled substrate samples (Table 3-5). For the substrate groups, differences are larger on average between the groups than within the groups (ratio of 1.1). This is not true for single- and multiple-channel differences, where this ratio is close to 1. Recapitulating the hypothesis, alpha-diversity is not influenced by the channel form being either single- or multiple-channel.

**Table 3-5.** Within- and between-group dissimilarity of section-pooled substrate samples. (A) difference between substrate groups independent of channel form; (B) differences between substrate groups in single- and multiple-channel sections separately. ratio = ratio of between- and within-group dissimilarity of substrates. Asterisks indicate level of significance: \*\*  $p < 0.05$ ; \*  $p < 0.1$ ; n.s. = not significant.

(A)	Block / Cobble	C-gravel / F-gravel	Sand / Loam	Wood / LPTP	CPOM / Mud
n	48	46	28	35	34
within	0.59	0.57	0.68	0.67	0.64
p			**		
between			0.68		
ratio			1.10		
(B)	Block / Cobble	C-gravel / F-gravel	Sand / Loam	Wood / LPTP	CPOM / Mud
n (single)	24	19	9	17	15
within	0.59	0.57	0.65	0.69	0.57
n (multiple)	24	27	19	18	19
within	0.58	0.58	0.68	0.64	0.68
p	*	n.s.	*	n.s.	*
between	0.59	0.57	0.68	0.66	0.64
ratio	1.01	1	1.01	1	1.01

### 3.4.5 Nestedness

Single-channel and multiple-channel sections are similar in their mean T (Mann-Whitney-U-test not significant) (Table 3-6). The multiple-channel sections of Orke, Nims and Lahn-W have a higher T (i.e. less predictability) compared to their single-channel control stream sections. This is in accordance with the aforementioned hypothesis. The single-channel section of the Eder is not likely to have a nested structure.

**Table 3-6.** Nestedness analysis for single- (1) and multiple-channel (2) sections. Rows sorted according to ascending System T. If  $T < T_{\text{calc}}$  and  $p < 0.1$  the community can be stated nested. Bold section names are in accordance with hypothesis  $T_{\text{single-section}} < T_{\text{multiple-section}}$  of a site. Fill (%) = presence (%) in the section taxon matrix; T = system temperature;  $T_{\text{calc}}$  = system temperature generated by Monte Carlo randomisation (500 iterations).

	No. samples	No. taxa	Fill (%)	T	$T_{\text{calc}}$ (mean $\pm$ SD)	p
<b>Orke_1</b>	23	113	22.0	22.7	61.2 $\pm$ 2.6	<0.05
Orke_2	28	115	21.0	24.2	60.7 $\pm$ 2.6	<0.05
Lahn-C_2	28	96	24.2	26.3	64.4 $\pm$ 2.8	<0.05
<b>Nims_1</b>	10	78	30.0	27.0	55.6 $\pm$ 4.4	<0.05
<b>Lahn-W_1</b>	11	79	33.2	27.4	59.2 $\pm$ 4.0	<0.05
Lahn-LH_2	13	66	27.3	29.2	57.5 $\pm$ 4.4	<0.05
Lahn-C_1	21	94	27.4	29.9	64.9 $\pm$ 3.1	<0.05
Bröl_2	13	74	31.8	33.8	60.3 $\pm$ 4.2	<0.05
Lahn-W_2	8	62	29.8	34.6	51.0 $\pm$ 5.8	<0.05
Eder_2	11	76	25.0	34.8	52.7 $\pm$ 4.7	<0.05
Bröl_1	7	49	41.1	39.5	51.5 $\pm$ 5.7	<0.05
Lahn-LH_1	7	56	41.5	44.7	52.7 $\pm$ 5.5	<0.1
Nims_2	10	74	32.0	45.7	57.2 $\pm$ 4.4	<0.05
Eder_1	7	74	29.3	49.4	49.2 $\pm$ 5.7	n.s.

Table 3-7 summarises the substrate nestedness analysis. Mean T is equal for single- and multiple-channel sections (Mann-Whitney-U-test not significant). The formulated hypothesis, that nestedness is higher, i.e. T is lower, for the various substrates of multiple-channel sections, is not supported. The substrates mud, loam, blocks, and living parts of terrestrial plants have a lower T when found in the multiple-channel sections. Five samples (at the end of the table) are not nested. These are mostly organic substrates (mud, living parts of terrestrial plants, CPOM, loam), four of which are from single-channel sections.

**Table 3-7.** Nestedness analysis for single- (1) and multiple-channel (2) substrates. Rows sorted according to ascending System T. If  $T < T_{calc}$  and  $p < 0.1$  the community can be stated nested. Bold stream section names are in accordance with hypothesis  $T_{multiple-section} < T_{single-section}$  of a site. Fill (%) = presence (%) in the substrate taxon matrix; T = system temperature,  $T_{calc}$  = system temperature generated by Monte Carlo randomisation (500 iterations).

	No. samples	No. taxa	Fill (%)	T	$T_{calc}$ (mean $\pm$ SD)	p
<b>Mud_2</b>	10	64	23.9	16.7	50.5 $\pm$ 5.3	<0.05
F-gravel_1	5	52	44.2	20.2	44.9 $\pm$ 5.8	<0.05
Wood_1	7	50	25.7	22.0	46.3 $\pm$ 6.4	<0.05
Sand_1	5	54	34.0	23.3	47.1 $\pm$ 7.8	<0.05
<b>Loam_2</b>	8	73	31.1	26.5	52.4 $\pm$ 4.9	<0.05
Wood_2	10	79	23.5	28.7	50.2 $\pm$ 4.8	<0.05
<b>Blocks_2</b>	9	60	28.5	31.0	52.1 $\pm$ 5.8	<0.05
<b>LPTP_2</b>	8	74	34.1	32.1	54.9 $\pm$ 5.1	<0.05
Blocks_1	9	63	26.6	33.3	50.2 $\pm$ 5.3	<0.05
C-gravel_1	14	89	33.0	36.2	63.2 $\pm$ 3.7	<0.05
C-gravel_2	16	89	31.8	36.4	64.6 $\pm$ 3.4	<0.05
Cobble_1	14	93	30.3	36.7	62.2 $\pm$ 3.5	<0.05
Cobble_2	15	84	32.7	37.8	63.7 $\pm$ 3.4	<0.05
F-gravel_2	11	79	31.7	44.2	58.3 $\pm$ 4.4	<0.05
Sand_2	11	72	25.3	46.5	53.5 $\pm$ 4.7	<0.1
Mud_1	8	60	30.6	47.2	52.6 $\pm$ 5.7	n.s.
LPTP_1	9	71	29.1	47.9	53.2 $\pm$ 5.1	n.s.
CPOM_1	7	83	34.2	50.7	52.3 $\pm$ 5.1	n.s.
Loam_1	4	56	36.1	51.0	41.9 $\pm$ 7.1	n.s.
CPOM_2	9	91	31.7	51.4	55.6 $\pm$ 4.4	n.s.

### 3.5 Discussion

#### 3.5.1 Hydromorphological diversity

Morphological diversity increases at the multiple-channel sections at all scales. The paired sections differ in terms of overall and aquatic width in particular. Additional channel features occur in the multiple-channel sections as a consequence of the removal or absence of bank fixation and more open space for the stream. Depth and current velocity variability, as well as substrate distribution, are strongly influenced by the site location and surrounding environment. For example, the high diversity of depth and current velocity values at the single-channel sections of Lahn-W and Nims can be attributed to weirs located downstream of the investigated stream sections. These impound the water and lead to a wide range of depth and current velocity values. As single-channel substrates are monotonously distributed, and substrate arrangement in multiple-channel sections is much more diverse, metrics summarising the composition and spatial arrangement are better suited to describe the higher habitat

diversity in the multiple-channel sections. The rate of increase does not greatly differ for frequent substrates such as cobbles or coarse gravel or rare substrates of finer grain size or organic type (Table 3-3). Although habitats show a greater resemblance to reference conditions in the multiple-channel sections, many of the interacting large-scale parameters have not been tackled to the same extent (if at all), so the small scale natural patterns do exist, but presumably not yet in their near-natural range (Thomson *et al.*, 2001; Molnar *et al.*, 2002).

### 3.5.2 *Substrate-specific communities*

The analysed samples follow the common principle of different communities on different substrates (Jenkins *et al.*, 1984; Beisel *et al.*, 2000; Harrison *et al.*, 2004; Grafahrend-Belau and Brunke, 2005). They show characteristics comparable to those determined by Beauger *et al.* (2006), who found similar taxa richness in mineral and vegetation substrates, but large differences in density, which was much lower in mineral substrates. This pattern supports the idea of rich structured substrates providing refuge for prey. The data show the highest taxa numbers and highest evenness for cobbles and coarse gravel substrates, which is also congruent with the results described by Harrison *et al.* (2004). The special relevance of certain substrates in streams has been observed many times, where organic substrates such as large wood or living parts of terrestrial plants act as colonisation substrates, which give stable ground in faster flowing areas, offer biofilm for grazers, and feed the detritus pool. Such a community sustains predators as well. The rich structure and the highly complex surface of these substrates accounts for the higher abundances observed (Hoffmann and Hering, 2000). This is also reflected in my data with high taxa numbers and high abundances for living parts of terrestrial plants and CPOM.

### 3.5.3 *Substrate-specific communities at single- and multiple-channel sections*

This chapter is aimed at answering the question whether macroinvertebrate communities differed in substrate samples taken in multiple-channel sections, compared to substrate samples taken in the single-channel sections of the same stream. It was reasoned that increased habitat diversity would result in a differentiated colonisation of the same substrate. When the number of patches of the substrate mosaic increases, habitats at the macroinvertebrate scale are assumed to be more varied. The macroinvertebrate community might then be more diverse, because a higher number of taxa can find convenient ecological niches (Beisel *et al.*, 1998a).

Results from the more frequently sampled substrates at the sites Lahn-C and Orke, as well as samples from the other sites, suggest that there is no variation between substrates of single- or multiple-channel sections. Differences in taxa number, abundances, and evenness are not significant. The most dominant substrates cover the largest part of the stream bottom and are not greatly influenced by the habitat diversification (Table 3-3). Ordination of macroinvertebrate samples that were pooled according to substrate size reflects these substrate groups visually and statistically (Figure 3-3, Figure 3-4, Table 3-5). Some differences between samples from single- and multiple-channel sections occur (data not shown), but results are seen as not yet credible, either because the sample size was rather small (4 samples each for Lahn-C and Orke) or differences are in the range of 1%, i.e. exiguous. Macroinvertebrate communities in multiple-channel sections might thus differ because of a higher beta-diversity due to a different substrate composition, and not because of an increased alpha-diversity of the various substrates. But overall differences are small. The reasons for this not yet complete diversification are seen in spatially and temporally variable habitat forming processes, acting at different scales and above all, not yet being clearly understood.

**The micro-scale insufficiency:** Macroinvertebrate community structure is dependent on substrate diversity and patch spatial configuration (Beisel *et al.*, 2000). Thus higher substrate numbers with similar relative areas promote higher taxa numbers and evenness as is shown in several studies (Boyero, 2003; Brown, 2003; Beauger *et al.*, 2006). In this study added or increased substrates in the multiple-channel sections might not (yet) differ sufficiently from habitats in the single-channel sections. One indication for this are the similar substrate numbers in most of the single- and multiple-channel sections (Table 3-3). Only few invertebrates were added to the species pool, which were not present in other substrates (1–10 at the most: Figure 3-2). However, taxa that were already common on other substrates became more abundant. Corresponding experiences have been made in a post restoration study by Friberg *et al.* (1998), who found different communities in substrate types, but did not observe an effect attributable to restoration. A trend towards higher macroinvertebrate abundances, as reported by Boyero (2003), is at least partially true for the samples (Figure 3-1, B). However, abundance is the biological descriptor least influenced by the surrounding bottom heterogeneity (Beisel *et al.*, 1998a), which in this study is reflected by highly variable abundances. Due to the plasticity of response by many lotic macroinvertebrates, the apparent changes in physical habitat lie within the normal physical tolerance of taxa living in unrehabilitated sites.

**The macro-/meso-scale prevalence:** While particular substrates have partially distinct communities, this does not imply that those communities would be recreated by substrate recreation (Hughes, 2007). Habitats might easily be restored and later located as distinct substrate and flow patches, and they might further indicate the potential for processes such as primary productivity, respiration, and nutrient cycling (Clarke *et al.*, 2003), but the extent of their influence on the communities is not clear. The restoration of functional habitats such as riffles and pools has no or only a small influence on taxon richness and abundance (Harrison *et al.*, 2004). There are many processes acting at larger scales, which influence the complex life cycles of macroinvertebrates, e.g. different life stages use different parts of the aquatic and riparian environment (Bond and Lake, 2003). These requirements might not yet be fulfilled in the investigated sections and streams.

In addition to the various factors that govern biodiversity such as disturbance regime, habitat heterogeneity, and productivity, substantial effect might emanate from the ecotone frequency, described as an optimal mix of patch size and edge habitat. It is likely that in the investigated stream sections edges are still too big, so that the new or increased habitats do not have a large enough centre to support their own communities (Ward *et al.*, 1999).

**The meta-population simplicity:** Local number of taxa or macroinvertebrate colonisation rates are directly proportional to prevailing local numbers of individuals and taxa (Marchant *et al.*, 1991), but only little is known about the colonisation dynamics and habitat perception and selection at species level. If restored stream channels are considered as islands to be colonised, then the main factors governing this process – 'source distance' and 'stepping stone availability' – deserve attention (Gore, 1985). The study sites are all located in mountainous regions of Western Germany, pressured by land use with 10-15% urban high density, up to 30% agricultural, around 60% forested areas (Kail *et al.*, 2006) and the restored stream sections are only short. Multiple-factor impairments and cumulative alterations of the sites are common (Rabeni, 2000), and distances to possible re-colonisation sources are far. The size of the restored sections might be too small or stepping stones too scarce to sustain viable meta-populations.

**The deficient reference:** Although the investigated multiple-channel sections are characterised by higher hydromorphological and habitat diversity, these structures might occur in other abundances in unimpaired, natural streams. A large set of reference communities for the investigated stream type is lacking, because they are no longer available (Rabeni, 2000). Harper *et al.* (1998) stress the impact of the many variations of highly variable environmental conditions caused by natural stream systems with a network of active and abandoned

channels, their complex micro-environments and a cumulative impact on the whole system (Boyero, 2003). It is likely that physical and biological recovery at the restored stream sections of this study might have been incomplete for the time being.

#### 3.5.4 *Nestedness*

Nestedness is a measure of predictability. If nestedness is high, the few species present in certain substrates will be those that are found everywhere, so only larger or more taxon-rich sites will support the more uncommon species (Patterson, 1987). Nestedness is viewed from two perspectives with a contradictory presumption regarding the multiple-channel situation. For the perspective of the site, I hypothesised nestedness and accordingly predictability should be lower in the multiple-channel sections, as the species pool would be increased and various substrates colonised differently. This was true for three sites, but overall not significant. This result is partially explained by a bias of the software, as every analysis maximally packs the taxa-section matrix and zero-frequent taxa are excluded, so different taxa may be excluded for single- and multiple-channel sections.

The results do not support previous suggestions of aquatic invertebrates being an exception to the principle of nestedness (Boecklen, 1997). But as many stream taxa are remarkably mobile and rapidly colonise habitat after disturbance an overall higher system temperature is characteristic (Atmar and Patterson, 1993; Malmqvist and Hoffsten, 2000). For example M'Closkey and Hecnar (1997) and Tockner *et al.* (2006) found much lower System T for amphibians, with temperatures well below 20; Atmar and Patterson (1993) calculated temperatures of below 10 for mammals and birds. The obtained results here are in the range of other studies found for aquatic macroinvertebrates e.g. by Schmera (2004) with T above 40 or by Yoshimura *et al.* (2006) with T of 30–40. The Orke has the lowest temperatures, and the smallest difference between single- and multiple-channel sections, together with the highest taxa number. This result is consistent with the equivocal results of the hydromorphology (see Chapter 1). The reason for this is seen in the comparably small land use pressure in this catchment, which leads to a relatively good status at the single-channel sections as well.

The substrates' perspective envisaged a higher nestedness in the various substrates of multiple-channel sections, because higher differentiation occurs. This pattern is confirmed for four substrates, three of them are organic substrates, suggesting that communities are currently becoming more specific in these habitats. These substrates play a major role in multiple-channel sections.

### 3.5.5 *Conclusions and implications*

Communities on alike substrates in single- and multiple-channel sections showed only minor differences. Despite higher habitat diversity alpha-diversity has not been changed. On the contrary, the substrates have different communities, meaning that beta-diversity of a section can be influenced. Numbers of invertebrate taxa on organic and mineral substrates are independent of patch size, i.e. substrates occurring only in small fractions (small grain sizes, organic substrates) have comparable taxa numbers and abundances. Nestedness is also unable to distinguish between stream sections and substrate samples of single- or multiple-channel sections, resembling these results. For implementation or evaluation of stream restoration projects this enforces focus on the creation or availability of high quality habitats, such as large wood.

Influences from other scales seem to be more important and restoration might have partially failed as certain important habitats have not been sufficiently restored to their full extent. Hydrological and sedimentation processes have not been consciously tackled. Stream restoration itself should not be condemned, merely because results obtained in various studies (Pretty *et al.*, 2003; Harrison *et al.*, 2004; Lepori *et al.*, 2005; Nilsson *et al.*, 2005) do not show the anticipated results, but rather the challenge to improve the results should be accepted. Furthermore, in-stream restoration serves multiple purposes, including landscape aesthetics and ecological functioning, and might be justified even where benefits to biodiversity fall short of one's expectations (Lepori *et al.*, 2005).

There are three tasks remaining: (1) To investigate the naturally occurring substrate composition in multiple-channel streams, and (2) to restore streams to a larger extent while (3) testing if the mentioned deficiencies were the missing parts in the investigated streams.

## **4 Habitat – Community Relationships in Multiple-channel Sections**

### **4.1 Abstract**

Seven pairs of single- and multiple-channel sections in German lower mountainous areas were compared in terms of hydromorphological diversity and their macroinvertebrate communities. The stream sections were characterised by 16 hydromorphological metrics at various scales, e.g. shore length, channel feature or substrate diversity, flow variability and substrate area. Community data were subject to similarity and cluster analyses as well as correlation analyses. Macroinvertebrate communities were described by 35 faunal and functional metrics, which included taxa number, abundance, feeding type, habitat and current preference among other metrics. Spearman rank correlation was calculated for combinations of hydromorphological and biological metrics. A priori, expected direction of correlation ("positive" or "negative") were formulated, and then compared to actual *r*-values. Micro-scale morphological metrics, such as certain substrates areas and substrate spatial diversity, showed consistent correlations with biological metrics, as did several meso- and macro-scale metrics like aquatic width and shore length. The biological metrics percentage of shredders, number of taxa, percentage of littoral preference and the percentage of current preference (rheo- to limnophil and rheobiont) showed the most consistent correlations with metrics of hydromorphological diversity. The metric percentage of rheobiont taxa (current preference) showed the expected negative correlation to multiple-channel sections, indicating that a higher proportion of low flow habitats is present. Other metrics were positively correlated with metrics of hydromorphological diversity, thus, with increasing morphological diversity, the biological metric values increased as well. Bray-Curtis similarity was very high (69–77%) between communities of single- and multiple-channel sections. Differences between stream sections can be attributed to single taxa, occurring only at either the single- or multiple-channel sections. These exclusive taxa were mainly found on organic substrates such as living parts of terrestrial plants, large wood, coarse particulate organic matter (CPOM) and mud. Reasons are discussed why macroinvertebrate communities from single- or multiple-channel sections cannot be distinguished, including influence of large scale catchment pressures, size of restoration measures and lack of potential re-colonisers.

## 4.2 Introduction

Spatial and temporal heterogeneity across various scales are key elements of aquatic systems (Wohl *et al.*, 2005). This heterogeneity has been widely suppressed by river regulation, by floodplain alteration and total catchment occupation. As European policy began to recognise the value of ecological intact river ecosystems, the Water Framework Directive (WFD) was developed and put into action in 2000 (EC, 2000). The overall goal of the WFD requires a "good ecological status" of all streams by 2015. Today this is far from being achieved. The recently completed first river basin analyses for Central Europe revealed that 80% of the streams would fail the WFD requirements due to "poor hydromorphology" (e.g. BMU, 2005; ICPDR, 2005; ICPR, 2005). This inevitably calls for restoration measures to improve stream hydromorphology. The increasing necessity to restore streams and rivers for legal, ecological, economical and safety reasons – consider flood problems induced by climate change (Clewell and Aronson, 2006) – have made riverine systems a priority when considering policy, ecology and application (Gore and Shields, 1995; Wohl *et al.*, 2005; Newson and Large, 2006; Peter, 2006).

Restoration measures should be orientated at the natural or near-natural situation (Palmer *et al.*, 2005). In about 45% of German lower mountainous areas, catchment geology, slope and discharge characteristics would support multiple-channel streams (LUA NRW, 2001a; Sommerhäuser and Pottgiesser, 2005). These streams create a network of active and abandoned channels within the relevant floodplains. Restoration measures often try to increase habitat diversity at various scales, which is assumed to affect the fauna as well. Positive results in terms of increased habitat heterogeneity are numerous (Muotka *et al.*, 2002; Moerke *et al.*, 2004; Chapter 1 and 2), but the biological implications, especially in terms of benthic macroinvertebrates used for stream assessment, remain unclear.

Many studies report dependencies of macroinvertebrate diversity, abundance, traits or productivity with patch number, substrate number, surface-perimeter ratio (Beisel *et al.*, 1998a; Beisel *et al.*, 2000; Lancaster, 2000), mesohabitat formation (Pardo and Armitage, 1997) or large scale influences (Sponseller *et al.*, 2001; Chaves *et al.*, 2005; Martel *et al.*, 2006). But few studies actually show distinct changes due to riverine habitat restoration and are rather precautionous in accrediting any effect to it (Pretty *et al.*, 2003; Harrison *et al.*, 2004; Lepori *et al.*, 2005; Jansson *et al.*, 2007).

In the previous Chapter, micro-scale changes of aquatic habitat diversity on substrate-specific macroinvertebrate communities were investigated. Effects were found to be exiguous, with most differences occurring between habitats, thus stressing the importance of the re-estab-

lishment of new and high quality habitats. But the effect of a stream section representative of a given hydromorphology on the community has not been investigated so far.

Based on hydromorphological differences, this chapter aims to refine differences between the macroinvertebrate communities in single- and multiple-channel sections and to analyse the relationship between morphological and biological characteristics inherent to the macroinvertebrate community. Two hypotheses were formulated beforehand:

- A greater number and more varied mosaic of aquatic habitats support a higher macroinvertebrate diversity within the multiple-channel sections.
- Biological traits of the macroinvertebrate community (e.g. diversity, abundance, habitat preferences, current preferences, feeding types) are correlated to morphological features on various scales.

### **4.3 Material and Methods**

#### *4.3.1 Study sites*

The study sites have been described in Chapter 1 (Figure 1-1, Table 1-1) and only key information will be given here. The streams are located in the German Federal States of Hesse, North Rhine-Westphalia and Rhineland-Palatinate. They comprise the upper parts of the rivers Lahn and Eder, and tributaries to the Sieg and Mosel, which are tributaries to the Rhine and Weser. The catchments at the sampling sites range from 180 to 650 km<sup>2</sup>. The catchment geology mostly comprises acid rock (schist), with the exception of the Nims. Land use in the study catchments consists of forest (60%), pasture and agriculture (30%) and about 10% urban areas (Corine land cover data Germany, 2000). The research design followed a paired-site study: in the spring and summer of 2004 and 2005 seven multiple-channel sections were compared to nearby straightened single-channel sections for differences in hydromorphology and stream macroinvertebrate communities. The multiple-channel sections either resulted from restoration measures (Lahn-W, Lahn-LH, Lahn-C) or developed in less intensively maintained floodplain sections (Orke, Eder, Nims and Bröl) (Table 1-1). They are single outstanding stream sections within a largely uniform single-channel environment.

#### *4.3.2 Hydromorphological measurements and analyses*

A stretch of approximately 200 m was investigated at each section. Along 20 equidistant transects running between the left and right edge of the embankments the width of channel features were measured (Chapter 1; Table II). Along the transects at 20 points (limited to the aquatic areas) current velocity, water depth and substrate type, according to substrate

types used in multi-habitat sampling procedure (Hering *et al.*, 2003), were recorded, to determine each section's relative substrate composition. At the site Lahn-W investigations were limited to 16 transects per section, due to limited access to the riverbed. Depth was measured with a 2-m rule, fixed to a surveying pole; measuring accuracy was to the centimetre. Accessibility was limited to 140 cm; greater water depth values were standardised to 145 cm. Current velocity was measured using a Schiltknecht MiniAir2 device with a MiniWater20 Mini water sensor, which automatically calculates a 6-second mean from 0.5-second values within a measurement range from 0.02–5 m s<sup>-1</sup>. Calculation of 12 hydromorphological metrics was identical to Chapter 1 but differed for substrate proportion summation. Substrate types were weighted according to their (co-)occurrence at a given point. They were weighted 3-fold, if the substrate covered more than 60% of the relevant area. Another substrate type was recorded as sub-dominant, if present with 40–50%, or at steep banks when large tree roots or living parts of terrestrial plants added other substrates than the bottom ones. Substrates were recorded as additional substrate type, if floating macrophytes, logs or algae were covering the bottom or bank substrate. Substrate composition was then calculated by multiplying the records by 3, by 2 and by 1 appropriately. Substrates were summarised and standardised to 100%.

Indirect gradient analyses using the software package CANOCO 4.51 (Ter Braak and Smilauer, 2003) were applied in order to detect hydromorphological gradients between single- and multiple-channel sections. Hydromorphological data were analysed by Detrended Correspondence Analysis (DCA) to determine the length of the gradient in the data sets and to choose an appropriate ordination technique. The length of the gradient is <2 for all data sets. Therefore, Principal Component Analysis (PCA) was applied (Jongman *et al.*, 1995).

### 4.3.3 Macroinvertebrate sampling and data preparation

Altogether 199 macroinvertebrate samples were collected in 2004 and 2005 using a shovel sampler (500 µm mesh size, 0.0625 m<sup>2</sup> sampling area). Each sample was kept separately and substrate, depth and current velocity were recorded prior to sampling. Generally, each individually available substrate was sampled once in the single-channel section and once in the multiple-channel section. Substrates occurring only in the multiple-channel section were sampled twice there. No substrate occurred solely in the single-channel section (Table 4-1). Samples were preserved in 70% ethanol and transferred to the laboratory, where sorting took place following the RIVPACS-sorting scheme (Murray-Bligh *et al.*, 1997). The organisms were identified to species level where possible, except Oligochaeta which were recorded as

such or identified to family level, and Chironomidae, identified mostly to family or tribus level. Prior to data analyses all taxa lists were adjusted to the same taxonomic identification level (Verdonschot and Nijboer, 2002).

**Table 4-1.** Number of substrate-specific macroinvertebrate samples taken. Samples of Lahn-C and Orke were taken in 2004, other samples in 2005. Randomly selected samples for Lahn-C and Orke from a larger data set (Table 3-1) are indicated in Appendices 3 and 4. Substrate abbreviations see Table III.

	Lahn-C		Orke		Lahn-W		Lahn-LH		Eder		Nims		Bröl	
	single	multiple	single	multiple	single	multiple	single	multiple	single	multiple	single	multiple	single	multiple
Blocks	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Cobbles	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C-gravel	1	1	1	1	1	1	1	1	1	1	1	1	-	2
F-gravel	-	2	1	1	-	2	1	1	-	2	1	1	1	1
Sand	-	2	1	1	-	2	-	-	-	-	1	1	-	2
Loam	1	1	1	1	1	1	-	-	-	-	1	1	-	2
Subm	-	-	-	-	-	-	-	2	1	1	-	-	-	-
LPTP	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Wood	1	1	1	1	1	1	-	2	1	1	1	1	1	1
CPOM	1	1	1	1	1	1	1	1	-	-	1	1	-	2
Mud	1	1	1	1	1	1	-	2	1	1	1	1	1	1
Sum	8	13	10	11	8	12	7	13	7	11	10	10	7	13

For a comparison of stream sections, a taxa list for each section was compiled from the single substrate taxa lists. For each substrate a mean list of the two subsamples was calculated, either by averaging a mean list of samples of the single- and multiple-channel section; or, if no sample for a particular substrate was collected from the single-channel section, by averaging two lists from the multiple-channel sections. The compilation of a mean list per substrate has been shown valid in Chapter 3 (Table 3-5), as benthic macroinvertebrate communities of substrates do not differ significantly between single- and multiple-channel sections. This mean substrate list was used for multiplying the abundance of each taxon with the fraction of the substrate at the section (differentiated in single- and multiple-channel). At last the lists were summarised. This produced 14 section taxa lists, always considering the relative substrate distribution. Important but area-limited habitats that are often not sampled in multi-habitat sampling procedures are this way included in each section's list (Rabeni, 2000).

Furthermore, conductivity ( $\mu\text{S cm}^{-1}$ ), temperature ( $^{\circ}\text{C}$ ), dissolved oxygen content ( $\text{mg l}^{-1}$  and %), and pH were measured at each stream section with WTW portable devices (Oxi-meter 197, Conductivity-meter 197 and pH-meter 197; Appendix 10).

#### 4.3.4 *Macroinvertebrate data analyses*

Stream section community taxa data were clustered using the software PC-ORD 4.41 (PC-ORD; McCune and Mefford, 1999) with the flexible beta linkage method (flexible clustering,  $\beta = -0.25$ ) and Bray-Curtis similarity as distance measures. Similarity was calculated with log-transformed abundance data. Differences within each stream section were calculated using the Multi-Response Permutation Procedures (MRPP) of PC-ORD and focussed on single- and multiple-channel differences. Differences between stream sections were calculated using the MEANSIM-calculator of Van Sickle (1998) to estimate within- and between-group dissimilarity of macroinvertebrate communities of single- and multiple-channel sections.

#### 4.3.5 *Spearman rank correlation*

Spearman rank correlation ( $r$ ) between hydromorphological and biological metrics was calculated for every stream section. The rationale was to investigate the overall importance of structural heterogeneity to the macroinvertebrate community, independently of single- and multiple-channel section categories.

The hydromorphological metrics reflect the multiple-channel conditions. They are proxies for the degree of naturalness, either from restoration processes or the natural development of a stream section (Table 4-2). Faunal and functional community traits – hereafter summarised as biological metrics – were calculated from the section taxa lists using the software ASTERICS 3.01 (ASTERICS, 2006). Biological metrics were chosen based on the expectation that they would react in some way to morphological changes, for example a different habitat situation or food supply. Hence metrics describing substrate preferences, current preferences, stream zonation preferences and others were considered for correlation analyses (Table 4-3).

**Table 4-2.** Hydromorphological metrics used for Spearman rank correlations. Explanation of metrics and reasoning for indicated correlation direction (r) (multiple-channel in comparison to single-channel). Details on metric calculation see Chapter 1.

Scale	Metric	Explanation	Direction r	Reasoning
Macro-scale	sect_ha	Section area (ha)	↗	Increased area available to the stream.
	shore	Length of all water-edges, e.g. to islands, bars	↗	Non-channelised flow, islands, bars and floodplain pools increase shore length.
	av_width	Mean width of a stream section	↗	Increased width available to the stream.
	aquatic_width	Mean width of all aquatic features	↗	Several stream channels, floodplain pools increase aquatic width.
Meso-scale	cf_no	Number of channel features	↗	Besides main channel and embankment also islands, bars, standing water bodies and others are available.
	cf_swi	Shannon-Wiener-Index channel features	↗	Number and relative width of channel features is more diverse.
	cv_depth	Coefficient of variation depth	↗	Increasing due to more diverse hydromorphology.
	cv_veloc	Coefficient of variation current velocity	↗	Increasing due to more diverse hydromorphology and current velocity conditions.
Micro-scale	su_no	Number of substrates	↗	Increasing due to fine mineral sedimentation and organic substrates available and sedimented.
	su_swi	Shannon-Wiener-Index substrates	↗	Number and relative amount of substrates is more diverse.
	su_sdi	Spatial-Diversity-Index substrates	↗	Spatial mosaic is more diverse.
Substrate area	block-cobble_A	Block and cobble	↘	As more fine mineral and organic substrates are available block or cobble substrate might decrease.
	gravel_A	Coarse and fine gravel	↗	As more fine organic and organic substrates are available gravel substrate might decrease.
	sand-loam_A	Sand and loam	↗	Increase due to low current velocities and sedimentation, as well as available erodible material.
	lptp-wood_A	LPTP and large wood	↗	Increase due to large wood from banks and floodplains is allowed to fall and remain in channels.
	cpom-mud_A	CPOM and mud	↗	Increase due to low current velocities and sedimentation.

**Table 4-3.** Biological metrics used for Spearman rank correlations. Metrics calculated by ASTERICS; explanation of metrics and reasoning for indicated correlation direction (r) according to ASTERICS software manual (multiple-channel in comparison to single-channel).

Trait	Metric	Explanation	Direction r	Reasoning
	abund	Abundance (Ind. m <sup>-2</sup> )	↗	Increase, might depend on habitat diversity.
	# taxa	Number of taxa	↗	Increase, might depend on habitat diversity.
	EPTCBO	Number of EPTCBO	↗	EPTCBO (Ephemeroptera, Plecoptera, Trichoptera, Coleoptera, Bivalvia, Odonata) is a subset of overall taxa number; increase as it depends on habitat diversity.
	evenness	Indicates reduction of dominant taxa	↗	As habitat diversity increases, dominant taxa are reduced.

Table 4-3 continued.

Trait	Metric	Explanation	Direction r	Reasoning
Microhabitat preference (percentage of community preferring a certain microhabitat)	[%] pel	Pelal: mud; grain size < 0.063 mm	↗	Mud will accumulate at more areas and will then be inhabited by specialised taxa.
	[%] psa	Psammal: sand grain size 0.063–2 mm	↗ or ↘	More diverse in-stream features allow for current velocity reduced areas, followed by deposition of sand. Decrease if area of block-cobble or gravel substrate are increasing.
	[%] aka	Akal: fine or coarse gravel; grain size 0.2–2 cm	↗	A more diverse substrate composition will support relevant taxa.
	[%] lit	Lithal: coarse gravel, stones, boulders; grain size > 2 cm	↗ or ↘	Lithal subsumes hard substrates, including wood; increases with higher morphological variability; might decrease if a high proportion of fine or organic substrates is present.
	[%] phy	Phytal: algae, mosses and macrophytes, living parts of terrestrial plants	↗	Taxa adapted to phytal as food or living resource mostly prefer low current velocity areas; macrophytes slow down the current and lead to an increasing number of taxa preferring lower current velocity.
	[%] aka+lit+psa	Sum of [%] aka, [%] lit, [%] phy	↗	Associated with increasing habitat diversity and mineral substrate diversity.
Feeding types (percentage of community)	[%] grazers_scrapers	Grazers and scrapers	↗	Might increase or not be influenced by a stream sections morphological status.
	[%] miners	Miners	↗	Associated with increased vegetation and available woody substrates.
	[%] xylophag	Xylophagous taxa	↗	Associated with increased availability of woody substrates.
	[%] shredders	Shredders	↗	Floodplain and riparian vegetation, inundation and flooding increase available particulate material.
	[%] gatherer_collectors	Gatherers and collectors	↗	Might increase or not be influenced by a stream sections morphological status.
	[%] active filtfeed	Active filter feeders	↗ or ↘	Varied effect, e.g. mussels might be mixed affected – shallow areas and too much sediment will result in sedimentation cover of the organisms.
	[%] passive filtfeed	Passive filter feeders	↗ or ↘	Varied effect, slow flowing effects might lead to a decrease.
	[%] predators	Predators	↗	Overall stable but different species might occur.
	[%] parasites	Parasites	↗	The parasitic community follows the overall increase of biodiversity.
	[%] other feedtyp	Other feeding types	↗	Might increase or not be influenced by a stream sections morphological status.
[%] xsap	Xylophagous taxa + Shredders + Active filter feeders + Passive filter feeders	↗ ↘	The metric depends on organic material input and a balanced substrate composition and distribution within the stream sections. Decreases when lithal areas are dominant.	

**Table 4-3 continued.**

Trait	Metric	Explanation	Direction r	Reasoning
Zonation (percentage of community preferring a certain zone)	[%] hypocrenal	Hypocrenal: spring-brook	↘	Hypocrenal taxa should not be affected or decrease due to increasing potamal areas in the stream sections.
	[%] epirhithral	Epirhithral: upper-trout region	↘	Decrease due to increasing potamal areas. Epirhithral taxa are adapted to high current velocities, coarse substrates, high oxygen content, low saprobic stress and low summer temperatures.
	[%] metarhithral	Metarhithral: lower-trout region	↘	Metarhithral taxa are associated with higher current velocity, high oxygen contents, low saprobic values, low summer temperatures. Multiple-channel sections have more low velocity areas, more open canopy i.e. higher temperatures and longer residual time of water.
	[%] hyporhithral	Hyporhithral: greyling region	↗	Increase, as taxa are adapted to hyporhithral zone of the streams, i.e. relatively high current velocities, mixed substrates and connectivity to the riparian areas.
	[%] epipotamal	Epipotamal: barbel region	↗	Epipotamal taxa are better than rhithral taxa adapted to lower current, finer substrates and low oxygen content.
	[%] metapotamal	Metapotamal: brass region	↗	Current is yet lower, substrates are fine, oxygen reduced, supporting potamal taxa.
	[%] littoral	Littoral	↗	Littoral organisms prefer low current velocities, fine substrates and high temperatures. They often additionally need submergent or emergent macrophytes.
Current preference (percentage of community preferring a certain current velocity)	[%] LP	Limnophil	↗	Preferably occurring in standing waters; avoid current; rarely found in slowly flowing streams.
	[%] LR	Limno to rheophil	↗	Preferably occurring in standing waters but regularly occurring in slowly flowing streams.
	[%] RL	Rheo to limnophil	↗	Usually found in streams; prefer slowly flowing streams and lentic zones; also found in standing waters.
	[%] RP	Rheophil	↗	Occurring in streams; prefer zones with moderate to high current.
	[%] RB	Rheobiont	↘	Occurring in streams; bound to zones with high current.
	[%] IN	Indifferent	↗	Taxa with no preference for a certain current velocity.
	even_curr	Evenness of current preference distribution	↗	The current preference distribution of the community will be more balanced, thus the evenness of it should increase.

A priori for each metric pair (altogether 560) an expected direction of the correlation was estimated, and could be either 1 for a positive correlation or -1 for a negative correlation.

In an abstraction step actual correlation results were transformed, independently of the significance level of the result:

- if  $r > 0.1$  the result was set to 1
- if  $r < -0.1$  the result was set to -1
- if  $-0.1 < r < 0.1$  the result was set to 0

The number of correlation results meeting the expectations was calculated. Results were sorted in descending order of number of "ok" results in rows and columns.

## **4.4 Results**

### **4.4.1 Hydromorphological diversity**

Hydromorphological variables were separated in morphological data and substrate area data to provide clearer analyses (Figure 4-1, Figure 4-2).

The first and second PCA axes of ten morphological metrics at the 14 stream sections (Figure 4-1) explain 89.8% of the variance in the morphological data set. Eigenvalues were 0.792 for the first and 0.106 for the second PCA axes (eigenvalues for the third and fourth PCA axes were 0.048 and 0.027, respectively). The first axis is interpreted as being strongly correlated to meso- and macro-scale parameters, such as stream section area, mean width or number of channel features. The second axis describes habitat features, it is positively correlated to substrate-specific parameters and negatively correlated to depth and current velocity variance. As the first axis has such a strong explanation value, the stream sections can be found in a left–right division.

The first and second PCA axes of the data on substrate metrics (area of 10 substrate types, Figure 4-2) explain 74.4% of the variance in the morphological data set. Eigenvalues were 0.559 for the first and 0.185 for the second PCA axes (eigenvalues for the third and fourth PCA axes were 0.091 and 0.071, respectively). The first axis is positively correlated to the area of blocks, and negatively correlated to coarse gravel and to area of wood. The second axis is only vaguely correlated to amount of various organic and mineral substrates, such as sand and living parts of terrestrial plants, and negatively correlated to mud and cobble. Most single-channel sections can be found according to their amount of large mineral substrates in the right part of the diagram. Smaller mineral and organic substrates are characteristic for the multiple-channel sections.

The existing gradients displayed for both data sets qualifies for correlation analyses involving macroinvertebrate data.

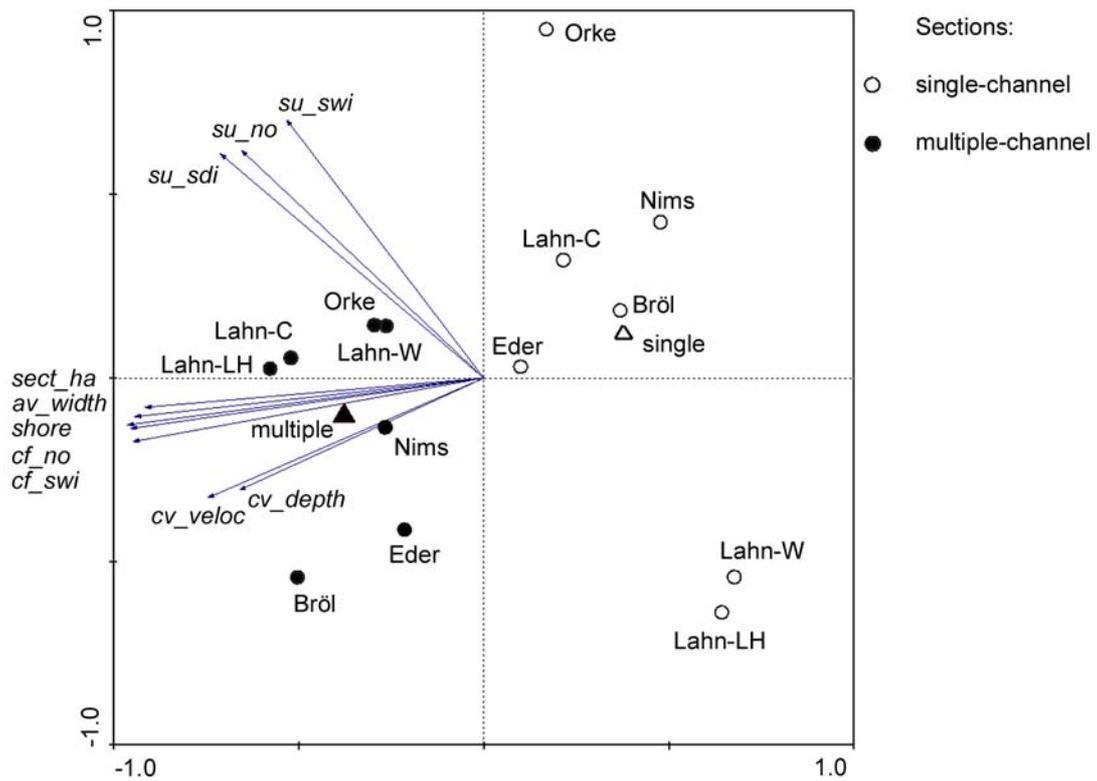


Figure 4-1. PCA graph of morphological data of single- and multiple-channel sections. Abbreviations see Table 4-2.

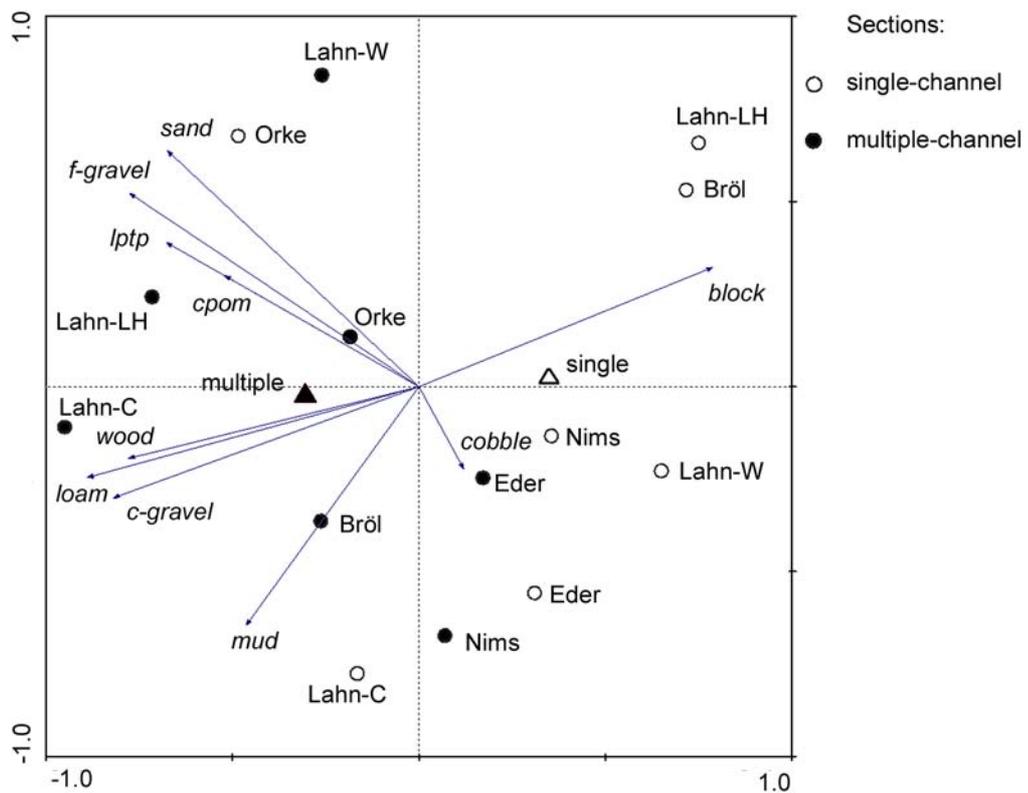


Figure 4-2. PCA graph of substrate area data of single- and multiple-channel sections. Abbreviations see Table 4-2.

#### 4.4.2 Overview of macroinvertebrate communities

A total of 74,539 individuals, belonging to 65 families and 169 taxa were found. The most diverse groups were Trichoptera (41 taxa), Coleoptera (37 taxa), Diptera (23 taxa) and Ephemeroptera (22 taxa). The mean number of taxa per stream section was  $92.6 \pm 10.6$ , ranging from 77 to 111 (Table 4-4). The mean abundance for all stream sections was  $5,324 \pm 1,941$  individuals  $m^{-2}$  (ranging from 3,006 to 9,675).

**Table 4-4.** Key community metrics (abundance, number of taxa and genera, evenness and Bray-Curtis similarity) for single- and multiple-channel sections. Higher values of section pairs are marked in bold.

	Abundance (Ind. $m^{-2}$ )		Number of Taxa		Number of Genera		Evenness		Bray-Curtis similarity (%)
	single	multiple	single	multiple	single	multiple	single	multiple	single vs. multiple
Lahn-W	6110	<b>7420</b>	91	<b>96</b>	69	<b>72</b>	0.58	<b>0.62</b>	82.0
Lahn-LH	<b>9675</b>	8306	78	<b>81</b>	56	<b>59</b>	<b>0.66</b>	0.65	82.5
Lahn-C	4452	<b>6132</b>	95	95	64	64	<b>0.64</b>	0.59	80.4
Orke	<b>4434</b>	3023	111	111	82	82	0.51	<b>0.68</b>	69.2
Eder	<b>4816</b>	4123	98	<b>100</b>	67	<b>69</b>	0.69	<b>0.70</b>	84.9
Nims	4919	<b>5059</b>	91	91	67	67	0.75	0.75	88.3
Bröl	<b>3064</b>	3006	77	<b>79</b>	56	<b>58</b>	0.71	<b>0.73</b>	76.1

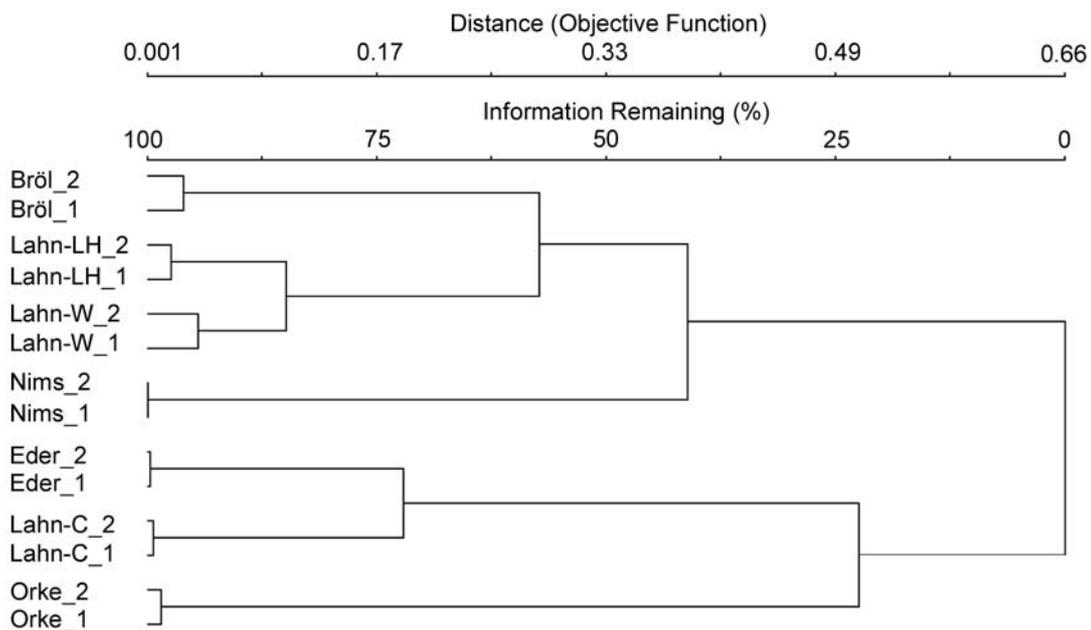
The parameters number of taxa and genera are all as high or slightly higher at the multiple-channel sections as compared to the single-channel sections, with a maximum of five more taxa (Lahn-W). The greatest difference in the number of genera was three (i.e. three more at the multiple-channel section). The abundance varies from more than 1,410 fewer individuals (Orke) to 1,681 individuals more (Lahn-C), while almost even abundances occur at the Nims (140 individuals more) and Bröl (58 less). The mean evenness for single-channel sections is  $0.65 \pm 0.07$  and for multiple-channel sections  $0.67 \pm 0.05$ . It is higher at five of the seven sites in the multiple-channel sections. Differences are greatest at the Orke and smallest at the Nims. The Mann-Whitney-U-test between single- and multiple-channel section data is not significant for any parameter. Bray-Curtis similarity is high between the stream sections, with highest similarity for the Nims (88.3%) and lowest for the Orke (69.2%).

MEANSIM analyses revealed that communities of single-channel versus multiple-channel sections are more different among themselves than between each other, thus single- and multiple-channel sections are not significantly different (Table 4-5).

**Table 4-5.** Analyses of dissimilarity within and between single- and multiple-channel sections. ratio = between- / within-dissimilarity; n.s. = not significant.

Stream section	n	Within-group dissimilarity	p	Between-group dissimilarity	ratio
single-channel	7	0.39	n.s.	0.34	0.9
multiple-channel	7	0.37			

The cluster analysis (Figure 4-4) further supports the stream sections' similarity. Each of the pairs forms a separate branch. The two main branches are divided at about 66% dissimilarity. The Orke sections are separated first at about 50% dissimilarity and form their own branch, while the two pairs of the Eder and Lahn-C are only about 16% dissimilar. In the other branch, the sites at Nims and Bröl show the greatest difference (divided at about 35 and 22% dissimilarity). The sites Lahn-W and Lahn-LH are the most similar pairs amongst each other, but with the greatest difference between sections (still less than 6%).



**Figure 4-3.** Cluster diagram of macroinvertebrate communities of single- (1) and multiple-channel (2) sections. Distance measure: Bray-Curtis similarity; linkage method: flexible beta (flexible clustering,  $\beta = -0.25$ ).

#### 4.4.3 *Habitat – community relationships*

Values of biological and hydromorphological metrics are shown in Appendix 11-A and 11-B. Spearman rank correlation expectations are shown in Appendix 11-C. Table 4-6 displays actual correlation results and whether the results met the expectations. In the upper left corner, metric pairs are found that display an expected result, while in the other parts unexpected correlations prevail. Mostly micro-scale morphological parameters, such as certain substrates areas and substrate spatial diversity, and the most influential meso-scale parameters, such as overall width and aquatic width, are found in the top left quadrant. On the community side, the fraction of shredders, preference for a certain substrate or a longitudinal zonation, together with taxa number and number of EPTCBO taxa show most consistent correlations.

38.8% of the results correspond to the a priori formulated expectations. 4.6% show a positive correlation although had been expected to react negatively, and almost 20% show a negative correlation although had been predicted to react positively. Almost 35% show no correlation at all.

**Table 4-6 (next page).** Spearman rank correlation ( $r$ ) of hydromorphological and biological metrics. Correlations where expected correspond to actual correlation direction are shaded grey; rows and columns sorted according to number of results meeting the expectation. Letter format indicate level of significance  $p < 0.1$  (red),  $p < 0.05$  (bold red).

**Table 4-6.** Spearman rank correlation (r) of hydromorphological and biological metrics. Table heading see previous page.

	sand-loam_A	aquatic_width	su_sdi	cv_depth	lptp-wood_A	av_width	shore	gravel_A	cpom-mud_A	sect_ha	su_no	su_swi	block-cobble_A	cv_velo	cf_no	cf_swi
[%] shredders	0.27	0.13	0.24	0.16	0.38	0.12	0.22	0.06	0.45	0.20	0.38	0.23	-0.17	0.09	0.13	0.13
# taxa	0.27	<b>0.51</b>	<b>0.52</b>	-0.08	0.37	0.26	0.13	0.38	0.11	0.21	0.36	0.22	-0.02	-0.06	0.08	0.07
[%] RL	0.27	0.37	0.40	-0.04	0.36	0.26	0.15	0.31	-0.02	0.26	0.16	0.18	0.15	-0.05	0.16	0.12
[%] RB	-0.16	<b>-0.54</b>	-0.34	-0.24	-0.17	-0.13	-0.18	<b>-0.47</b>	-0.22	-0.25	-0.29	-0.19	0.30	-0.08	-0.01	-0.02
[%] LR	<b>0.59</b>	0.02	<b>0.58</b>	-0.19	0.45	0.17	0.21	0.34	0.23	0.10	<b>0.56</b>	<b>0.46</b>	-0.40	-0.02	0.13	0.15
EPTCBO	0.24	<b>0.55</b>	<b>0.50</b>	-0.09	0.37	0.26	0.11	0.36	0.09	0.20	0.32	0.20	0.00	-0.09	0.04	0.03
[%] other feedtypes	0.23	0.15	0.31	0.12	0.41	0.02	0.16	0.13	0.43	0.09	<b>0.50</b>	0.31	-0.32	0.07	0.06	0.07
[%] littoral	0.33	0.26	0.39	0.14	0.29	0.36	0.23	<b>0.53</b>	-0.13	0.26	0.08	0.21	-0.31	0.07	0.05	0.02
[%] psa	0.31	-0.10	0.39	-0.16	0.44	0.22	0.15	0.05	0.33	0.02	<b>0.49</b>	0.31	-0.08	0.04	0.19	<b>0.20</b>
[%] epipotamal	0.20	<b>0.62</b>	0.44	0.04	0.14	0.31	0.17	<b>0.50</b>	0.06	0.41	0.05	0.09	0.29	-0.08	0.11	0.07
[%] aka	0.03	0.44	-0.05	0.43	-0.14	0.19	0.21	0.22	0.12	0.45	-0.23	-0.17	0.17	0.11	<b>0.09</b>	0.06
[%] xsap	0.08	<b>0.49</b>	0.14	0.32	0.10	0.04	0.17	0.28	0.29	0.27	0.17	0.10	-0.23	0.08	-0.02	-0.02
[%] metarhithral	-0.23	<b>-0.50</b>	-0.34	-0.12	-0.12	-0.30	-0.17	<b>-0.53</b>	0.10	-0.32	0.01	-0.06	0.07	0.03	-0.04	-0.03
[%] metapotamal	0.11	<b>0.49</b>	0.21	0.10	0.05	0.24	0.09	0.39	-0.13	0.21	-0.08	-0.04	-0.13	-0.05	-0.04	-0.05
[%] grazers_scrapers	-0.32	<b>-0.61</b>	<b>-0.56</b>	0.22	<b>-0.53</b>	-0.11	-0.03	-0.36	-0.11	-0.04	-0.38	-0.26	<b>0.47</b>	0.29	0.17	0.17
[%] passive filtfeed	-0.09	0.35	-0.05	<b>0.46</b>	-0.13	0.02	0.13	0.26	0.11	0.24	-0.03	-0.03	-0.13	0.18	-0.02	-0.01
[%] gatherers_collectors	0.21	0.02	0.26	-0.31	0.21	0.22	0.04	0.05	0.04	0.06	0.07	0.12	0.29	-0.16	0.11	0.08
[%] hypocrenal	0.23	-0.32	0.06	-0.19	0.13	-0.11	0.05	-0.25	0.32	-0.07	0.28	0.13	0.01	0.00	0.15	0.18
[%] phy	-0.26	<b>-0.64</b>	<b>-0.48</b>	0.15	-0.37	-0.01	0.02	-0.29	-0.26	-0.06	-0.37	-0.12	0.31	0.31	0.14	0.11
[%] epirhithral	0.24	-0.22	0.07	-0.31	0.14	-0.02	-0.02	-0.10	-0.16	-0.05	-0.06	0.08	0.05	-0.16	0.02	-0.01
[%] active filtfeed	0.31	-0.04	0.23	0.06	0.36	0.03	0.10	0.28	0.06	-0.04	0.23	0.29	<b>-0.71</b>	0.01	-0.06	-0.04
[%] xylophag	-0.08	0.16	0.16	-0.26	0.09	-0.21	-0.18	-0.19	0.21	-0.19	0.24	-0.03	-0.02	-0.19	-0.19	-0.20
[%] lit	-0.42	-0.14	<b>-0.49</b>	0.38	-0.52	-0.20	-0.02	-0.27	0.20	0.03	-0.21	-0.30	0.31	0.26	0.07	0.10
evenness	-0.30	-0.32	-0.41	0.30	<b>-0.51</b>	-0.12	0.05	-0.39	0.35	0.09	-0.14	-0.31	<b>0.49</b>	0.33	0.22	0.23
[%] pel	0.16	-0.04	0.14	-0.30	0.16	0.04	-0.10	0.11	-0.35	-0.17	-0.10	0.05	-0.30	-0.22	-0.16	-0.18
[%] RP	-0.19	0.29	-0.11	0.31	-0.11	-0.13	0.02	0.07	0.26	0.09	0.07	0.00	-0.07	0.10	-0.08	-0.06
[%] predators	-0.18	-0.45	-0.23	0.02	-0.19	-0.09	-0.08	-0.33	-0.05	-0.24	0.01	-0.16	-0.04	0.22	0.07	0.09
[%] LP	0.06	-0.35	-0.01	<b>-0.58</b>	0.11	-0.16	-0.20	-0.34	-0.34	-0.38	-0.06	0.01	-0.17	-0.24	-0.16	-0.19
abund	0.08	-0.32	-0.07	0.04	0.02	0.00	0.02	0.02	-0.26	-0.16	0.07	0.11	-0.42	0.15	0.00	0.04
[%] aka+lit+psa	-0.10	0.23	0.06	0.02	0.11	-0.17	-0.07	-0.05	0.35	-0.03	0.27	0.07	0.08	-0.10	-0.03	0.00
[%] IN	0.13	-0.17	0.08	-0.10	-0.01	0.13	0.04	0.07	-0.13	-0.04	-0.06	-0.04	-0.14	0.02	0.07	0.07
[%] hyporhithral	-0.34	-0.25	-0.33	0.01	-0.25	-0.22	-0.10	-0.40	0.15	-0.16	-0.05	-0.14	0.28	0.12	0.04	0.05
even_curr	0.11	-0.44	-0.01	-0.33	0.05	0.07	-0.05	-0.16	-0.37	-0.15	-0.19	-0.02	0.05	-0.07	0.02	-0.02
[%] miners	-0.10	-0.07	-0.21	0.03	-0.28	-0.01	-0.11	-0.09	-0.30	-0.06	-0.33	-0.28	0.02	-0.05	-0.14	-0.15
[%] parasites	0.04	-0.03	-0.12	-0.01	-0.20	0.09	0.00	0.00	-0.27	0.03	-0.33	-0.23	-0.03	-0.03	-0.05	-0.07

Table 4-7 highlights the significant Spearman rank correlations. Of 560 total possible combinations, 19 are significant at  $p < 0.1$  and 12 are significant at  $p < 0.05$ . Negative and positive correlations are almost equivocal: 13 are negative of which ten are contrary to the expectations. The mean significant Spearman rank  $r$  is 0.53. The number of taxa, number of EPTCBO, evenness, and several habitat-related metrics are positively correlated. The proportions of lithal- or phytal-preferring taxa, grazers and scrapers, and filter feeders or limnophil taxa are negatively correlated. Rheobiont taxa and metarhithral taxa show a negative correlation as expected.

**Table 4-7.** Significant ( $p < 0.1$  or  $p < 0.05$ ) Spearman rank correlation ( $r$ ) of hydromorphological and biological metrics. Asterisk indicate higher level of significance \*  $p < 0.05$ ; correlations where expected correspond to actual correlation direction are shaded grey.

	aquatic_ width	cv_depth	su_no	swi_su	sdi_su	block- cobble_A	gravel_A	sand- loam_A	lptp- wood_A
# taxa	0.51				0.52				
EPTCBO	0.55				0.50				
evenness						0.49			-0.51
[%] psa			0.49						
[%] lit					-0.49				
[%] phy	-0.64 *				-0.48				
[%] grazers_scrapers	-0.61 *				-0.56 *	0.47			-0.53 *
[%] active filtfeed						-0.71 *			
[%] passive filtfeed		0.46							
[%] other feedtypes			0.50						
[%] xsap	0.49								
[%] metarhithral	-0.50						-0.53		
[%] hyporhithral									
[%] epipotamal	0.62 *						0.50		
[%] metapotamal	0.49								
[%] littoral							0.53		
[%] LP		-0.58 *							
[%] LR			0.56 *	0.46	0.58 *			0.59 *	
[%] RB	-0.54 *						-0.47		

#### 4.4.4 Taxa exclusive to single- and multiple-channel sections

The differences that were detected are small and can largely be attributed to taxa that occur exclusively at either the single- or multiple-channel sections (Table 4-8). Eight taxa occur in the single-channel sections only, with three of these being Trichoptera, two being Coleoptera and Ephemeroptera each, and one being a Diptera taxon. In the multiple-channel sections,

15 taxa occur exclusively, eight of which are Coleoptera. The exclusive taxa occur in low abundances.

**Table 4-8.** Taxa exclusive to single- and multiple-channel sections. Number and composition of taxa occurring at either the single- or multiple-channel sections, including their respective abundance and the groups' overall mean abundance per sample.

Taxa	single-channel section			multiple-channel section		
	Number of taxa	Mean abundance	mean abund. group <sup>-1</sup> sample <sup>-1</sup>	Number of taxa	Mean abundance	mean abund. group <sup>-1</sup> sample <sup>-1</sup>
<b>Ephemeroptera</b>	<b>2</b>	<b>480</b>	<b>115.5</b>	<b>2</b>	<b>1016</b>	<b>162.1</b>
<i>Baetis liebenauae</i>		912				
<i>Potamanthus luteus</i>		48				
<i>Alainites muticus</i>					112	
<i>Cloeon dipterum</i>					1317	
<b>Odonata</b>						
<i>Aeshna cyanea</i>				1	72	38.7
<b>Plecoptera</b>						
<i>Protonemura sp.</i>				1	16	75.9
<b>Planipennia</b>						
<i>Osmylus fulvicephalus</i>				1	64	64.0
<b>Trichoptera</b>	<b>3</b>	<b>41.6</b>	<b>88.9</b>			
<i>Notidobia ciliaris</i>	32					
<i>Athripsodes aterrimus</i>	96					
<i>Leptocerus interruptus</i>	80					
<i>Potamophylax cingulatus/latipennis/luctuosus</i>				1	80	95.4
<b>Coleoptera</b>	<b>2</b>	<b>64</b>	<b>54.1</b>	<b>8</b>	<b>34</b>	<b>64.7</b>
<i>Platambus maculatus Lv.</i>		80				
<i>Anacaena bipustulata Ad.</i>		32				
<i>Longitarsus sp. Ad.</i>					32	
<i>Agabus sp. Lv.</i>					32	
<i>Stictotarsus duodecimpustulatus Ad.</i>					16	
<i>Helophorus arvernicus Ad.</i>					48	
<i>Hydraena dentipes Ad.</i>					69	
<i>Hydraena melas Ad.</i>					24	
<i>Hydraena minutissima Ad.</i>					24	
<i>Laccobius sp. Ad.</i>					24	
<b>Diptera</b>						
<i>Atrichops crassipes</i>	1	48	266.4			
<i>Limnophora sp.</i>				1	53.3	365.6
Mean		158.4	131.2		190.8	123.8
Mean excluding Ephemeroptera		51.2	136.5		53.2	117.4

The taxa that occur only in the multiple-channel sections were mainly found on organic substrates, such as living parts of terrestrial plants, wood, CPOM, mud or submergent macrophytes (Table 4-9).

**Table 4-9.** Number of taxa exclusive to multiple-channel sections and samples where they were found. Substrate abbreviations see Table III.

	Block, cobble	C-gravel, f-gravel	Sand, loam	LPTP, wood	CPOM, mud	Subm
Ephemeroptera				2	1	1
Odonata					1	
Plecoptera	1				1	
Planipennia					1	
Trichoptera	1			1		
Coleoptera	1	3	2	3	6	1
Diptera			1		1	
Sum	3	3	3	6	11	2

## 4.5 Discussion

### 4.5.1 Hydromorphological diversity

The multiple-channel sections show a considerable diversification of hydromorphological features in comparison to the single-channel sections (detailed results for macro- and meso-scale parameters can be found throughout Chapter 1). The mean overall width is increased by a factor of 2.1. Shore length increases by a factor of 2.4 for comparable stream sections. Increased coefficients of variation for the parameters depth and current velocity, higher numbers of substrates and higher substrate diversity indices indicate the increased aquatic habitat diversity as well.

Morphological diversity is enhanced at the multiple-channel sections at all scales, hence provides the precondition to influence the living environment. However, even though habitat diversity develops, the full natural range is unlikely to re-occur (Thomson *et al.*, 2001; Molnar *et al.*, 2002), or will at least need much effort to be restored. Inspiration for habitat diversity is possible from well studied natural braided alpine rivers, such as the Tagliamento (Tockner *et al.*, 2003), the Isar (Hering *et al.*, 2004) or the Upper Rhone (Cellot *et al.*, 1994). Obviously the studied streams lack size, dynamics, and hence extent of diversity.

### 4.5.2 Constraints to macroinvertebrate community development

There is no evidence within the data that restoration or natural development of multiple-channel sections has had positive effects on the macroinvertebrate fauna in terms of abundance, number of taxa or genera, and evenness (Table 4-4). This is further supported by the cluster analysis which groups the respective pairs most closely together (Figure 4-3). The sites with a natural origin of the multiple-channel sections (Orke, Nims, Bröl) are the first to

be separated from the restored sites. These differences (although only small) can be attributed to several causes. First, the method of creating joined taxa lists has the potential to create very similar section lists. However, this is closely linked to the substrate composition and only problematic if the alteration is not far-reaching. The substrates CPOM, mud, living parts of terrestrial plants and wood increasingly – yet only to a small degree – contribute to the substrate composition of the multiple-channel sections. The large mineral substrates blocks and cobble are very dominant. Other studies suggest that substrate composition, defined by diversity and patch spatial configuration, influence macroinvertebrate communities if the patches are large enough (Boyero, 2003).

Second, the (re-) colonisation of sites will differ between taxa, partly due to their variable dispersal abilities. Minor changes within the communities are detectable in the number of Coleoptera and Trichoptera. Many taxa of these orders are highly mobile and colonise new habitats quickly (Drury and Kelso, 2000; Sanderson *et al.*, 2005a). Most of the new taxa can be found on organic substrates such as CPOM, mud, and living parts of terrestrial plants. However, abundance of these taxa is below the order sample mean (Table 4-8). Overall, the abundance in these lesser frequent substrates is not different from the dominant substrates (Figure 3-1, B).

These results stress the role of abiotic factors at various scales in determining a site's taxonomic composition (e.g. Chaves *et al.*, 2005; Newson and Large, 2006). For near-natural streams, the macro-scale parameters geology, catchment size and altitude influence benthic invertebrate communities the most. In many studies anthropogenic factors have proven to be dominant (Roy *et al.*, 2003; Blakely *et al.*, 2006; Martel *et al.*, 2006). The triumvirate of substrate, depth and current velocity configure habitat at the micro-scale (Pardo and Armitage, 1997; Sanderson *et al.*, 2005b; Beauger *et al.*, 2006). Thus, parameters such as sediment grain size, discharge-related variables, current velocity and channel width build the fairground to develop a high level of habitat diversity and influence biodiversity. However, the investigated sites do not show a change in the invertebrate diversity. Either the fauna reacts on other scales, or the changes were insufficient or incomplete for the given effects on the fauna. New habitats, such as deep (and floodplain) pools, irregular banks, backwaters, shallow (hydropetric) gravelbars, debris dams or large wood were not developed in sufficient number and area to have a discernible effect on the benthic fauna (Hilderbrand *et al.*, 1997; Kail and Hering, 2005; Lepori *et al.*, 2005). Namely, the multiple-channel sections are short, accounting for a maximum of 2% of the streams lengths (Table 4-10), and supply of large wood to the stream is still insufficient. Kail (2005) describes the median number of large

wood logs for near-natural streams in lower mountainous areas as 200 logs km<sup>-1</sup>, which corresponds to a mean spacing of about 5 m. Moreover, he draws attention to the fact that this number would likely be much higher in natural streams. Only an estimated 5 to 10 logs were present at the multiple-channel sections, yielding a mean distance of 10–20 m per section. Even fewer logs, if none, were found at the single-channel sections.

**Table 4-10.** Stream site characteristics and potential constraints to improvements of the macroinvertebrate communities.

	Lahn-W	Lahn-LH	Lahn-C	Orke	Eder	Nims	Bröl
Stream length (distance to source) (km)	25	26	50	31	74	44	30
Length of multiple-channel sections up to sites (m)	200	400	1000	200	250	200	600
Proportion of multiple-channel sections compared to stream length (%)	0.8	1.5	2	0.6	0.6	0.3	2
Potential length of multiple-channel sections estimated from stream type length (m)	6000	7000	36000	15500	40000	17000	11800
Potential proportion of multiple-channel sections compared to stream length (%)	24	27	72	50	54	39	39
Estimated distance between large wood elements in studied multiple-channel sections (m)	~20	10-20	~20	~50	~100	10-20	~10
Distance between large wood elements in natural streams (Kail 2005) (m)	5	5	5	5	5	5	5

Additionally, areas for re-colonisation are quite far away. The estimates given in Table 4-11 are rather optimistic in terms of potential stream colonisation sources. The very short near-natural stream sections found in today's landscape make re-colonisation an even more bold venture, moreover affected by agriculture or urban settlement.

**Table 4-11.** Estimation of re-colonisation distances for large and small streams in mountainous areas in Germany.

Estimated distance of re-colonisation sites for this stream type (as proxy for re-colonisation potential) (km) <sup>1</sup>	14
Estimated distance of re-colonisation sites for small streams in mountainous areas (km): calculated as above; but stream type length is almost 20,000 km; the most frequent stream type in Germany.	7

1) Calculated as 40% of German area (357,092 km<sup>2</sup>) are estimated mountainous areas, the investigated streams belong to stream type 9, to which about 4.5% of all streams-km in Germany belong (Sommerhäuser and Pottgiesser, 2005). Re-colonisation is assumed to occur from lower parts of smaller streams and upper parts of larger streams, totaling to approximately 10,000 km length (this is a rather positive count): distance = mountainous area of Germany / potential re-colonisation stream length.

The differences between single- and multiple-channel section communities are extremely small. They are, however, not surprising when summarising re-colonisation possibilities and recalling central European catchment conditions from land use to catchment history, or taking into consideration the ratio of multiple-channel to upstream reach.

Island biogeography is a helpful concept in this context (Gore, 1985): the chance of sites being colonised by taxa that are not present (any more) in the streams diminishes with increasing distance from the source of colonists (Fuchs and Statzner, 1990; Suren and McMurtrie, 2005; Hughes, 2007). The estimates in Table 4-10 and Table 4-11 clearly illustrate this problem.

Biotic factors influence the species composition further (Heino *et al.*, 2003; Sanderson *et al.*, 2005b). Dissimilar communities have been frequently attributed to differences within the surrounding taxa pool (Ricklefs, 1987; Hildrew and Giller, 1992; Palmer *et al.*, 1996; Vinson and Hawkins, 1998). Drift and upstream migration contribute up to 80% to a new community (Gore, 1985; Doeg *et al.* 1989), and colonisation from aerial sources (oviposition by adults) compensate for general downstream drift of larvae and nymphs (Harper and Everard, 1998; Malmqvist, 2002). Only a very small proportion of macroinvertebrate communities venture out to new sites – if sites with a good ecological status are scarce, they will likely not reach suitable new living space. And if such sites are too short, they will not support self-sustainable populations either. Furthermore, high quality habitats might already be occupied by ubiquitous taxa, competing against the (new) specialists taxa (Graf, personal communication). Yet, the quality of the new community depends on undisturbed source areas of colonisers up- or downstream. The sites investigated here are dominated by long, degraded single-channel stretches and facilitate only few differences on the "islands of restoration". Hence macro-scale factors outweigh any improvements in the process of rehabilitation (Harrison *et al.*, 2004; Sanderson *et al.*, 2005b). This explanation can be applied in the other direction, concerning the Orke site, where a relatively undisturbed catchment back up both stream sections. The Orke stream sections display a high similarity and are characterised by high taxa numbers (Table 4-4) and a unique position in the cluster diagram (Figure 4-1).

The macroinvertebrate fauna shows no considerable differences because abiotic constraints and faunal impoverishment outweigh positive effects from increased habitat diversity. Riparian arthropods have been more successful at re-colonising new channel features such as midchannel and side bars (Manderbach and Hering, 2001; Pätzold, 2004; Sadler *et al.*, 2004; Günther and Assmann, 2005; Gacek and Hering, 2007). However, developing or maintaining multiple-channel stream sections still has hydrologic and, not for least importance, aesthetic value (Mutz *et al.*, 2006).

#### 4.5.3 *Habitat – community relationships*

Using Spearman rank correlations, the relationships between hydromorphological and biological metrics of aquatic macroinvertebrate communities were investigated. Micro-scale

characteristics such as the area of sand and loam, the Spatial-Diversity-Index or area of the high-quality substrate wood (Hoffmann and Hering, 2000) and living parts of terrestrial plants were most often correlated. Biotic metrics related to a higher input of organic material and a more balanced substrate composition and distribution show the greatest responses, as was originally anticipated. These are, for example, the percentage of shredders in the community and metrics indicating a community preference for potamal areas (lower current preferences, littoral areas, sandy substrates). The increasing amount of shredders suggests that the restored sites accumulate more detritus, generating a change in the feeding traits. The significant results regarding the current preference distribution can be judged as presence of more low flow areas, typical for a diverse array of habitats in mountain streams. Metrics related to substrate preferences are irregular. The percentage of phytal-preferring taxa shows rather stochastic correlations but might be attributed to the fact that only two sites had larger phytal areas, so the basis for comparison is small. Substrate preferences related to hard substrates (being both lithal and xylal, [%] type aka+lit+psa) also showed no clear behavior and mostly no correlation at all. It is likely the case that specialised taxa do not any longer inhabit these areas.

Meso-scale metrics were rather unpredictable in their effect on macroinvertebrate communities, with the exception of aquatic width. Yet meso-scale conditions are the pre-requisite to create local variation, for example in current velocity or substrate, thus forming patches in the first place, which then allow invertebrates to find satisfactory habitats (Beisel *et al.*, 1998b).

The metrics tested here indicate relationships and dependencies between hydro-morphological changes and community traits. A selected set avoiding autocorrelation and covering different spatial and temporal scales could be used for the development of a multi-metric, multi-scale restoration effectiveness index to evaluate restoration progress or success.

#### 4.5.4 Conclusions and implications

An overwhelming majority of up to date studies have identified various spatial scales to influence the fauna of river stretches (Bis *et al.*, 2000; Sponseller *et al.*, 2001; Wang *et al.*, 2001; Chaves *et al.*, 2005; Hering *et al.*, 2006; Moerke and Lamberti, 2006). Thus, opportunistically and neither strategically nor comprehensively planned restoration measures that target no large-scale parameters are likely ineffective (Clarke *et al.*, 2003). The study aligns with other restoration-related studies which found only marginal or less than expected effects on the fauna (Brooks *et al.*, 2002; Pretty *et al.*, 2003; Suren and McMurtrie, 2005;

Lepori *et al.*, 2006). The main reasons for these few effects are seen in inappropriate design and scale of the measures for the target streams (Bond and Lake, 2003), and a lack of potential for recovery because the schemes were isolated within longer stream sections of degraded streams (Pretty *et al.*, 2003). Furthermore, the in-stream changes might not have been sufficiently improved, and colonisation bottlenecks for aerial stages of these animals occur. As the multiple-channel sections are only very short within long single-channel sections, the inability of individuals at other sites to perceive these enhanced 'islands' of good habitat is another non-negligible factor (Bond and Lake, 2003).

Macroinvertebrate communities of single- and multiple-channel sections studied in this chapter cannot (yet) be distinguished. Large scale impacts from the catchment that act on both single- and multiple-channel sections seem to be more influential. Other parameters might conclude more positive effects: (Brown, 2003) found that more diverse macroinvertebrate communities had profound effects on aspects of temporal stability. Other taxonomic groups (fish, floodplain fauna and flora) might reflect more influence from enhanced habitat diversity (de Nooij *et al.*, 2006; Gacek and Hering, 2007). The measurement of other parameters, such as ecosystem function variables (e.g., production, respiration, decomposition), may also indicate change at local scales (Brooks *et al.*, 2002).

The potential for successful rehabilitation might be increased if longer stretches are restored and stepping stone sections are created in-between. Emphasis should be placed on substrate diversity and important organic substrates, such as large wood, in which case the addition of these might be required in the first place. Refreshing of the taxa pool by re-introducing former occurring taxa in the now improved stream sections would be a possible method, tested with mammals like the beaver but not yet with macroinvertebrates.

This chapter shows that the use of physical responses to rehabilitation as a surrogate or reliable predictor of ecological response is not always appropriate. It suggests a much broader approach to the restoration of streams and rivers.

## Summary, conclusion and prospects of future research

This thesis investigates restored and naturally developed multiple-channel sections in German mountainous areas. Without human interference most streams in these areas would show this hydromorphological pattern. Unfortunately only short multiple-channels sections can be found or have been built in restoration projects. The quantity of hydromorphological differences compared to anthropogenically straightened single-channel sections and effects on macroinvertebrate communities are largely unknown. In a paired site study seven multiple- and seven single-channel sections were investigated and compared. The hypothesis was tested that multiple-channel sections have a larger area and higher habitat diversity, which also influences the biota.

A standardised transect-point-protocol was applied in the summer of 2004 and 2005. Width of channel features (main and secondary channels, sidearms, standing water bodies, bars, banks, floodplains and embankments) and their habitat characteristics (aquatic, terrestrial or transient) were recorded along 20 equidistant transects across the bankfull width. Along these transects, aquatic habitats (substrate type, depth, current velocity) were recorded at 400 points per stream section. Section-wise analyses of both years built the elaborate basis against which macroinvertebrate data were tested. Altogether 199 substrate-specific macroinvertebrate samples were taken and processed separately. Analyses focussed on diversity patterns at the habitat- and section-scale by comparing alpha- and beta-diversity, as well as nestedness patterns. Finally, the relationships between hydromorphological characteristics and each section's community were evaluated. Four hypotheses were put forward.

*In multiple-channel sections, hydromorphological characteristics at all scales are more diverse and variable than in single-channel sections.*

*→ The analyses support this hypothesis.*

Twelve hydromorphological metrics were calculated from the transect and point data of the year 2004. Metrics at three scales differentiated well between single- and multiple-channel sections: the macro-scale metrics mean channel width and shore length increased by factors of 2.1 and 2.4, respectively; the meso-scale metric mean number of channel features increased from two to ten per section; several micro-scale metrics, such as current velocity and depth variance, were significantly different between single-channel sections and most

multiple-channel sections. Furthermore, substrate composition was more diverse in the multiple-channel sections. Correlation analyses of hydromorphological parameters showed autocorrelation within scales but rarely between scales. The findings suggest that metrics of different scales should be combined in order to evaluate hydromorphological diversity.

*Higher substrate dynamic will be observable within the multiple-channel sections.*

→ *The analyses support this hypothesis.*

The sites were revisited in 2005 and transect-point recordings were repeated to quantify annual changes within the sections. Hydromorphological metrics between the single- and multiple-channel sections were compared just like in 2004. Differences were comparable for both years. Likewise, the amount of changes between two years differs between single- and multiple-channel sections. Water depths, aquatic widths and cross-section, riparian areas, and the waterside margins of the embankments have been modified by the streams in the course of the year. Multiple-channel sections showed more annual changes than the single-channel sections. Within the multiple-channel sections, natural and restored sites showed different extents of change with the latter showing higher and more varied changes in the multiple-channel sections. Despite the fact that the multiple-channel sections have not achieved (and probably never will achieve) a status of hydromorphological diversity comparable to totally unconstrained streams, they show highly dynamic features. One can't help but assume positive ecological implications from this central element of stream morphology.

*The diversified habitat situation at the multiple-channel sections will affect macroinvertebrate communities at the micro-scale, leading to higher alpha-diversity in similar substrates.*

→ *The analyses refute this hypothesis.*

Communities of various substrates within the stream sections were compared for alpha- and beta-diversity and nestedness patterns. Taxa number, abundance, and evenness of macroinvertebrate communities found on multiple-channel substrates were not significantly different from the same substrates at single-channel sections. Rather, Non-metric Multidimensional Scaling (NMS), separated substrate-specific communities independent of stream sections with distinct communities on organic and mineral substrates. Nestedness, which describes the predictability of species composition, implies that the present species are ubiquitous, and rare species would only occur at species rich sites. Only few substrates, namely mud, loam and living parts of terrestrial plants, show the assumed pattern, that nestedness will be higher in the multiple-channel sections. Nestedness analyses recommends these substrates as valuable for the multiple-channel sections. Some taxa, mainly from the groups of Coleoptera

and Trichoptera, occur exclusively at either the single- or the multiple-channel sections. They were found in fine mineral substrates (loam and sand) and on organic substrates such as living parts of terrestrial plants, CPOM and wood. The results show equal alpha-diversity of substrates at single- and multiple-channel sections, implying that substrates have similar communities in spite of an increased habitat mosaic around them. Beta-diversity of stream sections is influenced by other and more frequent high-quality substrates such as wood and fine organic substrates.

*Overall macroinvertebrate diversity of stream sections will be increased and community traits are changed.*

→ *The analyses refute this hypothesis.*

Principal component analyses (PCA) ascertained hydromorphological gradients at the section scale against which macroinvertebrate data were tested. PCA gradients were displayed for stream sections' area, mean width or number of channel features, together with substrate diversity, depth- and current velocity variability. The PCA differentiated well single- and multiple-channel sections. Substrate area of fine mineral and organic substrates were characteristic for the multiple-channel sections, while a high proportion of large mineral substrates (block, cobble) is typical for single-channel sections. For each stream section a sample was mathematically aggregated based on the substrate-specific macroinvertebrate samples and relative substrate composition. Abundance, number of taxa, and evenness were similar for macroinvertebrate communities of stream sections, and Bray-Curtis similarity between the stream section pairs was high (69–88%). Cluster analysis supported these findings. Community traits described by faunal and functional (biological) metrics (e.g. taxa number, abundance, feeding type, micro habitat and current preference) were Spearman rank correlated with hydromorphological metrics ( $n=14$ ). Prior to analyses, expected correlation direction, "positive" or "negative", had been formulated, which was then compared to the actual  $r$  value. 39% of the correlations turned out as expected, but almost as many showed no correlation (35%), and 24.6% showed an unexpected correlation direction, indicating high variability in the data. Of the 560 pairs, 5.5% were significant. The number of taxa, number of EPTCBO (Ephemeroptera, Plecoptera, Trichoptera, Coleoptera, Bivalvia, Odonata), evenness, and habitat-related metrics (sand-loam area, current preference distribution) are positively correlated, as are the percentage of lithal- or phytal-preferring taxa, grazers and scrapers, filter feeders or limnophil taxa. Rheobiont taxa and metarhithral taxa show a negative correlation as expected, indicating a greater number of areas with low current velocities.

### *Conclusion*

The hydromorphological diversity of the multiple-channel sections is improved towards the reference condition. Habitat diversity is increased and a higher sediment dynamic becomes manifest in cross-section changes. However, effects on the macroinvertebrate community of substrates or the overall stream sections are not detectable and at best display a general tendency towards improvement. This lack of diversification of the macroinvertebrate community is attributed to several causes and a mixture of abiotic and biotic constraints likely apply. First, micro-scale changes might be insufficient. The increase in spatial heterogeneity of substrate number and area has not been large enough to support different macroinvertebrate communities. Second, meso-scale conditions are still prevalent, subsuming influences at larger scales. For example, the requirements that macroinvertebrates have of the riparian environment during the aerial stage of their life cycle might not be fulfilled, or a dominant edge effect without unique centre impedes separated communities. Overall, the magnitude of changes is not large enough: to the present day, multiple-channel sections constitute a maximum of 2% of the total stream length, although 25–75% is an appropriate estimate of the potential proportion of multiple-channel sections if the relevant stream type is considered. The amount of large wood, an essential feature in stream morphology, is low. Estimates about the potential amount that should be available are five times higher than the amount observed at the investigated stream sections. Third, from a biological point of view, simple and impoverished meta-populations are suggested, so streams lack re-colonisation potential. This especially applies for larger streams, where the catchment area is completely transformed. Fourth, the stream sections' areas and habitat diversities are sufficient and re-colonisers are principally available but in refuges too far away to be reached by normal dispersal mechanisms. And fifth, there is a deficient reference, meaning that improvement might occur, but often the assessment of its degree or the evaluation of missing parts that might further improve the ecological status is speculative as references are missing.

### *Prospects of future research*

These shortcomings lead the way for future application and research in terms of multiple-channel streams and possible restoration measures:

- Longer stretches should be restored or allowed to develop.
- Re-colonisation sources should be identified and considered, in both longitudinal and lateral direction.
- Stepping stone measures are necessary to facilitate stepwise re-colonisation.

- Dispersal patterns of macroinvertebrates should be taken into consideration for further restoration measures and the respective distance to recolonisation sources.
- Important habitat features, such as large wood, need to be enhanced.

Before-after-control-impact studies should gather knowledge regarding if and when substrate-specific macroinvertebrate communities develop and under which conditions stream sections are able to maintain different populations. Other biotic elements (riparian arthropods, fish, vegetation) might be suited for monitoring soon after restoration as they reflect morphological improvements much more quickly and cover another spatial scale, which needs elaboration. It is unknown which longitudinal extent of a multiple-channel section is necessary to affect macroinvertebrate communities and maintain vivid populations. The quality and condition of macroinvertebrate meta-populations is a black box, and future research could take into consideration the applicability of refreshment or enhancement with former occurring taxa and success of such experiments. Different restoration measures (cessation of maintenance, removal of bank fixations, initiative measures or re-construction of a near-natural situation) are all potentially effective but act over different time scales concerning hydromorphology and even more so concerning biological changes.

In conclusion, this thesis is only a small but helpful and comprehensive glimpse into restoration aspects of one stream type, excluding other stream types and sizes. Fair and accurate evaluation of success is only possible if these are also better known.

## Zusammenfassung

### **Vergleich der Hydromorphologie und Makrozoobenthos-Gemeinschaft an verzweigten und unverzweigten Abschnitten deutscher Mittelgebirgsflüsse**

#### *Hintergrund*

Verzweigte Flussabschnitte lassen sich heute in der Landschaft kaum noch finden, hingegen ist das Bild geprägt von an Sohle und Ufern befestigten, einarmigen, im Regelprofil verlaufenden Flüssen. Bei Beseitigung der Ufersicherung bilden sich jedoch verzweigte Gerinneformen schnell wieder aus. Für solche Rückentwicklungen gibt es in Deutschland bisher nur wenige Beispiele, bei denen Flüsse nach Renaturierungsmaßnahmen oder durch zugelassene Eigendynamik wieder für eine kurze Strecke eine verzweigte Gerinneform annehmen. Für ca. 45 % der Fließgewässer in deutschen Mittelgebirgen wird als Referenzzustand ein verzweigter Verlauf angenommen (Fließgewässertypen 9, 9.2, 10; Sommerhäuser und Pottgiesser, 2005; LUA NRW, 2001b). Charakteristische Merkmale sind großflächige Schotterbänke, flache Profile und (lokale) Verzweigungen. Sie sind des Weiteren durch hohe Sedimentdynamik gekennzeichnet (Träbing, 1996; Knighton, 1998; LUA NRW, 2001b; Gurnell und Petts, 2002).

Zwei Entwicklungen lassen den Schluss zu, dass die Entstehung verzweigter Flussabschnitte zukünftig häufiger auftreten könnte. Zum einen werden durch den Klimawandel häufigere und stärkere Hochwasserereignisse prognostiziert (IPCC, 2001; IPCC, 2007), die erhöhte Erosionskräfte besitzen. Aus Gründen des Hochwasserschutzes werden deshalb wieder vermehrt Auengebiete an ihre Flüsse angeschlossen und dort die eigendynamische Entwicklung ermöglicht. Zum anderen besteht mit der Einführung der Europäischen Wasserrahmenrichtlinie (WRRL), die Notwendigkeit einen "guten ökologischen Zustand" der Fließgewässer bis 2015 zu erreichen (EC, 2000). Von diesem Ziel ist Europa nach einer ersten Bestandsaufnahme noch weit entfernt (z.B. HLUG, 2004; ICPDR, 2005; ICPR, 2005). Der am häufigsten genannte Grund, warum ca. 80 % der Fließgewässer diesen Zustand bis 2015 nicht erreichen werden, ist die hydromorphologische Situation. Das Ergebnis der Bestandsaufnahme erfordert erhebliche und vielfältige Renaturierungsmaßnahmen.

Auf Grund beträchtlicher naturräumlicher Unterschiede in der Ausprägung, sollen regional differenzierte Renaturierungsmaßnahmen erfolgen, die sich am Referenzzustand bzw. dem

Leitbild orientieren (Palmer *et al.*, 2005). Die durch Renaturierung erreichten vielfältigeren Substrat- und Strömungsverhältnisse sollten sich auf die Besiedlung durch aquatische Organismen auswirken (Brosse *et al.*, 2003; Townsend *et al.*, 2003). Der Einfluss der Veränderung der Laufform auf die Substrat- und Strömungsverhältnisse und damit auf die Besiedlung durch Organismen – speziell in Bezug auf die zur Bewertung von Fließgewässern häufig herangezogenen bodenlebenden Wirbellosen (Makrozoobenthos) – ist im Detail noch nicht ausreichend erforscht. Eine Bewertung des Erfolges oder die Entwicklung wirkungsvoller zukünftiger Renaturierungsmaßnahmen ist somit nur schwer möglich.

Ein detaillierter Vergleich morphologischer und biologischer Charakteristika unverzweigter und verzweigter Fließgewässer in deutschen Mittelgebirgen wurde noch nicht vorgenommen, doch anhand der Literatur zu Renaturierungs- und Naturschutzfragen (z.B. Ward *et al.*, 1999; Beisel *et al.*, 2000; Muotka *et al.*, 2002; Richards *et al.*, 2002; Robinson *et al.*, 2002) lassen sich folgende Annahmen treffen: Verzweigte Flussabschnitte haben

- eine größere Breiten-Tiefenvarianz,
- eine größere hydromorphologische Strukturvielfalt,
- eine erhöhte Tiefen- und Strömungsvariabilität,
- eine erhöhte Substratdiversität,
- eine erhöhte Sedimentdynamik,
- und damit eine erhöhte Habitatvielfalt, die wiederum zu einer erhöhten faunistischen Diversität führt.

Ziel der vorliegenden Forschungsarbeit war es, unverzweigte und verzweigte Flussabschnitte im Mittelgebirge hinsichtlich ihrer hydromorphologischen Ausprägungen zu vergleichen sowie die jeweiligen Makrozoobenthos-Gemeinschaften zu charakterisieren und im Vergleich zu quantifizieren, um zukünftige Renaturierungsvorhaben gezielter planen und bewerten zu können. Die Arbeit trägt somit zum besseren Verständnis von Fließgewässerökosystemen bei und hat praktische Relevanz für Renaturierungsfragen.

Hieraus leiten sich die im Rahmen dieser Arbeit zu prüfenden Arbeitshypothesen ab:

*(1) Verzweigte Flussabschnitte weisen eine höhere Habitatdiversität auf.*

Die höhere Habitatdiversität äußert sich makro-, meso-, und mikroskalig. Makroskalige Veränderungen sind z.B. eine verlängerte Uferlinie, zu den mesoskaligen Veränderungen zählt das Vorhandensein verschiedener Flussbereiche, z.B. Haupt- und Nebenarm, strömungsberuhigte Bereiche, Inseln, Kiesbänke. Mikroskalige Veränderungen führen zu einer erhöhten aquatischen Habitatdiversität, die durch die Parameter Substrattyp, Strömung und Tiefe definiert wird.

*(2) Verzweigte Flussabschnitte besitzen eine höhere Sedimentdynamik.*

Die erhöhte Sedimentdynamik ist z.B. an umgelagertem Material, veränderten Flussquerschnitten oder Lageveränderungen von Inseln und Schotterbänken im Vergleich zweier Untersuchungstermine zu erkennen.

*(3) Gleiche Habitate werden in verzweigten Flussabschnitten von einer vielfältigeren Makrozoobenthos-Gemeinschaft besiedelt als in unverzweigten Flussabschnitten.*

In den verzweigten Flussabschnitten finden sich mehr und kleinräumiger wechselnde Habitate. Dieses "buntere" Habitatmosaik erlaubt eine vielfältigere Besiedlung der Substrattypen in verzweigten Flussabschnitten, da mehr und variabelere Besiedlungsmöglichkeiten aus Nachbarhabitaten zur Verfügung stehen und diese von einer größeren Zahl von Taxa genutzt werden können.

*(4) Verzweigte Flussabschnitte sind vielfältiger besiedelt und ökologische Merkmale der Makrozoobenthos-Gemeinschaften werden durch die aquatische Habitatdiversität beeinflusst.*

Die erhöhte Habitatdiversität und die variabelere Verteilung der Habitate in verzweigten Flussabschnitten führen zu einer allgemein höheren Makrozoobenthos-Diversität. Dies spiegelt sich auch in den ökologisch relevanten Merkmalen der Makrozoobenthos-Gemeinschaften wieder, z.B. hinsichtlich der Habitatpräferenzen, der Strömungspräferenzen, der Ernährungstypenzusammensetzung oder der längszonalen Präferenzen.

Jeder Arbeitshypothese ist jeweils ein Kapitel gewidmet. Die wichtigsten Vorgehensweisen, Ergebnisse und Erkenntnisse werden im Folgenden dargestellt.

### *1 Differenzierung der Flussabschnitte anhand hydromorphologischer Parameter*

An sieben Probestellen der Mittelgebirgsflüsse Lahn, Eder, Orke, Nims und Bröl wurden im Frühjahr und Sommer 2004 und 2005 Untersuchungen der Hydromorphologie und des Makrozoobenthos durchgeführt. Die Flüsse sind den silikatisch, fein- bis grobmaterialreichen Mittelgebirgsflüssen zuzuordnen. Jede Probestelle umfasste einen renaturierten oder naturnahen, verzweigten Flussabschnitt und einen begradigten, unverzweigten Vergleichsabschnitt. An den verzweigten Flussabschnitten war durch die naturräumliche Situation oder durch Renaturierungsmaßnahmen die laterale Ausdehnung der Flüsse in die Aue und die Entwicklung von verzweigten Flussverläufen möglich. Die Probestellen sind in Bezug auf Abfluss, großräumige Landnutzung und Wasserbeschaffenheit vergleichbar. An den einzelnen Flussabschnitten der Probestellen wurden entlang von 20 gleichmäßig verteilten, quer zur Hauptfließrichtung verlaufenden Transekten makro-, meso- und mikroskalige Parameter aufgenommen. Mittlere Breite, Uferlängen und Fläche der Abschnitte zählten zu den makroskaligen Parametern. Breite und

Abfolge von so genannten Gewässerelementen galten als mesoskalige Parameter. Die Gewässerelemente ließen sich in sechs aquatische (Hauptarm, Nebenarm, Seitenarm mit und ohne Anschluss, temporäre und permanente Auengewässer), zwei semiaquatische (Inselbank, Uferbank) und drei terrestrische Elemente (Böschung, bewachsene Inseln, Auenbereiche) differenzieren. Die aquatischen Habitateigenschaften wurden als mikroskalig gewertet und für jeden Flussabschnitt mit 400 Messpunkten (20 Punkte entlang der 20 Transekte in aquatischen Elementen) über die Parameter Substrattyp, Tiefe und Strömungsgeschwindigkeit untersucht. Sechs mineralische (in abnehmender Korngröße: Blöcke, Schotter, Grobkies, Feinkies, Sand, Lehm) und fünf organische (submerse Makrophyten, lebende Teile terrestrischer Pflanzen<sup>1</sup>, Totholz, CPOM<sup>2</sup> und organischer Schlamm) Substrattypen wurden unterschieden. Diese Parameter waren Berechnungsgrundlage für elf hydromorphologische Kenngrößen (Metrics) je Flussabschnitt: Uferlänge, mittlere Breite eines Flussabschnittes, mittlere Breite von aquatischen/terrestrischen/semiaquatischen Bereichen der Gewässerelemente, Anzahl und mittlere Länge der Gewässerelemente, Shannon-Wiener-Diversität der Gewässerelemente, Anzahl Substrattypen, Shannon-Wiener-Diversität der Substrattypen (Anzahl und relativer Anteil), Spatial-Diversity-Index (SDI, räumliche Verteilung der Substrattypen; Fortin *et al.*, 1999), extrapolierte Flächen der Substrattypen, Variationskoeffizient für Strömungs- und Tiefenmessungen.

Die hydromorphologischen Merkmale der Flussabschnitte wurden für das Jahr 2004 auf den drei räumlichen Ebenen (makro-, meso-, mikroskalig) verglichen. Die verzweigten Flussabschnitte zeigten eine deutlich erhöhte makro- und mesoskalige Habitatdiversität. Diese Abschnitte waren im Mittel um das 2,3-fache verbreitert und die Uferlänge aller aquatischen Bereiche nahm bei vergleichbar langen Flussabschnitten um den Faktor 3,3 zu. Am wenigsten unterschieden sich die mittleren aquatischen Breiten zwischen den Vergleichsabschnitten. Große Abweichungen traten jedoch bei den terrestrischen und den semiaquatischen Breiten auf. Letztere waren an drei der sieben Probestellen nur in den verzweigten Flussabschnitten zu finden. Die mikroskalige aquatische Habitatvielfalt war in den verzweigten Flussabschnitten ebenfalls erhöht. Dies ist an den erhöhten Variationskoeffizienten von Strömungsgeschwindigkeit und Tiefe, zusammen mit dem Auftreten weiterer Substrattypen, erkennbar. Die Veränderungen betreffen besonders die feinmineralischen Substrattypen Feinkies, Sand und Lehm und die organischen Substrattypen Holz, CPOM und lebende Teile terrestrischer Pflanzen. Der Anteil des dominanten Substrattypes (Schotter oder Grobkies) nahm im Mittel von 75 % auf 62 % ab. Die Diversitätsindices (Shannon-Wiener-Index und Spatial-Diversity-Index) waren in den verzweigten Flussabschnitten jeweils erhöht. Eine Korrelationsanalyse der Metrics

1 z.B. feine Wurzeln der Ufervegetation

2 CPOM = **c**oarse **p**articulate **o**rganic **m**atter: grobpartikuläres organisches Material; Durchmesser 0.1–2 cm.

untereinander zeigte innerhalb der jeweiligen räumlichen Ebenen eine hohe Autokorrelation – so korrelierten die makroskaligen Metrics Uferlänge und mittlere Breite signifikant. Geringe Korrelationen zeigten sich zwischen makro- und mikroskaligen Parametern.

Das erfasste Spektrum der Unterschiede an den sieben Probestellen lässt sich zumeist im lokalen, regionalen oder historischen Kontext erläutern. An der Orke fanden sich z.B. nur geringe Abweichungen bei der Substrattypenvielfalt: diese sind durch eine vergleichsweise hohe Substratdiversität im unverzweigten Flussabschnitt bedingt. Die mittlere Breite oder die Anzahl der Gewässerelemente war hingegen deutlich verschieden. An der Nims war die Tiefenvariabilität im unverzweigten Flussabschnitt höher als im verzweigten Flussabschnitt: dies kann auf ein Wehr unterhalb des unverzweigten Flussabschnittes zurückgeführt werden. Die Substratdiversität zeigt jedoch die erwartete Erhöhung im verzweigten Flussabschnitt. Diese Beispiele belegen, dass die morphologische Vielfalt und Habitatdiversität nicht durch einzelne Metrics, sondern nur durch eine Kombination mehrerer Kenngrößen ausgedrückt werden kann. Die verzweigten Flussabschnitte wiesen makro-, meso- und mikroskalige Merkmale im Sinne ihres Leitbildes auf. Die erarbeiteten Parameter sind somit geeignet, Unterschiede zwischen unverzweigten und verzweigten Flussabschnitten zu identifizieren und zu quantifizieren.

Die Hypothese *"Verzweigte Flussabschnitte weisen eine höhere Habitatdiversität auf"* wird durch die Ergebnisse gestützt.

## *2 Quantifizierung hydromorphologischer Veränderungen binnen eines Jahres*

An allen Flussabschnitten wurden im Jahr 2005 die hydromorphologischen Parameter nach dem gleichen Verfahren wie 2004 aufgenommen. Die wiederholte Untersuchung aller Flussabschnitte hatte zum Ziel, morphologische Veränderungen, die innerhalb eines Jahres aufgetreten waren, zu erfassen. Zunächst wurden die Unterschiede zwischen den unverzweigten und verzweigten Flussabschnitten im Jahr 2005 ermittelt. Die Unterschiede waren in 2004 und 2005 vergleichbar. Als Maß für die angenommene unterschiedliche Dynamik innerhalb der Flussabschnitte wurde die Veränderung der Breite von Gewässerelementen, der Tiefe und des Querschnittes in aquatischen Bereichen verwendet. Unterschiedliche Abflüsse an den Untersuchungsterminen einer Probestelle erforderten die Normierung der Daten des Jahres 2004. Hierzu wurde für jeden in 2004 aufgenommenen Transekt ein virtueller Wasserstand, der dem Wasserstand beim Abfluss des Untersuchungstermines in 2005 entspricht, berechnet. Nach dieser Datenstandardisierung wurden virtuelle Querschnitte, Tiefen- und Breitenparameter des Jahres 2004 mit den reellen Daten von 2005 verglichen.

Mittlere Wassertiefe, Breite, Querschnitt und durch Erosion veränderbare Bereiche wurden im Laufe eines Jahres durch normale Erosion und ein abflussstarkes Hochwasser im Winter 2004/05 verändert. Diese Veränderungen waren für die verzweigten Flussabschnitte signifikant größer als für die unverzweigten. Beim Vergleich natürlicher und renaturierter verzweigter Flussabschnitte, zeigten letztere signifikant größere Veränderungen der oben genannten Parameter. Diese größeren Veränderungen sind durch besser erodierbare Ufer erklärbar, da die Uferbefestigung und –vegetation durch Renaturierungsmaßnahmen maschinell entfernt wurden. Ebenso wurde schwer erodierbarer Auenlehm abgeschoben, so dass die laterale Verlagerung der Flüsse erleichtert wird. Die natürlich verzweigten Flussabschnitte sind in diesen Punkten hinsichtlich der Dynamik eingeschränkt und müssen z.B. Auenlehm aus eigener Kraft erodieren. An der Eder, deren Einzugsgebiet stark landwirtschaftlich genutzt wird, ist Ufer- und Auenvegetation selten bis gar nicht vorhanden, so dass der Strukturbildner Totholz im Gewässer fehlt. An der Orke finden sich am Hauptarm noch alte Uferbefestigungen, die nur langsam vom Fluss erodiert werden. Es kann geschlossen werden, dass selbst initiierte Wiederverzweigungen (repräsentiert durch die natürlich verzweigten Flussabschnitte) geringere Veränderungen aufweisen und somit lange Zeiträume benötigen um morphologische Unterschiede zu bewirken.

Die Ergebnisse zeigen, dass an den verzweigten Flussabschnitten nicht nur eine höhere Habitatdiversität auftritt, sondern an diesen durch die Ermöglichung dynamischer Prozesse ein wesentliches Merkmal natürlicher Gewässer erfüllt wird (Ward *et al.*, 2002b).

Die Hypothese "*Verzweigte Flussabschnitte besitzen eine höhere Sedimentdynamik*" wird somit unterstützt.

### *3 Substratspezifische Makrozoobenthos-Gemeinschaften innerhalb der Flussabschnitte*

Insgesamt wurden 199 habitatspezifische Makrozoobenthos-Aufsammlungen mit Hilfe eines Shovel-Samplers (25 cm x 25 cm, 500 µm Maschenweite) durchgeführt. Die in den Flussabschnitten vorgefundenen Substrattypen wurden unabhängig von ihrer relativen Häufigkeit beprobt.

Die Substrattypen der unverzweigten und verzweigten Flussabschnitte wurden in Hinsicht auf taxonomische Kennzahlen (Anzahl Taxa, Abundanz, Shannon-Wiener-Index, Bray-Curtis-Ähnlichkeit) analysiert. Die Analyse der Ähnlichkeiten der Substratbesiedlung zwischen den jeweiligen Flussabschnitten mittels "nicht-metrischer multi-dimensionaler Skalierung" (NMS) diente der Überprüfung und bildhaften Darstellung der Ergebnisse. Die Nestedness ("Schachtelung"; Atmar und Patterson, 1993) der Proben wurde berechnet, um Gesetzmäßigkeiten der Artenzusammensetzung zu analysieren. Die Nestedness ist hoch, wenn artenärmere Gemeinschaften Teilmengen von artenreicheren Gemeinschaften sind. Auf Grund der Annahme, dass

es in den unverzweigten Flussabschnitten weniger Arten gibt, diese jedoch in allen Substrattypen zu finden sind, sollten unverzweigte Flussabschnitte eine höhere Nestedness aufweisen als verzweigte. Auf die Substrate bezogen sollte die Nestedness in Substrattypen der verzweigten Flussabschnitte höher sein, da eine stärkere Differenzierung der Makrozoobenthos-Gemeinschaft angenommen wird.

Ein Vergleich der Besiedlung einzelner Substrattypen in unverzweigten und verzweigten Flussabschnitten zeigt gleich hohe Taxazahlen, Abundanzen und Evenness, unabhängig von der Gerinneform des Flussabschnittes. Die NMS-Analysen bestätigte die ähnliche Besiedlung der einzelnen Substrattypen in unverzweigten und verzweigten Flussabschnitten. Im Gegensatz dazu waren die einzelnen Substrattypen unterschiedlich besiedelt. Drei Gruppen wurden unterschieden: Holz und lebende Teile terrestrischer Pflanzen bildeten eine Gruppe, CPOM und organischer Schlamm sowie alle übrigen mineralischen Substrattypen bildeten die anderen beiden Gruppen. Die Nestedness war im Mittel gleich in unverzweigten und verzweigten Flussabschnitten und auch zwischen den Substrattypen. Nur in wenigen Fällen wurde die Erwartung unterschiedlicher Nestedness erfüllt. In den feinkörnigen Substrattypen Schlamm und Lehm und im organischen Substrattyp lebende Teile terrestrischer Pflanzen war die Nestedness der verzweigten Flussabschnitte höher, d.h. die Lebensgemeinschaften in den verschiedenen Substrattypen waren sich ähnlicher als in den Flussabschnitten. Aus den Ordnungen der Coleoptera, Trichoptera und Ephemeroptera kamen 15 Arten ausschließlich in den verzweigten Flussabschnitten vor. Diese Taxa wurden in feinmineralischen Substraten (Lehm und Sand) und in organischen Substraten (lebende Teile terrestrischer Pflanzen, CPOM und auf Holz) gefunden. Acht andere Arten aus den genannten Ordnungen wurden ausschließlich in den unverzweigten Flussabschnitten gefunden, zumeist in organischen Substrattypen.

Die Ergebnisse zeigen, dass die Besiedlung von Substrattypen, die in unverzweigten und verzweigten Flussabschnitten vorkommen, trotz erhöhter Habitatdiversität in den verzweigten Flussabschnitten unverändert bleibt. Organische oder feinmineralische Substrattypen zeigten am deutlichsten das Habitatpotential für zusätzliche Taxa. Trotz erhöhter Habitatdiversität traten diese Substrattypen immer noch selten (<5% Häufigkeit) auf, zeigten gleichzeitig jedoch die deutlichsten Veränderungen der Besiedlung im Vergleich der unverzweigten und verzweigten Flussabschnitte. Die Besiedlung eines Flussabschnittes ließe sich demnach nur über die Habitatdiversität selbst steuern, d.h. über ein möglichst vielfältiges Angebot verschiedener aquatischer Habitate in ausreichender Menge und Größe.

Die Hypothese *"Gleiche Habitats weisen an verzweigten Flussabschnitten eine vielfältigere Besiedlung auf als an unverzweigten Flussabschnitten"* kann durch die Ergebnisse nicht bestätigt werden.

#### *4 Habitatzusammensetzung und Makrozoobenthos-Gemeinschaften der Flussabschnitte*

Im Mittelpunkt dieses Teils der vorliegenden Arbeit stand der Vergleich der Makrozoobenthos-Gemeinschaften und ihrer ökologischen Merkmale zwischen den Flussabschnitten sowie deren Bezug zu hydromorphologischen Metrics. Eine Hauptkomponentenanalyse (PCA) bestätigte Gradienten zwischen unverzweigten und verzweigten Flussabschnitten für die folgenden Metrics: Fläche eines Flussabschnitts, mittlere Breite, Anzahl und Diversität der Flussbereiche, die Indices der Substratdiversität und Strömungs- und Tiefenvarianz. Für unverzweigte Flussabschnitte ist des Weiteren die Fläche großer mineralischer Substrattypen (Blöcke, Schotter) charakteristisch, während feinmineralische und organische Substrattypen typisch für verzweigte Flussabschnitte sind. Zur Erstellung einer Taxaliste für einen gesamten Flussabschnitt wurden die Teillisten der verschiedenen Substrattypen unter Berücksichtigung des jeweiligen im Freiland erhobenen Flächenanteils rechnerisch zu einer Gesamtprobe vereinigt. Die Makrozoobenthos-Gemeinschaften der Flussabschnitte wurden über taxonomische Kennzahlen und eine Clusteranalyse verglichen. Die ökologischen Merkmale der Makrozoobenthos-Fauna wurden durch Metrics dargestellt, die die funktionellen Beziehungen zwischen den Organismen und ihrem Lebensraum beschreiben. Hierzu gehören die Zusammensetzung der Makrozoobenthos-Gemeinschaft hinsichtlich der Präferenz innerhalb der längszonalen Gliederung eines Flusses, der Strömung, des Habitats (auf den Substrattyp bezogen), und des Ernährungstypes. Die ökologischen Metrics wurden mit Hilfe des Programms ASTERICS berechnet. Die Zusammenhänge zwischen hydromorphologischer Vielfalt und ökologischen Eigenschaften der Makrozoobenthos-Gemeinschaften wurden mit Hilfe von Spearman Rang Korrelationen untersucht. Zur Analyse wurden jene biologischen Metrics ausgewählt, die eine Reaktion auf veränderte Bedingungen durch den Wandel der Gerinneform erwarten ließen, z.B. durch veränderte Strömungsbedingungen, verändertes Nahrungsangebot, Potamalisierung u.ä.. Die Hydromorphologie der Flussabschnitte wurde durch die bereits vorgestellten Metrics parametrisiert. Für jede Kombination aus hydromorphologischen und biologischen Metrics wurde a priori die erwartete Korrelationsrichtung bestimmt. Eine positive Korrelation drückt aus, dass mit zunehmender hydromorphologischer Diversität auch die biologischen Metrics ansteigen. Eine negative Richtung drückt aus, dass mit zunehmender hydromorphologischer Diversität die biologischen Metrics abnehmen. Diese erwartete Richtung wurde dann mit der realen Korrelation verglichen.

Die Makrozoobenthos-Gemeinschaften glichen sich in unverzweigten und verzweigten Flussabschnitten hinsichtlich Abundanzen, Taxazahlen und Evenness. Mit 69 bis 88 % ist die Bray-Curtis-Ähnlichkeit der jeweiligen Flussabschnittspaare sehr hoch. Die Clusteranalyse bestätigte dies und legt übergeordnete Einflüsse nahe, die die Lebensgemeinschaften strukturieren. Probestellen mit natürlich entstandenen verzweigten Flussabschnitten wurden zuerst abgetrennt; ebenso bilden zwei der Probestellen, die deutlich größere Einzugsgebiete besitzen, eine eigene Untergruppe. Durch Spearman Rang Korrelationsanalyse wurden 560 Metric-Kombinationen überprüft. Fast 40 % der erwarteten Korrelationsrichtungen stimmten mit der berechneten überein, fast genauso viele Paarungen zeigten keine Korrelation (35 %) und rund 25 % unterschieden sich in Erwartung und Realität. 5,5 % der Korrelationen waren signifikant ( $p < 0,1$ ). Positive Korrelationen ergaben sich u.a. für Taxazahl, Anzahl EPTCBO<sup>3</sup>, Evenness und habitatbezogene Metrics, wie dem Anteil der Phytalbesiedler, limno- bis rheophiler Arten oder epipotamaler Arten. Eine negative Korrelation hingegen zeigte sich beim Anteil rheobionter Taxa oder beim Anteil der Metarhithral-Taxa.

Die veränderten hydromorphologischen Bedingungen spiegelten sich zum Teil in den ökologischen Merkmalen der Makrozoobenthos-Gemeinschaften wieder. So indizieren die ökologischen Metrics ein vermehrtes Auftreten von strömungsberuhigten Bereichen, die ein leitbildkonformes Habitatelement in verzweigten Flussabschnitten darstellen. Insgesamt waren die Korrelationen aber schwach ausgeprägt und variabel, so dass kein Effekt ableitbar ist. Das erweiterte Strukturangebot wird zunächst von mobilen Organismen genutzt. Die vagilen Coleoptera und Trichoptera stellen die Mehrzahl der Taxa, die nur in verzweigten Flussabschnitten vorkommen. In diesen Abschnitten wurden sie hauptsächlich auf organischen Substrattypen gefunden. Diese Ergebnisse geben Hinweise auf sensible Lebensräume, die bei Renaturierungsmaßnahmen besonders gefördert werden sollten, um positive Effekte auf das Makrozoobenthos zu erzielen.

Die Hypothese *"Verzweigte Flussabschnitte sind vielfältiger besiedelt und die ökologischen Eigenschaften der Lebensgemeinschaften werden durch die Habitatdiversität beeinflusst"* wird durch die Ergebnisse nicht unterstützt.

### *Schlussfolgerungen*

Die signifikante Erhöhung der Struktur- und aquatischen Habitatvielfalt sowie die erhöhte Dynamik in den verzweigten Flussabschnitten zeigt in den untersuchten Flussabschnitten keine messbaren Auswirkungen auf die Makrozoobenthos-Gemeinschaften. Hierfür gibt es mehrere Gründe. An den in der vorliegenden Arbeit untersuchten Gewässern ist die Größe der Renatu-

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<sup>3</sup> Anzahl der Taxa der Ordnungen Ephemeroptera (Eintagsfliegen), Plecoptera (Steinfliegen), Trichoptera (Köcherfliegen), Coleoptera (Käfer), Bivalvia (Muscheln) und Odonata (Libellen).

rierungsmaßnahmen im Vergleich zum oberhalb liegenden Gebiet scheinbar zu gering, so dass die übergeordnete Belastungssituation im Einzugsgebiet entscheidenderen Einfluss auf die Fauna hat als die singuläre Maßnahme selbst. Zudem liegen die Flussabschnitte isoliert in langen morphologisch degradierten Flussabschnitten. Die verzweigten Flussabschnitte sind mit ca. 200 m Länge vergleichsweise kurz und betragen höchstens 2 % der gesamten Fließstrecke. Unter Berücksichtigung der Länge des verzweigten Referenzzustandes wurde geschätzt, dass potentiell 25 bis 75 % der Fließstrecke verzweigt sein könnten. Auch die Menge von strukturförderndem Totholz ist gering und liegt weit unter der des angenommenen Referenzzustandes (Kail und Hering, 2005). In Bezug auf das Makrozoobenthos lassen sich die geringen Unterschiede am ehesten durch artenarme Metapopulationen erklären. Die in den vorwiegend anthropogen geprägten Einzugsgebieten für die Wiederbesiedlung zur Verfügung stehenden Metapopulationen sind vermutlich verarmt, doch von ihnen hängen in großem Maße Qualität und Quantität der Wiederbesiedlung ab (Gore, 1985; Marchant *et al.*, 1991).

Unter Berücksichtigung der potentiell verzweigten Fließgewässerabschnittslängen in Mittelgebirgsregionen in Deutschland wurde eine mittlere Distanz von fast 14 km als "Wiederbesiedlungsraaster" überschlägig berechnet. Werden also Flussabschnitte nicht direkt aus flussauf- oder flussabwärts liegenden Bereichen wieder besiedelt, so müsste im Schnitt diese Distanz fliegend zurück gelegt werden. Durch die geringe Anzahl und Länge der verzweigten Flussabschnitte sinkt die Wahrscheinlichkeit eines erfolgreichen Wiederbesiedlungsversuches aus der Luft. Hinzu kommt die Lage der größeren Fließgewässer in Tälern, voneinander getrennt durch Bergzüge, oder durch landwirtschaftliche oder urbane Flächen getrennt, die mögliche Wiederbesiedlungsflüge behindern.

Die vorliegende Arbeit zeigt, dass leitbildkonforme verzweigte Flussabschnitte hydromorphologisch erheblich diverser sind als die vielerorts anthropogen stark überformten unverzweigten Flussabschnitte. Auswirkungen auf die aquatische wirbellose Fauna sind bisher aber nicht oder nur in ganz geringem Maße feststellbar. Die Lebensgemeinschaften sind von einer ganzen Reihe übergeordneter Faktoren beeinflusst, z.B. der unveränderten Landnutzung im Einzugsgebiet. Durch vermutlich verarmte Metapopulationen erfolgt die Wiederbesiedlung gleichförmig.

Um eine nachhaltige Veränderung auch des Makrozoobenthos in Richtung des Leitbildes zu erreichen, sind zahlreiche und großflächigere Renaturierungsmaßnahmen im Einzugsgebiet notwendig, so dass sich übergreifende Metapopulationen ausbilden können. Gleichzeitig ist darauf zu achten, dass sich der Anteil hochwertiger Habitats, wie z.B. Totholz stark erhöht. Und, zumindest in größeren Gewässern, sollten lange Zeiträume eingeplant werden, ehe ein guter ökologischer Zustand erreicht werden kann.

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## Appendix

Appendices are available on the enclosed CD-ROM.

- Appendix 1      Formulas for hydromorphological metrics.
- Appendix 2      Substrate mosaic, example Lahn-W.
- Annotation to Appendices 3 to 9.
- Appendix 3-A    Taxa lists of substrate samples: Lahn-C, single-channel section.
- Appendix 3-B    Taxa lists of substrate samples: Lahn-C, multiple-channel section.
- Appendix 4-A    Taxa lists of substrate samples: Orke, single-channel section.
- Appendix 4-B    Taxa lists of substrate samples: Orke, multiple-channel section.
- Appendix 5      Taxa lists of substrate samples: Lahn-W single- and multiple-channel section.
- Appendix 6      Taxa lists of substrate samples: Lahn-LH single- and multiple-channel section.
- Appendix 7      Taxa lists of substrate samples: Eder single- and multiple-channel section.
- Appendix 8      Taxa lists of substrate samples: Nims single- and multiple-channel sections.
- Appendix 9      Taxa lists of substrate samples: Bröl single- and multiple-channel section.
- Appendix 10     Physico-chemical parameters of multiple-channel samples.
- Appendix 11-A   Spearman rank correlation: Input hydromorphological metrics.
- Appendix 11-B   Spearman rank correlation: Input biological metrics.
- Appendix 11-C   Spearman rank correlation: A priori formulated correlation direction.

**Appendix 1.** Formulas for hydromorphological metrics.

Braiding-Index (Brice, 1960)

$$BI = \frac{2 * (\text{sum of lengths of all islands \& bars in the reach})}{\text{centreline length of the reach}}$$

Shannon-Wiener-Index (Shannon and Weaver, 1949)

$$H' = -1 \times \sum \left( \frac{n_j}{N} \right) \times \ln \left( \frac{n_j}{N} \right)$$

 $n_j$  = Number of features of each group  $j$  $N$  = Sum of channel features / substrates

This index considers the number of channel features or substrates and the proportion of each feature (substrate) within a section. The index is increased either by an increased number of features or substrates, and by a more even distribution of these.

Spatial-Diversity-Index (Fortin *et al.*, 1999)

$$SDI = \sum_{i=1}^s \frac{\text{number of patches of substrate } i}{\text{range of area occupied by substrate } i}$$

The Spatial-Diversity-Index (Fortin *et al.*, 1999) was originally developed for forest ecosystems for transect-point recordings. A ratio of 1 characterises isolated substrate patches, the value of the ratio decreases as the patches increase in area.

**Appendix 2.** Substrate mosaic, example Lahn-W; single-channel (top) and multiple-channel section (bottom); T (rows) = transect; No.1–20 (columns) = point of record; Substrates: 1 = blocks; 2 = cobble; 3 = coarse gravel; 4 = fine gravel; 5 = sand; 6 = loam; 10 = living parts of terrestrial plants; 11 = large wood; 12 = cpm.

T	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1		1			2				3						2					3
2		1										2								11
3			1										2							11
4			1											2						
5		1										2								11
6	1											2								11
7	1											2								11
8										2										10
9										2										11
10										2										10
11	1											2								11
12	1												2							
13	1												2							
14			1											2						
15		1											2							
16										2										10

T	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
17	2		3			5			3		5		3	2	3					10
18	11	3	4			3		1	3	2	5		3	2	3					10
19			3			2	3	2	3		2	10	5	10		2			3	1
20			3			2	3	11	3	5					2					3
21	2	3		2		3	1	5	1	10	5	14	2	5	1	2	1			2
22	6		3			12				2			11	1	3	2				3
23	5	3	2	3		2		10	5	11		3		2	1	3	2			3
24	11				2					3			5	11	10	4	3	2		3
25	3						2						11		3			2		3
26	3			2			3		2		1	11		3	2	3		2		3
27	2	5			3					2							3			11
28	1	1				3				2			3				5		2	3
29	1								2								5	3		2
30	1			2			3			2			11	5	12		3		2	3
31	1									2										3
32	1							2							3	2	10	3	5	3

### Annotation to Appendices 3 to 9.

Appendix 3 to 9 contain taxa lists of all substrate specific samples.

**Tabelle IV:** Sample code explanation: Site\_Section\_Substrate+Sample No.

Site	Section	Substrate	Sample No.
Lahn-W	1 (single-channel)	block	1
Lahn-LH	2 (multiple-channel)	cobble	2
Lahn-C		c-gravel (coarse gravel)	3-8 only Lahn-C and Orke
Orke		f-gravel (fine gravel)	
Eder		sand	
Nims		loam	
Bröl		lptp (living parts of terrestrial plants)	
		subM (submerged macrophytes)	
		wood (large wood)	
		cpom (coarse particulate organic matter)	
		mud	
		pool (floodplain pool, only Lahn-C and Orke)	

→ e.g. Eder\_1\_block1

- Samples of Lahn-C and Orke are split according to single- and multiple-channel section samples, Appendix are marked (A) and (B) respectively. For general overview taxa of the whole site are listed, rows are shaded grey when taxa occur zero frequent in a section.
- Bold marked samples were randomly chosen for section taxa lists (Chapter 4).
- All other sites list single- and multiple-channel section samples together.
- Taxon names as used in ASTERICS 3.01.

Abbreviations of taxa groups:

Tu	Turbellaria	Pl	Plecoptera
Ga	Gastropoda	He	Heteroptera
Bi	Bivalvia	Pp	Planipennia
Ol	Oligochaeta	Me	Megaloptera
Hi	Hirudinea	Tr	Trichoptera
Cr	Crustacea	Co	Coleoptera
Ep	Ephemeroptera	Di	Diptera
Od	Odonata		

**Appendix 3-A.** Taxa lists of substrate samples: Lahn-C, single-channel section (Ind. m<sup>-2</sup>). Grey rows are taxa of Lahn-C multiple-channel section with zero occurrence here. Bold marked samples randomly chosen for section taxa lists (Chapter 4). Information on sample code and abbreviations see p 129.

Taxa group	Taxon	<b>Lahn-C_1_block1</b>	Lahn-C_1_block2	<b>Lahn-C_1_cobble1</b>	Lahn-C_1_cobble2	Lahn-C_1_cgravel1	Lahn-C_1_cgravel2	Lahn-C_1_cgravel3	<b>Lahn-C_1_cgravel4</b>	Lahn-C_1_cgravel5	Lahn-C_1_cgravel6	Lahn-C_1_cgravel7	Lahn-C_1_cgravel8	<b>Lahn-C_1_loam1</b>	<b>Lahn-C_1_lptp1</b>	Lahn-C_1_lptp2	<b>Lahn-C_1_wood1</b>	Lahn-C_1_wood2	Lahn-C_1_cpom1	<b>Lahn-C_1_cpom2</b>	Lahn-C_1_mud1	<b>Lahn-C_1_mud2</b>
Tu	Dugesia sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<b>0</b>
Tu	Polycelis sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	240	64	0	0	0	0	0	0
Tu	Turbellaria Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0
Ga	Ancylus fluviatilis	0	0	16	0	0	0	0	0	16	0	0	32	0	0	0	0	0	0	0	32	0
Ga	Hippeutis complanatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bi	Pisidium sp.	16	0	0	0	0	0	0	0	0	0	16	0	448	0	0	0	0	144	112	432	192
Ol	Eiseniella tetraedra	0	0	0	0	0	0	0	0	0	0	32	16	0	0	0	0	0	0	0	0	0
Ol	Naididae/Tubificidae Gen. sp.	16	0	0	0	256	48	32	0	0	352	624	0	112	0	0	0	0	32	0	144	480
Ol	Oligochaeta Gen. sp.	1	0	0	32	1	1	1	16	0	96	1	1	16	0	0	0	0	1	0	1	1
Ol	Stylodrilus heringianus	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hi	Erpobdella octoculata	0	0	32	112	32	0	0	0	0	48	0	16	0	16	0	0	16	160	64	256	16
Hi	Erpobdella vilnensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hi	Glossiphonia complanata	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0
Hi	Glossiphonia nebulosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0
Hi	Glossiphonia verrucata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hi	Glossiphonia sp.	0	0	0	0	16	0	0	0	0	0	0	0	16	0	0	0	0	0	1	32	0
Hi	Helobdella stagnalis	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0	304	96
Cr	Asellus aquaticus	160	0	0	16	400	0	80	0	16	16	0	16	288	2816	368	16	0	1088	1472	543	480
Cr	Gammarus fossarum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	80	0	0	0	0	0	0
Cr	Gammarus pulex	0	16	0	0	16	0	0	16	0	0	0	0	0	0	0	144	0	0	0	32	0
Cr	Gammarus roeselii	1232	1488	16	16	1040	0	208	112	16	16	0	0	704	1472	3008	0	64	9056	2464	3264	560
Cr	Gammarus sp.	96	64	1	96	224	64	112	48	48	1	16	32	576	64	544	0	16	1792	256	624	1504
Cr	Niphargus sp.	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cr	Proasellus coxalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	64	32	33	0
Ep	Baetis buceratus/vernus	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
Ep	Baetis fuscatus	0	0	48	0	0	0	48	0	16	0	0	0	0	0	0	0	0	0	0	0	0
Ep	Baetis fuscatus/scambus	0	0	1	1	0	0	32	64	1	33	0	256	0	0	0	0	0	0	0	0	0
Ep	Baetis lutheri	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ep	Baetis rhodani	48	0	0	0	0	0	128	0	0	83	16	224	16	0	16	96	16	0	0	0	0
Ep	Baetis scambus	0	0	0	32	0	0	0	0	0	132	0	32	0	0	0	0	0	0	0	0	0
Ep	Baetis vernus	16	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	32	0	0	0	0
Ep	Baetis sp.	1	0	1	80	48	0	208	16	1	232	16	272	1	0	80	32	16	0	0	0	0
Ep	Caenis luctuosa	16	0	0	48	400	16	160	0	0	0	0	0	288	0	0	0	0	848	752	608	384

Appendix 3-A continued.

Taxa group	Taxon	Lahn-C_1_block1	Lahn-C_1_block2	Lahn-C_1_cobble1	Lahn-C_1_cobble2	Lahn-C_1_cgravel1	Lahn-C_1_cgravel2	Lahn-C_1_cgravel3	Lahn-C_1_cgravel4	Lahn-C_1_cgravel5	Lahn-C_1_cgravel6	Lahn-C_1_cgravel7	Lahn-C_1_cgravel8	Lahn-C_1_loam1	Lahn-C_1_lptp1	Lahn-C_1_lptp2	Lahn-C_1_wood1	Lahn-C_1_wood2	Lahn-C_1_cpom1	Lahn-C_1_cpom2	Lahn-C_1_mud1	Lahn-C_1_mud2
Ep	Centroptilum luteolum	48	0	0	0	0	0	0	0	0	0	0	0	16	16	0	0	16	0	0	0	0
Ep	Ecdyonurus venosus-Gr.	0	0	0	64	0	0	48	48	0	32	16	32	0	0	16	0	0	0	0	0	0
Ep	Ephemera danica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ep	Habrophlebia lauta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0
Ep	Potamanthus luteus	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0
Ep	Procloeon pulchrum	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0
Ep	Procloeon sp.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Ep	Serratella ignita	2608	704	48	256	80	224	1248	576	0	672	576	960	80	48	1296	240	704	6912	768	96	16
Od	Calopteryx sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0
Pl	Leuctra geniculata	0	0	0	16	96	16	80	112	32	0	16	32	0	0	0	0	0	16	0	0	0
Pl	Leuctra sp.	16	0	0	0	128	0	48	160	64	256	256	256	0	0	0	0	16	0	0	16	0
Pl	Siphonoperla torrentium	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0
He	Micronectinae Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pp	Sisyra sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0
Me	Sialis fuliginosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0
Me	Sialis lutaria	0	0	0	0	0	0	0	0	0	0	0	0	48	0	0	0	0	0	0	304	16
Me	Sialis sp.	0	16	0	0	16	0	48	0	0	0	0	0	304	0	0	0	0	224	80	144	304
Tr	Anomalopterygella chauviniana	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0
Tr	Athripsodes albifrons	80	16	0	32	20	0	0	113	96	192	199	48	0	32	46	0	32	48	32	0	0
Tr	Athripsodes bilineatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0
Tr	Athripsodes cinereus	48	0	0	48	60	0	16	95	0	0	25	0	224	0	162	0	0	288	96	96	16
Tr	Brachycentrus subnubilus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Ceraclea albimacula/alboguttata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0
Tr	Ceraclea dissimilis	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	32	0	0	0
Tr	Cheumatopsyche lepida	16	16	32	16	16	0	48	112	128	64	144	112	0	0	0	0	48	0	0	0	0
Tr	Cyrnus trimaculatus	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Goera pilosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Hydropsyche incognita	0	0	16	0	0	0	0	16	16	16	0	32	0	0	0	0	0	0	0	0	0
Tr	Hydropsyche instabilis	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0
Tr	Hydropsyche pellucidula	0	0	0	0	0	0	0	16	0	0	16	16	0	0	0	0	0	16	0	0	0
Tr	Hydropsyche siltalai	0	0	0	0	0	0	16	16	32	48	16	160	0	0	16	16	16	0	0	0	0
Tr	Hydropsyche sp.	0	0	1	16	0	0	16	48	64	112	240	624	0	0	32	1	1	1	0	0	0
Tr	Hydroptila sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Lepidostoma hirtum	0	16	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	64	16	0	0

Appendix 3-A continued.

Taxa group	Taxon	Lahn-C_1_block1	Lahn-C_1_block2	Lahn-C_1_cobble1	Lahn-C_1_cobble2	Lahn-C_1_cgravel1	Lahn-C_1_cgravel2	Lahn-C_1_cgravel3	Lahn-C_1_cgravel4	Lahn-C_1_cgravel5	Lahn-C_1_cgravel6	Lahn-C_1_cgravel7	Lahn-C_1_cgravel8	Lahn-C_1_loam1	Lahn-C_1_lptp1	Lahn-C_1_lptp2	Lahn-C_1_wood1	Lahn-C_1_wood2	Lahn-C_1_cpom1	Lahn-C_1_cpom2	Lahn-C_1_mud1	Lahn-C_1_mud2
Tr	<i>Lype reducta</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	<i>Mystacides azurea</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	16	0	0
Tr	<i>Mystacides longicornis/nigra</i>	16	0	0	0	0	0	0	0	0	0	0	0	32	48	0	0	0	96	16	0	0
Tr	<i>Oecetis testacea</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	<i>Plectrocnemia</i> sp.	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	<i>Polycentropus flavomaculatus</i>	48	80	16	160	0	16	32	32	16	0	16	0	0	48	80	0	32	240	0	0	0
Tr	<i>Potamophylax cingulatus/latipennis/luctuosus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	<i>Psychomyia pusilla</i>	64	0	0	16	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0
Tr	<i>Rhyacophila dorsalis/nubila</i>	0	0	0	0	0	0	0	0	96	0	16	128	0	0	0	128	0	16	0	0	0
Tr	<i>Silo</i> sp.	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0
Co	<i>Elmis aenea</i> Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	64	0	40	0	0	0	0
Co	<i>Elmis maugetii</i> Ad.	112	0	0	16	0	0	0	0	48	0	16	32	0	0	64	240	40	0	0	0	0
Co	<i>Elmis obscura</i> Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0
Co	<i>Elmis rioloides</i> Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	<i>Elmis</i> sp. Lv.	80	0	0	48	16	0	0	48	64	16	96	176	0	0	16	16	96	160	0	16	0
Co	<i>Esolus angustatus</i> Ad.	0	0	0	0	0	0	0	0	128	0	0	0	0	0	0	0	0	0	0	0	0
Co	<i>Esolus parallelepipedus</i> Ad.	0	0	0	0	32	0	0	64	0	32	96	128	0	0	0	0	0	0	0	0	0
Co	<i>Esolus</i> sp. Lv.	0	0	0	0	64	0	32	32	48	256	176	160	0	0	0	0	0	32	0	0	0
Co	<i>Helophorus brevipalpis</i> Ad.	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	32	0	16	0	0
Co	<i>Helophorus flavipes</i> Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0
Co	<i>Hydraena excisa</i> Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	<i>Hydraena gracilis</i> Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	<i>Hydraena minutissima</i> Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	<i>Hydraena</i> sp. Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0
Co	<i>Hydroporinae</i> Gen. sp. Lv.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0
Co	<i>Limnius opacus</i> Lv.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	<i>Limnius volckmari</i> Ad.	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0
Co	<i>Limnius volckmari</i> Lv.	16	0	0	0	320	0	0	0	0	176	64	16	0	0	0	0	0	32	64	0	48
Co	<i>Nebrioporus elegans</i> Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	<i>Nebrioporus</i> sp. Lv.	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	32	0	0	0
Co	<i>Ochthebius bicolon</i> Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0
Co	<i>Orectochilus villosus</i> Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0
Co	<i>Oulimnius tuberculatus</i> Ad.	672	0	0	0	128	0	64	16	64	48	16	32	32	576	176	112	128	48	0	0	0
Co	<i>Oulimnius tuberculatus</i> Lv.	112	32	0	16	208	16	0	16	16	192	48	16	0	0	0	0	16	48	112	0	16

Appendix 3-A continued.

Taxa group	Taxon	Lahn-C_1_block1	Lahn-C_1_block2	Lahn-C_1_cobble1	Lahn-C_1_cobble2	Lahn-C_1_cgravel1	Lahn-C_1_cgravel2	Lahn-C_1_cgravel3	Lahn-C_1_cgravel4	Lahn-C_1_cgravel5	Lahn-C_1_cgravel6	Lahn-C_1_cgravel7	Lahn-C_1_cgravel8	Lahn-C_1_loam1	Lahn-C_1_lptp1	Lahn-C_1_lptp2	Lahn-C_1_wood1	Lahn-C_1_wood2	Lahn-C_1_cpom1	Lahn-C_1_cpom2	Lahn-C_1_mud1	Lahn-C_1_mud2
Co	Platambus maculatus Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	Stictotarsus duodecimpustulatus Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Di	Antocha sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Di	Atherix/Ibisia sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0
Di	Ceratopogoninae Gen. sp.	0	0	0	0	64	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0
Di	Chironomidae Gen. sp.	2144	1920	48	256	320	64	560	160	128	640	320	1296	1	16	80	720	1248	368	976	256	336
Di	Chironomini Gen. sp.	487	1716	77	96	260	96	295	44	176	96	41	168	752	0	48	224	400	1968	4051	528	3173
Di	Clinocerinae Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Di	Culicidae Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Di	Dicranota sp.	16	0	0	0	192	0	0	0	48	144	128	256	0	0	0	0	0	0	0	0	16
Di	Ephydriidae Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Di	Limnophila sp.	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Di	Lispe sp.	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Di	Prodiamesa olivacea	0	16	0	0	64	0	0	0	0	0	0	0	224	0	0	0	0	32	736	272	13696
Di	Psychodidae Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Di	Simulium sp.	32	0	0	16	0	0	16	0	0	0	0	0	0	0	0	64	0	0	0	0	0
Di	Tabanidae Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Di	Tanypodinae Gen. sp.	400	160	16	48	0	0	96	16	16	16	0	32	560	0	32	32	32	544	128	16	1392
Di	Tanytarsini Gen. sp.	2873	988	19	304	764	0	137	132	0	128	247	152	320	32	16	32	176	464	3389	80	6203

**Appendix 3-B.** Taxa lists of substrate samples: Lahn-C, multiple-channel section (Ind. m<sup>-2</sup>). Grey rows are taxa of Lahn-C single-channel section with zero occurrence here. Bold marked samples randomly chosen for section taxa lists (Chapter 4). Information on sample code and abbreviations see p 129.

Taxa group	Taxon	Lahn-C_2_block1	Lahn-C_2_block2	Lahn-C_2_cobble1	Lahn-C_2_cobble2	Lahn-C_2_cgravel1	Lahn-C_2_cgravel2	Lahn-C_2_cgravel3	Lahn-C_2_cgravel4	Lahn-C_2_cgravel5	Lahn-C_2_cgravel6	Lahn-C_2_cgravel7	Lahn-C_2_cgravel8	C_2_fgravel1Lahn-	Lahn-C_2_fgravel2	Lahn-C_2_sand1	Lahn-C_2_sand2	Lahn-C_2_loam1	Lahn-C_2_loam2	Lahn-C_2_lptp1	Lahn-C_2_lptp2	Lahn-C_2_wood1	Lahn-C_2_wood2	Lahn-C_2_cpom1	Lahn-C_2_cpom2	Lahn-C_2_mud1	Lahn-C_2_mud2	Lahn-C_2_pool1	Lahn-C_2_pool2
Tu	Dugesia sp.	0	0	0	0	0	0	0	0	16	0	0	0	0	16	0	0	0	0	16	0	32	0	16	16	0	0	0	0
Tu	Polycelis sp.	0	0	96	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	176	0	0	96	16	0	0	
Tu	Turbellaria Gen. sp.	0	0	16	0	96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	48	48	0	0	0	
Ga	Ancylus fluviatilis	0	0	16	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	16	0	0	0	
Ga	Hippeutis complanatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	32	16	48	0	0	
Bi	Pisidium sp.	0	0	0	0	144	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	48	64	0	0	
Ol	Eiseniella tetraedra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Ol	Naididae/Tubificidae Gen. sp.	0	0	0	0	288	0	0	16	16	16	0	0	64	0	160	176	0	0	0	0	0	0	304	1808	592	976	736	80
Ol	Oligochaeta Gen. sp.	0	0	0	0	1	0	0	1	1	1	0	0	1	0	1	16	0	0	0	16	0	0	1	400	64	1	1	1
Ol	Stylodrilus heringianus	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Hi	Erpobdella octoculata	0	0	80	16	160	32	96	160	80	16	48	16	32	0	0	16	0	0	0	16	16	0	192	96	32	64	192	80
Hi	Erpobdella vilnensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	
Hi	Glossiphonia complanata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	
Hi	Glossiphonia nebulosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	16	0	
Hi	Glossiphonia verrucata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	16	0	0	
Hi	Glossiphonia sp.	0	0	0	0	16	0	0	16	16	0	0	0	0	0	0	0	0	0	0	0	1	0	0	176	16	1	1	0
Hi	Helobdella stagnalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	2320	80	112	128	0
Cr	Asellus aquaticus	0	0	528	32	1728	16	176	256	80	16	0	0	64	16	32	0	16	0	32	160	1648	80	4800	7376	448	640	256	112
Cr	Gammarus fossarum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cr	Gammarus pulex	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	32	0	32	16	0	0	0	0	0	0
Cr	Gammarus roeselii	0	0	48	0	3008	16	0	16	48	0	0	0	1824	32	1120	0	0	0	128	304	464	288	7280	16576	688	144	224	16
Cr	Gammarus sp.	0	0	32	32	736	48	16	32	80	0	64	16	2304	16	640	48	0	16	32	96	240	1	512	4160	800	1	160	1
Cr	Niphargus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cr	Proasellus coxalis	0	0	0	0	64	0	0	0	0	0	0	0	0	0	0	0	0	32	0	32	0	384	0	32	0	0	0	0
Ep	Baetis buceratus/vernus	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	16	0	1	0	1	1	0	0	0	0	0	0
Ep	Baetis fuscatus	0	0	0	224	0	32	0	0	0	0	16	0	0	0	0	16	16	0	0	0	0	0	0	0	0	0	0	0
Ep	Baetis fuscatus/scambus	16	0	64	1	0	112	0	1	240	160	48	0	48	48	16	0	1	1	0	112	0	16	0	32	0	0	0	0
Ep	Baetis lutheri	0	48	0	0	0	0	0	0	32	0	64	0	0	0	0	0	0	64	0	160	0	0	0	0	0	0	0	0
Ep	Baetis rhodani	0	80	224	368	0	64	0	0	64	80	912	16	288	0	32	0	0	64	144	624	0	0	0	0	0	0	0	0
Ep	Baetis scambus	0	0	0	0	0	112	0	32	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ep	Baetis vernus	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	16	0	32	0	16	16	0	0	0	0	0	0
Ep	Baetis sp.	16	1	32	304	0	32	16	1	16	112	480	1	128	1	32	16	1	96	1	160	0	16	0	16	0	0	0	0
Ep	Caenis luctuosa	0	0	0	0	16	0	0	0	0	0	0	0	0	0	32	16	0	0	0	0	32	0	208	320	80	32	64	32
Ep	Centroptilum luteolum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ep	Ecdyonurus venosus-Gr.	0	0	32	16	32	96	0	32	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0

Appendix 3-B continued.

Taxa group	Taxon	Lahn-C_2_block1	Lahn-C_2_block2	Lahn-C_2_cobble1	Lahn-C_2_cobble2	Lahn-C_2_cgravel1	Lahn-C_2_cgravel2	Lahn-C_2_cgravel3	Lahn-C_2_cgravel4	Lahn-C_2_cgravel5	Lahn-C_2_cgravel6	Lahn-C_2_cgravel7	Lahn-C_2_cgravel8	C_2_fgravel1	Lahn-C_2_fgravel2	Lahn-C_2_sand1	Lahn-C_2_sand2	Lahn-C_2_loam1	Lahn-C_2_loam2	Lahn-C_2_lptp1	Lahn-C_2_lptp2	Lahn-C_2_wood1	Lahn-C_2_wood2	Lahn-C_2_cpom1	Lahn-C_2_cpom2	Lahn-C_2_mud1	Lahn-C_2_mud2	Lahn-C_2_pool1	Lahn-C_2_pool2
Ep	Ephemera danica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	16	0	0	0	
Ep	Habrophlebia lauta	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Ep	Potamanthus luteus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Ep	Procloeon pulchrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Ep	Procloeon sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Ep	Serratella ignita	32	64	928	192	112	320	400	224	912	176	1088	80	1328	224	16	0	96	32	1456	6592	416	352	720	1840	0	0	0	16
Od	Calopteryx sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	
Pl	Leuctra geniculata	0	0	48	32	208	48	32	16	112	0	64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Pl	Leuctra sp.	0	0	160	272	96	80	16	0	96	0	560	48	64	0	0	0	0	0	0	32	0	0	0	0	0	0	0	
Pl	Siphonoperla torrentium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
He	Micronectinae Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	
Pp	Sisyra sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Me	Sialis fuliginosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Me	Sialis lutaria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	16	0
Me	Sialis sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	208	32	672	48	32	64
Tr	Anomalopterygella chauviniana	0	0	0	0	0	0	0	0	0	16	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tr	Athripsodes albifrons	0	0	0	0	102	32	0	48	160	64	16	0	32	48	16	0	0	0	32	48	80	0	0	64	0	0	0	0
Tr	Athripsodes bilineatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Athripsodes cinereus	0	0	0	0	186	0	0	0	0	0	0	16	0	48	16	0	0	0	0	0	0	0	80	160	16	0	64	0
Tr	Brachycentrus subnubilus	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Ceraclea albimacula/alboguttata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0
Tr	Ceraclea dissimilis	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	16	0	0	0	0	0
Tr	Cheumatopsyche lepida	0	0	0	128	16	32	0	32	16	16	192	0	0	0	0	0	0	0	80	96	80	0	0	16	0	0	0	0
Tr	Cyrnus trimaculatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Goera pilosa	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Hydropsyche incognita	0	0	0	0	16	0	0	0	0	0	32	16	0	16	0	0	0	0	0	16	16	0	0	0	0	0	0	0
Tr	Hydropsyche instabilis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Hydropsyche pellucidula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Hydropsyche sitalai	0	0	0	16	0	0	0	0	0	0	80	16	0	0	0	0	0	0	64	256	80	0	0	0	0	0	0	0
Tr	Hydropsyche sp.	0	0	0	144	1	16	0	0	32	0	912	16	0	32	0	0	16	16	80	1024	192	0	0	0	16	0	0	0
Tr	Hydroptila sp.	64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Lepidostoma hirtum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	32	0	48	16	0	0	0	0
Tr	Lype reducta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	336	0	0	0	0	0	0	0
Tr	Mystacides azurea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	0	0	0	0
Tr	Mystacides longicornis/nigra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 3-B continued.

Taxa group	Taxon	Lahn-C_2_block1	Lahn-C_2_block2	C_2_cobble1	Lahn-C_2_cobble2	Lahn-C_2_cgravel1	Lahn-C_2_cgravel2	Lahn-C_2_cgravel3	Lahn-C_2_cgravel4	Lahn-C_2_cgravel5	Lahn-C_2_cgravel6	Lahn-C_2_cgravel7	Lahn-C_2_cgravel8	Lahn-C_2_fggravel1	Lahn-C_2_fggravel2	Lahn-C_2_sand1	Lahn-C_2_sand2	Lahn-C_2_loam1	Lahn-C_2_loam2	Lahn-C_2_lptp1	Lahn-C_2_lptp2	Lahn-C_2_wood1	Lahn-C_2_wood2	Lahn-C_2_cpom1	Lahn-C_2_cpom2	Lahn-C_2_mud1	Lahn-C_2_mud2	Lahn-C_2_pool1	Lahn-C_2_pool2
Tr	Oecetis testacea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0
Tr	Plectrocnemia sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Polycentropus flavomaculatus	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Potamophylax cingulatus/latipennis/luctuosus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0
Tr	Psychomyia pusilla	64	0	0	0	16	16	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Rhyacophila dorsalis/nubila	0	16	0	80	0	0	0	48	0	0	224	16	0	0	0	0	0	16	32	336	128	32	0	0	0	0	0	0
Tr	Silo sp.	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	Elmis aenea Ad.	0	213	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0
Co	Elmis maugetii Ad.	0	61	112	48	0	0	16	16	48	16	128	32	0	0	0	0	0	0	96	1140	0	0	0	304	0	0	0	0
Co	Elmis obscura Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	Elmis rioloides Ad.	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0
Co	Elmis sp. Lv.	0	0	48	96	32	64	48	0	16	0	112	0	0	0	0	0	0	0	0	544	192	0	32	464	0	0	0	0
Co	Esolus angustatus Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	Esolus parallelepipedus Ad.	0	0	144	432	0	16	16	16	112	48	272	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0
Co	Esolus sp. Lv.	0	0	64	16	64	48	16	32	48	208	208	0	128	16	0	96	0	0	0	112	0	0	16	0	0	0	0	48
Co	Helophorus brevipalpis Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0
Co	Helophorus flavipes Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	Hydraena excisa Ad.	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	Hydraena gracilis Ad.	0	0	0	16	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	160	0	0	0	0	0	0	0	0
Co	Hydraena minutissima Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0
Co	Hydraena sp. Ad.	0	0	16	16	0	0	0	0	0	0	32	0	0	0	0	0	0	0	16	32	0	0	0	0	0	0	0	0
Co	Hydroporinae Gen. sp. Lv.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	Limnius opacus Lv.	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	Limnius volckmari Ad.	0	0	16	16	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	Limnius volckmari Lv.	0	0	0	32	64	48	0	16	48	240	224	0	64	0	0	16	0	0	0	16	16	0	0	64	16	16	0	16
Co	Nebrioporus elegans Ad.	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	Nebrioporus sp. Lv.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	Ochthebius bicolor Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	Orectochilus villosus Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0
Co	Oulimnius tuberculatus Ad.	0	416	32	64	48	64	0	32	64	64	16	0	64	16	0	0	0	0	0	176	80	0	32	1120	0	0	32	0
Co	Oulimnius tuberculatus Lv.	0	0	16	0	144	32	16	0	16	0	96	16	0	0	0	160	0	0	0	160	64	0	16	560	16	32	0	0
Co	Platambus maculatus Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	64	0	0	0	0	0	0	0
Co	Stictotarsus duodecimpustulatus Ad.	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 3-B continued.

Taxa group	Taxon	Lahn-C_2_block1	Lahn-C_2_block2	C_2_cobble1	Lahn-C_2_cobble2	Lahn-C_2_cgravel1	Lahn-C_2_cgravel2	Lahn-C_2_cgravel3	Lahn-C_2_cgravel4	Lahn-C_2_cgravel5	Lahn-C_2_cgravel6	Lahn-C_2_cgravel7	Lahn-C_2_cgravel8	Lahn-C_2_fggravel1	Lahn-C_2_fggravel2	Lahn-C_2_sand1	Lahn-C_2_sand2	Lahn-C_2_loam1	Lahn-C_2_loam2	Lahn-C_2_lptp1	Lahn-C_2_lptp2	Lahn-C_2_wood1	Lahn-C_2_wood2	Lahn-C_2_cpom1	Lahn-C_2_cpom2	Lahn-C_2_mud1	Lahn-C_2_mud2	Lahn-C_2_pool1	Lahn-C_2_pool2
Di	Antocha sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0
Di	Atherix/Ibisia sp.	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	16	0	0	208	0	0	0	32	0	0	0	0
Di	Ceratopogoninae Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	32	0	
Di	Chironomidae Gen. sp.	400	2448	1024	272	624	256	288	592	208	592	672	96	1152	14608	48	192	112	48	560	10768	400	752	160	2288	16	192	1	352
Di	Chironomini Gen. sp.	32	0	96	48	64	32	64	0	0	0	0	16	2068	1556	82	1186	48	16	0	640	112	140	3440	1840	304	6160	952	928
Di	Clinocerinae Gen. sp.	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Di	Culicidae Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0
Di	Dicranota sp.	0	0	0	192	128	48	16	32	0	80	512	32	0	176	0	16	0	0	0	16	0	0	0	0	0	0	0	0
Di	Ephydriidae Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0
Di	Limnophila sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Di	Lispe sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Di	Prodiamesa olivacea	0	0	0	0	0	0	0	0	0	0	0	464	0	160	48	0	0	0	0	0	0	0	0	304	3872	208	0	80
Di	Psychodidae Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	32	0	0	0	0	0	0
Di	Simulium sp.	0	0	0	1280	0	0	0	80	16	0	32	64	0	0	0	64	0	64	32	76128	0	0	0	32	0	0	0	0
Di	Tabanidae Gen. sp.	0	0	0	0	0	0	0	0	16	16	16	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0
Di	Tanypodinae Gen. sp.	0	0	16	0	16	0	0	0	0	0	32	16	64	0	0	0	16	0	0	128	16	16	0	224	48	304	112	208
Di	Tanytarsini Gen. sp.	160	32	144	16	192	0	496	0	64	112	512	0	1884	54188	350	1470	80	32	0	288	224	244	304	864	768	224	168	720

**Appendix 4-A.** Taxa lists of substrate samples: Orke, single-channel section (Ind. m<sup>-2</sup>). Grey rows are taxa of Orke multiple-channel section with zero occurrence here. Bold marked samples randomly chosen for section taxa lists (Chapter 4). Information on sample code and abbreviations see p 129.

Taxa group	Taxon	Orke_1_block1	Orke_1_block2	Orke_1_cobble1	Orke_1_cobble2	Orke_1_cobble3	Orke_1_cobble4	Orke_1_cobble5	Orke_1_cobble6	Orke_1_cobble7	Orke_1_cobble8	Orke_1_cgravel1	Orke_1_cgravel2	Orke_1_fgravel1	Orke_1_fgravel2	Orke_1_sand1	Orke_1_sand2	Orke_1_loam1	Orke_1_lptp1	Orke_1_lptp2	Orke_1_wood1	Orke_1_wood2	Orke_1_cpom1	Orke_1_cpom2	Orke_1_mud1	Orke_1_mud2
Tu	Dugesia sp.	0	0	0	0	0	0	0	0	96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tu	Turbellaria Gen. sp.	0	0	0	0	16	16	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0
Ga	Ancylus fluviatilis	0	0	0	0	16	32	16	32	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0
Ga	Gyraulus albus	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	16	0	48
Ga	Hippeutis complanatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0
Ga	Potamopyrgus antipodarum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ga	Radix balthica	0	0	0	0	0	0	32	0	16	0	16	0	0	0	0	144	0	16	0	0	0	0	0	48	32
Ga	Succinea sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0
Bi	Pisidium sp.	0	0	0	0	0	0	272	0	80	0	16	0	0	0	224	304	96	0	16	0	0	16	32	288	1216
Ol	Eiseniella tetraedra	0	0	0	0	16	0	0	48	0	0	16	16	0	0	16	0	0	0	0	0	0	0	0	0	0
Ol	Naididae/Tubificidae Gen. sp.	0	224	272	16	16	0	32	0	0	16	288	64	0	208	144	128	0	0	16	0	0	0	48	256	0
Ol	Oligochaeta Gen. sp.	0	16	1	64	1	0	32	1	0	1	80	1	0	1	1	16	0	0	1	0	0	0	1	32	0
Ol	Stylodrilus heringianus	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0
Hi	Erpobdella octoculata	16	16	48	0	0	0	112	0	0	32	224	224	0	16	0	0	32	16	0	0	0	96	0	80	160
Hi	Erpobdella vilnensis	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hi	Glossiphonia complanata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16
Hi	Glossiphonia nebulosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hi	Glossiphonia verrucata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0
Hi	Glossiphonia sp.	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0	64
Hi	Helobdella stagnalis	0	0	0	16	0	0	16	0	0	0	0	0	0	0	0	48	0	0	0	0	0	0	0	32	64
Cr	Asellus aquaticus	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cr	Gammarus fossarum	0	0	0	0	0	0	32	0	0	0	0	0	0	0	240	0	0	0	0	0	0	96	80	0	0
Cr	Gammarus pulex	0	0	0	0	0	0	0	0	0	0	0	0	0	0	240	0	32	32	80	0	0	16	112	16	0
Cr	Gammarus roeselii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cr	Gammarus sp.	0	0	0	80	32	0	64	0	16	48	32	48	0	0	7008	2688	784	1	512	16	0	640	592	864	0
Cr	Proasellus coxalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ep	Alainites muticus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ep	Baetis fuscatus	0	0	0	0	48	0	18	0	16	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ep	Baetis fuscatus/scambus	0	0	112	0	1	0	35	16	1	16	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ep	Baetis liebenauae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	144	0	0	0
Ep	Baetis lutheri	0	0	0	0	0	0	0	160	0	64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ep	Baetis rhodani	0	32	16	0	16	0	141	48	112	16	0	0	0	0	16	0	0	0	0	32	0	54	0	0	0
Ep	Baetis scambus	0	0	48	0	0	0	71	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ep	Baetis sp.	0	32	96	0	128	0	53	240	256	128	64	16	16	0	1	0	0	0	0	1	0	90	0	16	0
Ep	Caenis luctuosa	0	0	96	0	48	0	208	16	0	0	80	0	16	0	448	16	0	0	0	0	0	208	32	288	16
Ep	Centropilum luteolum	0	0	0	0	0	0	18	0	0	0	0	0	0	0	80	16	0	48	64	0	0	0	64	144	0

Appendix 4-A continued.

Taxa group	Taxon	Orke_1_block1	Orke_1_block2	Orke_1_cobble1	Orke_1_cobble2	Orke_1_cobble3	Orke_1_cobble4	Orke_1_cobble5	Orke_1_cobble6	Orke_1_cobble7	Orke_1_cobble8	Orke_1_cgravel1	Orke_1_cgravel2	Orke_1_fgavel1	Orke_1_fgavel2	Orke_1_sand1	Orke_1_sand2	Orke_1_loam1	Orke_1_lptp1	Orke_1_lptp2	Orke_1_wood1	Orke_1_wood2	Orke_1_cpom1	Orke_1_cpom2	Orke_1_mud1	Orke_1_mud2
Ep	Ecdyonurus venosus-Gr.	0	0	64	80	80	0	224	16	48	0	0	0	0	0	0	0	0	32	0	0	32	16	0	0	
Ep	Ephemera danica	0	0	0	0	0	0	224	0	0	0	0	16	0	0	48	16	0	0	0	0	0	16	32	16	
Ep	Habrophlebia lauta	0	0	16	0	0	0	0	48	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	
Ep	Procloeon pennulatum	0	0	16	0	0	0	0	0	0	0	0	0	0	0	16	16	0	0	0	0	0	0	0	0	
Ep	Procloeon pulchrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	
Ep	Procloeon sp.	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	
Ep	Serratella ignita	16	832	240	3328	640	128	592	592	1104	224	624	0	240	0	112	288	176	64	0	64	0	2896	16	128	80
Od	Aeshna cyanea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Od	Calopteryx sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	16	80	0	0	32	0	0	
Od	Platycnemis pennipes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	16	48	0	0	0	0	16	
Pl	Leuctra geniculata	0	0	96	80	176	0	96	64	16	0	16	32	0	16	16	0	0	0	0	0	0	0	0	0	
Pl	Leuctra sp.	0	0	80	32	352	112	80	416	80	64	16	240	0	16	0	0	0	0	0	0	0	32	0	0	
Pl	Perla burmeisteriana	0	0	64	0	80	32	48	16	16	96	0	16	0	0	0	0	0	0	0	0	0	0	0	0	
Pl	Protonemura sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
He	Gerridae Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	96	0	0	0	0	0	0	16	0	
He	Micronectinae Gen. sp.	0	0	0	0	0	0	16	0	0	0	0	0	0	0	64	0	0	0	0	0	0	16	80	704	
He	Nepa cinerea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	16	160	0	0	0	0	0	0	16	
Me	Sialis fuliginosa	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Me	Sialis lutaria	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Me	Sialis nigripes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	
Me	Sialis sp.	1	0	16	0	0	0	32	0	0	0	0	0	0	0	16	64	0	0	0	0	0	0	272	1	
Tr	Allogamus auricollis	16	16	16	0	144	0	16	96	0	0	0	16	0	0	0	0	0	48	48	0	0	64	176	32	0
Tr	Anabolia nervosa	0	0	32	0	0	0	16	0	0	0	0	0	0	0	0	0	0	48	48	0	0	64	176	32	0
Tr	Anomalopterygella chauviniana	0	0	32	48	48	0	0	16	16	32	80	48	0	16	0	0	0	0	0	0	0	0	0	0	0
Tr	Athripsodes albifrons	16	0	0	0	0	16	32	0	0	0	0	48	0	32	16	0	0	16	0	0	0	0	0	0	0
Tr	Athripsodes bilineatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	
Tr	Athripsodes cinereus	0	0	0	0	0	0	48	0	0	0	0	0	0	0	16	16	0	0	0	0	0	0	0	0	
Tr	Brachycentrus subnubilus	0	0	0	0	0	0	16	80	0	0	0	16	0	16	0	0	0	0	0	16	0	768	0	0	
Tr	Ceraclea dissimilis	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tr	Chaetopteryx villosa	0	0	16	16	0	0	0	0	0	0	0	0	0	0	0	16	16	16	48	0	0	128	0	0	
Tr	Cheumatopsyche lepida	0	0	0	16	0	80	0	384	176	32	0	16	0	0	0	0	0	0	0	0	0	0	0	0	
Tr	Cyrnus trimaculatus	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	16	0	0	0	0	0	
Tr	Goera pilosa	0	0	0	0	0	0	48	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tr	Halesus digitatus/tesselatus	0	0	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	32	0	0	
Tr	Halesus radiatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	0	0	0	16	0	0	

Appendix 4-A continued.

Taxa group	Taxon	Orke_1_block1	Orke_1_block2	Orke_1_cobble1	Orke_1_cobble2	Orke_1_cobble3	Orke_1_cobble4	Orke_1_cobble5	Orke_1_cobble6	Orke_1_cobble7	Orke_1_cobble8	Orke_1_cgravel1	Orke_1_cgravel2	Orke_1_fgavel1	Orke_1_fgavel2	Orke_1_sand1	Orke_1_sand2	Orke_1_loam1	Orke_1_lptp1	Orke_1_lptp2	Orke_1_wood1	Orke_1_wood2	Orke_1_cpom1	Orke_1_cpom2	Orke_1_mud1	Orke_1_mud2
Tr	Hydropsyche angustipennis	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Hydropsyche pellucidula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Hydropsyche siltalai	0	0	0	0	0	0	0	112	48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	Orectochilus villosus Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	80	0	0	0
Co	Oulimnius tuberculatus Ad.	0	0	0	0	0	0	0	16	0	0	16	384	0	0	0	0	416	0	176	0	0	16	0	0	0
Co	Oulimnius tuberculatus Lv.	0	0	80	0	64	16	0	0	0	0	16	32	0	96	112	0	64	0	16	0	0	0	0	16	0
Co	Platambus maculatus Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	64	0	0	0
Co	Stictotarsus duodecimpustulatus Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Di	Antocha sp.	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Di	Atherix/Ibisia sp.	0	0	0	16	0	16	0	48	16	0	0	0	0	0	0	0	0	0	16	0	0	16	0	0	0
Di	Ceratopogoninae Gen. sp.	0	0	32	0	0	0	16	0	0	0	0	48	0	16	48	64	272	16	0	0	0	0	0	64	80
Di	Chironomidae Gen. sp.	16	288	304	288	256	112	368	320	512	192	80	96	0	64	336	320	64	176	48	0	1	1472	1	1	112
Di	Chironomini Gen. sp.	0	112	618	112	256	0	23199	64	192	112	0	16	0	96	412	784	32	528	640	0	112	2992	4000	4916	1222
Di	Chrysops sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	16
Di	Clinocerinae Gen. sp.	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Di	Dicranota sp.	0	16	0	0	96	0	0	0	16	16	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0
Di	Limnophila sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	80	0	0	0	0	0	0	0	0
Di	Limnophora sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Di	Pilaria sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Di	Prodiamesa olivacea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	224	0	0	0	0	0	0	80	128	240
Di	Psychodidae Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0
Di	Ptychoptera sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	208	0	0	0	0	0	0	0	0	0	0
Di	Simulium sp.	0	0	0	0	0	0	0	32	0	144	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0
Di	Tabanidae Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	16	0	0	0	0	0	0	0	0
Di	Tanypodinae Gen. sp.	16	64	48	0	64	48	32	32	48	16	0	0	0	16	32	256	144	64	144	0	0	48	0	64	80
Di	Tanytarsini Gen. sp.	16	192	342	0	208	16	129	80	80	16	32	144	0	320	1444	2704	160	272	80	0	0	288	80	252	314
Di	Tipula sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	96	0	0	0	0	16	0	0	0

**Appendix 4-B.** Taxa lists of substrate samples: Orke, multiple-channel section (Ind. m<sup>-2</sup>). Grey rows are taxa of Orke single-channel section with zero occurrence here. Bold marked samples randomly chosen for section taxa lists (Chapter 4). Information on sample code and abbreviations see p 129.

Taxa group	Taxon	Orke_2_block1	Orke_2_block2	Orke_2_cobble1	Orke_2_cobble2	Orke_2_cobble3	Orke_2_cobble4	Orke_2_cobble5	Orke_2_cobble6	Orke_2_cobble7	Orke_2_cobble8	Orke_2_cgravel1	Orke_2_cgravel2	Orke_2_fg gravel1	Orke_2_fg gravel2	Orke_2_sand1	Orke_2_sand2	Orke_2_loam1	Orke_2_loam2	Orke_2_lptp1	Orke_2_lptp2	Orke_2_wood1	Orke_2_wood2	Orke_2_cpom1	Orke_2_cpom2	Orke_2_mud1	Orke_2_mud2	Orke_2_pool1	Orke_2_pool2
Tu	Dugesia sp.	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tu	Turbellaria Gen. sp.	0	0	0	0	0	0	0	0	16	16	0	0	0	0	16	0	0	0	16	0	0	0	0	0	0	0	0	
Ga	Ancylus fluviatilis	0	16	16	32	0	16	0	16	0	48	160	144	16	32	0	16	0	0	0	0	16	0	0	16	0	0	0	
Ga	Gyraulus albus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	16	0	16	16	0	48	0	0
Ga	Hippeutis complanatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	16	0	0	0	
Ga	Potamopyrgus antipodarum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	
Ga	Radix balthica	0	0	0	0	0	0	0	0	0	0	16	0	0	32	16	0	0	112	16	0	16	16	0	64	0	16	0	0
Ga	Succinea sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Bi	Pisidium sp.	0	0	32	32	0	16	0	0	16	0	48	16	16	80	144	1984	0	16	0	0	16	0	0	176	0	688	0	0
Ol	Eiseniella tetraedra	0	0	0	16	0	0	0	16	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Ol	Naididae/Tubificidae Gen. sp.	0	32	32	32	0	0	0	0	0	0	256	32	432	128	128	128	64	0	0	0	0	0	32	0	0	0	384	0
Ol	Oligochaeta Gen. sp.	0	1	48	1	0	0	0	1	16	0	1	1	16	16	144	1	112	0	0	0	0	0	1	0	0	0	1	0
Ol	Stylogdrilus heringianus	0	0	0	16	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hi	Erpobdella octoculata	0	0	48	16	96	48	0	48	16	0	112	288	32	80	0	48	0	0	0	16	0	16	0	288	0	16	0	0
Hi	Erpobdella vilnensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0
Hi	Glossiphonia complanata	0	0	0	0	0	0	0	0	0	0	0	32	16	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0
Hi	Glossiphonia nebulosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0
Hi	Glossiphonia verrucata	0	0	0	0	0	0	0	0	0	0	16	0	0	0	32	0	0	0	0	0	0	0	0	0	0	16	0	0
Hi	Glossiphonia sp.	0	0	0	0	0	0	0	0	0	0	16	1	16	16	0	64	0	0	0	0	0	0	0	96	0	16	0	0
Hi	Helobdella stagnalis	0	0	0	0	0	0	0	0	0	0	112	0	16	48	0	0	0	0	0	0	32	0	0	0	0	16	0	0
Cr	Asellus aquaticus	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cr	Gammarus fossarum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	80	0	0	0	0	0	0	0	0	0
Cr	Gammarus pulex	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	0	0	64	288	0	0	0	64	0	16	0	0	
Cr	Gammarus roeselii	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0
Cr	Gammarus sp.	0	16	64	1	0	0	0	16	16	0	80	224	128	976	224	368	48	96	672	1312	112	16	80	1120	0	784	0	0
Cr	Proasellus coxalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	1344
Ep	Alainites muticus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	112	0	0	0	0	0	0	0	0
Ep	Baetis fuscatus	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ep	Baetis fuscatus/scambus	16	0	80	1	0	0	0	0	0	0	40	49	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
Ep	Baetis liebenauae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ep	Baetis lutheri	0	0	0	0	0	0	0	347	208	96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ep	Baetis rhodani	16	0	128	48	368	0	64	27	720	1616	0	428	0	18	0	0	160	0	144	32	0	384	1760	0	0	0	0	0
Ep	Baetis scambus	0	0	0	80	0	0	0	0	0	0	20	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0
Ep	Baetis sp.	96	0	96	128	432	0	1	27	576	656	60	82	0	1	1	0	32	0	272	16	0	144	1264	0	0	0	0	0
Ep	Caenis luctuosa	16	32	64	0	0	48	0	16	0	0	416	32	96	128	64	16	16	0	0	16	0	0	224	0	0	0	0	0
Ep	Centroptilum luteolum	0	0	0	0	0	48	0	0	0	0	40	0	0	90	0	224	32	0	0	16	96	0	0	64	0	213	0	0

Appendix 4-B continued.

Taxa group	Taxon	Orke_2_block1	Orke_2_block2	Orke_2_cobble1	Orke_2_cobble2	Orke_2_cobble3	Orke_2_cobble4	Orke_2_cobble5	Orke_2_cobble6	Orke_2_cobble7	Orke_2_cobble8	Orke_2_cgravel1	Orke_2_cgravel2	Orke_2_fgravel1	Orke_2_fgravel2	Orke_2_sand1	Orke_2_sand2	Orke_2_loam1	Orke_2_loam2	Orke_2_lptp1	Orke_2_lptp2	Orke_2_wood1	Orke_2_wood2	Orke_2_cpom1	Orke_2_cpom2	Orke_2_mud1	Orke_2_mud2	Orke_2_pool1	Orke_2_pool2
Ep	Ecdyonurus venosus-Gr.	16	0	192	128	32	16	16	112	0	48	192	464	0	16	0	16	0	0	0	0	0	0	32	0	0	0	0	0
Ep	Ephemera danica	0	0	0	0	0	16	0	0	0	0	0	0	64	16	272	0	32	0	0	0	0	0	16	0	16	0	0	
Ep	Habrophlebia lauta	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	
Ep	Procloeon pennulatum	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Ep	Procloeon pulchrum	0	0	0	0	0	0	0	0	0	0	80	0	0	36	0	0	0	0	0	0	0	0	112	0	43	0	0	
Ep	Procloeon sp.	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	
Ep	Serratella ignita	368	192	224	176	352	0	192	544	752	1360	272	896	16	272	400	32	1248	0	1312	1136	16	1504	3632	208	0	32	0	0
Od	Aeshna cyanea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	128	
Od	Calopteryx sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0
Od	Platycnemis pennipes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	16	0	0	16	0	0	0	0
Pl	Leuctra geniculata	0	0	176	64	16	0	16	32	16	0	224	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pl	Leuctra sp.	0	0	0	64	208	0	48	192	160	16	16	16	0	0	0	16	32	16	0	0	32	32	0	0	0	0	0	0
Pl	Perla burmeisteriana	0	0	64	0	16	0	0	32	32	32	0	16	0	0	0	0	0	0	0	0	0	16	64	0	0	0	0	0
Pl	Protonemura sp.	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0
He	Gerridae Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	160
He	Micronectinae Gen. sp.	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0
He	Nepa cinerea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	160	0	0	0	0	0	0	0	0	0	80	0	16
Me	Sialis fuliginosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	16	0	0	0	0	0	0	0	0	0	0	0
Me	Sialis lutaria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Me	Sialis nigripes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Me	Sialis sp.	0	0	0	0	0	0	0	0	0	0	0	0	64	80	0	16	1	0	0	0	0	0	16	0	80	0	128	
Tr	Allogamus auricollis	0	0	0	0	0	0	64	0	96	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Anabolia nervosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	48	0	0	0	0	0	0	0
Tr	Anomalopterygella chauviniana	0	0	0	0	0	0	0	0	16	0	32	64	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Athripsodes albifrons	0	16	0	0	0	0	0	32	0	0	24	80	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Athripsodes bilineatus	0	0	0	0	0	0	0	0	0	0	24	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Athripsodes cinereus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Brachycentrus subnubilus	0	0	0	0	0	0	0	0	16	48	0	16	0	0	0	0	112	0	1776	128	0	0	32	0	0	0	0	0
Tr	Ceraclea dissimilis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0
Tr	Chaetopteryx villosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	192	0	0	0	0
Tr	Cheumatopsyche lepida	0	0	0	32	0	0	16	96	64	80	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0
Tr	Cyrnus trimaculatus	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	48	0	0	64	0	0	0	0
Tr	Goera pilosa	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Halesus digitatus/tesselatus	0	0	0	0	0	16	0	0	0	0	0	0	32	0	0	0	0	0	96	0	0	16	0	0	0	0	0	0
Tr	Halesus radiatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0

Appendix 4-B continued.

Taxa group	Taxon	Orke_2_block1	Orke_2_block2	Orke_2_cobble1	Orke_2_cobble2	Orke_2_cobble3	Orke_2_cobble4	Orke_2_cobble5	Orke_2_cobble6	Orke_2_cobble7	Orke_2_cobble8	Orke_2_cgravel1	Orke_2_cgravel2	Orke_2_fgavel1	Orke_2_fgavel2	Orke_2_sand1	Orke_2_sand2	Orke_2_loam1	Orke_2_loam2	Orke_2_lptp1	Orke_2_lptp2	Orke_2_wood1	Orke_2_wood2	Orke_2_cpom1	Orke_2_cpom2	Orke_2_mud1	Orke_2_mud2	Orke_2_pool1	Orke_2_pool2
Tr	<i>Hydropsyche angustipennis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tr	<i>Hydropsyche pellucidula</i>	0	0	0	0	0	0	0	0	0	48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tr	<i>Hydropsyche</i> sp.	32	0	16	48	288	0	272	464	880	1776	0	0	0	0	0	0	32	16	16	0	0	32	208	0	0	0	0	
Tr	<i>Hydroptila</i> sp.	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	
Tr	<i>Lepidostoma hirtum</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	48	0	0	0	768	0	16	0	0
Tr	<i>Lype phaeopa phaeopa</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	
Tr	<i>Mystacides azurea</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tr	<i>Mystacides longicornis/nigra</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tr	<i>Odontocerum albicorne</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tr	<i>Oecetis</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tr	<i>Polycentropus flavomaculatus</i>	32	0	48	16	32	16	32	144	16	192	80	32	0	16	0	0	0	32	32	96	64	0	48	128	0	0	0	0
Tr	<i>Polycentropus irroratus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0
Tr	<i>Psychomyia pusilla</i>	0	80	0	0	0	32	0	0	0	0	16	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0
Tr	<i>Rhyacophila dorsalis/nubila</i>	16	0	0	32	48	0	80	112	96	80	0	0	0	0	0	0	16	0	96	16	0	144	80	0	0	0	0	0
Tr	<i>Sericostoma flavicorne/personatum</i>	0	0	16	0	16	0	0	48	144	112	32	160	224	16	0	80	0	0	32	16	32	80	0	576	0	0	0	0
Co	<i>Agabus</i> sp. Lv.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	32	
Co	<i>Anacaena bipustulata</i> Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	<i>Elmis aenea</i> Ad.	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	16	76	75	0	59	0	0	0	0	0	0	0
Co	<i>Elmis maugetii</i> Ad.	16	0	0	16	16	0	0	240	151	96	0	0	0	0	0	0	0	0	431	37	16	501	192	32	0	0	0	0
Co	<i>Elmis obscura</i> Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0
Co	<i>Elmis rioloides</i> Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	76	0	0	0	0	0	0	0	0	0
Co	<i>Elmis</i> sp. Lv.	16	0	0	112	144	16	16	144	96	128	80	96	0	0	0	0	48	224	80	0	32	128	80	0	0	0	0	0
Co	<i>Esolus parallelepipedus</i> Ad.	0	0	0	0	0	0	16	112	16	80	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0
Co	<i>Esolus</i> sp. Lv.	0	0	0	0	48	0	0	16	16	0	16	32	0	16	0	0	0	0	16	0	0	0	0	0	0	0	0	0
Co	<i>Helophorus alternans</i> Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	<i>Helophorus brevipalpis</i> Ad.	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	16	0	16	16	0	0	96	0	0	0	0	0
Co	<i>Hydraena gracilis</i> Ad.	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0	80	0	0	0	0	64	0	0	16	0	0	0
Co	<i>Hydraena melas</i> Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	32	0	0	0	0	0	0
Co	<i>Hydraena minutissima</i> Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0
Co	<i>Hydraena</i> sp. Ad.	0	0	0	0	0	0	0	1	0	32	0	0	0	0	0	0	64	0	0	32	0	16	0	0	0	1	0	0
Co	<i>Hydroptilinae</i> Gen. sp. Lv.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	32	0	0	0	0
Co	<i>Laccobius</i> sp. Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0	16	0	0
Co	<i>Laccobius</i> sp. Lv.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	32	0	0	0	0	0	0	0	0	0	96	0	0
Co	<i>Limnebius truncatellus</i> Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	<i>Limnius opacus</i> Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	<i>Limnius opacus</i> Lv.	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 4-B continued.

Taxa group	Taxon	Orke_2_block1	Orke_2_block2	Orke_2_cobble1	Orke_2_cobble2	Orke_2_cobble3	Orke_2_cobble4	Orke_2_cobble5	Orke_2_cobble6	Orke_2_cobble7	Orke_2_cobble8	Orke_2_cgravel1	Orke_2_cgravel2	Orke_2_fgravel1	Orke_2_fgravel2	Orke_2_sand1	Orke_2_sand2	Orke_2_loam1	Orke_2_loam2	Orke_2_lptp1	Orke_2_lptp2	Orke_2_wood1	Orke_2_wood2	Orke_2_cpom1	Orke_2_cpom2	Orke_2_mud1	Orke_2_mud2	Orke_2_pool1	Orke_2_pool2	
Co	Limnius volckmari Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Co	Limnius volckmari Lv.	0	0	0	0	0	0	0	0	0	0	16	32	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Co	Nebrioporus elegans Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	0	0	0	0	0	0	0	
Co	Orectochilus villosus Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	96	0	0	0	0	0	
Co	Oulimnius tuberculatus Ad.	0	0	0	0	0	16	16	0	0	0	160	16	80	0	0	0	16	16	16	48	16	0	0	352	0	0	0	0	
Co	Oulimnius tuberculatus Lv.	0	0	0	0	16	32	0	0	16	16	208	32	0	16	0	16	0	0	16	0	16	0	0	64	0	0	0	0	
Co	Platambus maculatus Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Co	Stictotarsus duodecimpustulatus Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	
Di	Antocha sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Di	Atherix/Ibisia sp.	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Di	Ceratopogoninae Gen. sp.	0	0	0	0	0	0	0	0	0	32	16	32	0	0	0	144	112	112	0	0	16	0	0	0	0	0	96	0	0
Di	Chironomidae Gen. sp.	144	592	192	16	96	16	176	128	624	624	208	64	240	1	32	320	240	144	320	192	48	416	2224	400	1	192	64	400	
Di	Chironomini Gen. sp.	112	2688	96	32	160	3552	0	992	192	1328	1728	32	18688	14736	48	265	80	176	400	752	912	624	6368	4320	20512	4208	912	7984	
Di	Chrysops sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	
Di	Clinocerinae Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Di	Dicranota sp.	0	0	0	32	0	0	0	0	32	0	0	0	0	0	0	0	96	0	0	0	0	0	0	0	0	0	0	0	
Di	Limnophila sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	16	64	0	16	0	0	0	0	0	0	0	0	0	0	0	
Di	Limnophora sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0	
Di	Pilaria sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	80	0	16	
Di	Prodiamesa olivacea	0	0	0	0	0	0	0	0	0	0	0	0	160	0	0	0	0	0	0	0	16	0	0	0	1312	0	0	0	
Di	Psychodidae Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	16	0	0	0	0	0	16	0	0	0	0	0	0	
Di	Ptychoptera sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Di	Simulium sp.	16	0	0	0	16	0	16	5952	5120	1008	0	0	0	0	0	0	32	16	64	0	0	112	384	0	0	0	0	0	
Di	Tabanidae Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Di	Tanypodinae Gen. sp.	0	496	32	0	0	0	0	16	0	0	32	0	192	0	0	48	16	0	16	48	64	48	16	80	352	80	192	288	
Di	Tanytarsini Gen. sp.	48	1744	160	32	16	256	16	48	112	48	592	48	1440	544	0	2215	0	16	0	112	112	32	64	432	544	1248	0	0	
Di	Tipula sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	64	16	0	0	0	0	0	0	0	0	0	0	80	0	0	

**Appendix 5.** Taxa lists of substrate samples: Lahn-W, single- and multiple-channel section (Ind. m<sup>-2</sup>). Information on sample code and abbreviations see p 129.

Taxa group	Taxon	Lahn-W_1_block1	Lahn-W_1_cobble1	Lahn-W_1_cg gravel1	Lahn-W_1_loam1	Lahn-W_1_lptp1	Lahn-W_1_wood1	Lahn-W_1_cpom1	Lahn-W_1_mud1	Lahn-W_2_block1	Lahn-W_2_cobble1	Lahn-W_2_cg gravel1	Lahn-W_2_fg gravel1	Lahn-W_2_fg gravel2	Lahn-W_2_sand1	Lahn-W_2_sand2	Lahn-W_2_loam1	Lahn-W_2_wood1	Lahn-W_2_cpom1	Lahn-W_2_mud1
Ga	Ancylus fluviatilis	0	0	0	0	0	0	0	0	0	32	0	16	16	0	0	48	0	0	0
Ga	Gyraulus albus	0	0	0	16	0	0	32	0	0	0	0	16	0	0	0	0	0	0	0
Ga	Potamopyrgus antipodarum	0	16	48	0	0	0	0	0	0	48	0	48	0	80	128	0	0	0	0
Ga	Radix balthica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	0
Bi	Pisidium sp.	0	0	0	0	0	0	0	96	0	0	0	32	0	32	0	0	0	0	0
Bi	Sphaerium sp.	0	0	0	0	0	0	32	0	0	0	0	0	0	16	0	0	0	0	0
Ol	Eiseniella tetraedra	0	0	0	0	0	0	0	0	0	0	64	0	80	0	0	16	0	0	0
Ol	Naididae/Tubificidae Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	64	0	0	0	0	0
Ol	Oligochaeta Gen. sp.	0	0	1	0	0	0	0	0	0	1	48	80	1	96	0	16	0	0	0
Ol	Stylodrilus heringianus	0	0	128	0	0	0	0	0	0	16	0	240	0	16	0	0	0	0	0
Hi	Erpobdella octoculata	0	0	64	0	0	0	64	0	0	176	32	128	32	48	0	16	0	96	1280
Hi	Erpobdella vilnensis	0	0	0	0	0	0	0	0	0	0	0	0	80	0	0	0	0	0	0
Hi	Glossiphonia sp.	0	0	64	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	32
Hi	Helobdella stagnalis	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	80	96
Cr	Asellus aquaticus	0	0	512	77	0	0	192	0	0	48	48	768	1248	32	0	0	48	1872	384
Cr	Gammarus sp.	0	0	128	32	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cr	Niphargus sp.	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cr	Proasellus coxalis	0	0	0	19	0	0	0	0	0	0	0	16	0	0	0	16	0	0	0
Ep	Baetis fuscatus	0	0	0	0	0	0	0	0	32	0	0	96	0	0	0	0	261	0	0
Ep	Baetis fuscatus/scambus	0	0	0	0	0	0	0	0	16	1	0	1	1	0	0	16	244	18	0
Ep	Baetis lutheri	0	0	0	0	0	0	0	0	97	0	0	0	0	0	0	0	0	0	0
Ep	Baetis rhodani	0	0	0	0	0	37	0	0	745	0	1984	64	0	0	16	128	49	89	0
Ep	Baetis scambus	0	0	0	0	0	0	0	0	97	800	0	336	64	0	0	208	33	72	0
Ep	Baetis sp.	0	0	0	20	0	19	0	0	292	192	512	144	48	0	32	816	261	125	0
Ep	Caenis beskidensis/pseudorivulorum	0	16	0	0	0	0	0	0	0	0	0	16	0	0	16	0	0	0	0
Ep	Caenis luctuosa	0	16	0	0	0	0	0	96	0	0	0	0	0	0	0	0	32	96	0
Ep	Centroptilum luteolum	0	0	0	40	318	0	496	192	0	0	0	0	0	0	0	0	0	0	0
Ep	Ecdyonurus venosus-Gr.	0	0	0	0	0	0	0	0	0	32	80	16	0	0	0	0	0	0	0
Ep	Ephemera danica	0	0	32	16	0	0	64	0	0	0	0	16	0	0	16	48	0	0	0
Ep	Habrophlebia lauta	0	32	0	16	0	0	224	0	0	0	0	0	0	0	0	0	0	0	0
Ep	Proclleon pennulatum	0	0	0	0	17	56	32	0	0	0	0	0	0	0	0	0	33	0	0
Ep	Proclleon sp.	16	0	16	20	17	1	1	0	0	0	0	0	0	0	0	0	1	0	0
Ep	Serratella ignita	32	64	0	0	448	272	0	96	0	320	288	64	48	0	16	592	448	1488	0
Od	Platycnemis pennipes	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 5 continued.

Taxa group	Taxon	Lahn-W_1_block1	Lahn-W_1_cobble1	Lahn-W_1_cg gravel1	Lahn-W_1_loam1	Lahn-W_1_lptp1	Lahn-W_1_wood1	Lahn-W_1_cpom1	Lahn-W_1_mud1	Lahn-W_2_block1	Lahn-W_2_cobble1	Lahn-W_2_cg gravel1	Lahn-W_2_fg gravel1	Lahn-W_2_fg gravel2	Lahn-W_2_sand1	Lahn-W_2_sand2	Lahn-W_2_loam1	Lahn-W_2_wood1	Lahn-W_2_cpom1	Lahn-W_2_mud1
Pl	Leuctra geniculata	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0
Pl	Leuctra sp.	0	96	0	0	0	0	0	0	0	0	304	80	96	0	0	48	0	144	0
Me	Sialis fuliginosa	0	0	16	0	0	0	0	96	0	0	0	0	0	0	0	16	0	0	0
Me	Sialis sp.	0	16	128	0	0	0	288	144	0	0	0	0	0	0	0	1	0	16	0
Tr	Allogamus auricollis	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0
Tr	Anabolia nervosa	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0
Tr	Anomalopterygella chauviniana	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Athripsodes cinereus	0	0	48	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Chaetopteryx villosa	0	0	16	0	0	0	0	0	0	0	0	0	16	0	0	0	0	48	0
Tr	Goera pilosa	0	0	0	0	0	0	0	16	0	0	16	64	0	0	0	0	0	0	0
Tr	Halesus digitatus/tesselatus	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Hydropsyche incognita	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	0
Tr	Hydropsyche pellucidula	0	0	0	0	0	0	0	0	0	0	48	0	0	0	0	16	0	0	0
Tr	Hydropsyche siltalai	0	0	0	0	0	0	0	0	16	16	0	0	0	0	16	0	0	96	0
Tr	Hydropsyche sp.	0	0	16	0	0	16	0	0	1	32	96	0	0	0	1	96	0	384	0
Tr	Hydroptila sp.	0	0	0	0	16	96	0	48	0	0	0	0	0	0	0	0	0	0	0
Tr	Lepidostoma hirtum	0	0	0	32	16	0	0	0	0	16	16	0	0	0	0	0	32	96	0
Tr	Leptocerus interruptus	0	0	0	16	48	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Mystacides azurea	0	0	16	0	0	0	120	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Mystacides longicornis/nigra	0	0	0	0	0	0	40	0	0	0	0	16	0	0	0	0	0	0	0
Tr	Notidobia ciliaris	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Odontocerum albicorne	0	0	16	0	0	0	0	0	0	0	0	16	0	128	0	16	0	0	0
Tr	Oecetis testacea	0	0	0	32	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0
Tr	Polycentropus flavomaculatus	16	64	0	0	64	16	0	0	0	64	0	0	0	0	0	0	16	80	0
Tr	Potamophylax cingulatus/latipennis/luctuosus	0	0	0	0	0	0	0	0	0	144	0	0	0	0	0	0	0	0	0
Tr	Psychomyia pusilla	0	0	0	0	0	0	0	0	0	96	0	0	0	0	0	0	0	0	0
Tr	Rhyacophila dorsalis/nubila	0	0	0	0	0	0	0	0	16	144	80	16	16	0	0	176	48	16	0
Tr	Sericostoma flavicorne/personatum	0	64	16	0	0	0	80	48	0	96	0	16	0	16	32	16	0	0	0

Appendix 5 continued.

Taxa group	Taxon	Lahn-W_1_block1	Lahn-W_1_cobble1	Lahn-W_1_cggravel1	Lahn-W_1_loam1	Lahn-W_1_lptp1	Lahn-W_1_wood1	Lahn-W_1_cpom1	Lahn-W_1_mud1	Lahn-W_2_block1	Lahn-W_2_cobble1	Lahn-W_2_cggravel1	Lahn-W_2_fgravel1	Lahn-W_2_fgravel2	Lahn-W_2_sand1	Lahn-W_2_sand2	Lahn-W_2_loam1	Lahn-W_2_wood1	Lahn-W_2_cpom1	Lahn-W_2_mud1
Co	Elmis maugetii Ad.	0	0	128	0	48	0	0	0	32	352	384	16	32	0	0	300	0	1248	0
Co	Elmis rioloides Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0
Co	Elmis sp. Lv.	0	16	0	0	48	0	0	0	0	144	336	48	208	0	0	96	0	224	0
Co	Esolus angustatus Ad.	0	0	0	0	0	0	0	0	0	0	96	0	0	0	0	0	0	0	0
Co	Esolus parallelepipedus Ad.	0	0	0	0	0	0	0	0	0	448	1200	784	1264	80	16	224	0	16	0
Co	Esolus sp. Lv.	0	16	0	0	0	0	0	0	0	256	912	128	144	544	160	48	0	48	0
Co	Helophorus arvernicus Ad.	0	0	0	0	0	0	0	0	0	0	0	48	0	0	0	0	0	0	0
Co	Hydraena dentipes Ad.	0	0	0	0	0	0	0	0	0	0	144	0	0	0	0	32	0	0	0
Co	Hydraena gracilis Ad.	0	0	0	0	0	0	0	0	0	0	144	0	32	0	0	16	0	0	0
Co	Hydraena sp. Ad.	0	0	0	0	0	0	0	0	0	32	96	16	16	0	0	48	0	16	0
Co	Hydroporinae Gen. sp. Lv.	0	0	16	0	0	0	192	48	0	0	0	0	0	0	0	0	16	0	0
Co	Limnius volckmari Ad.	0	0	0	0	0	0	0	0	0	64	96	0	16	0	0	16	0	0	0
Co	Limnius volckmari Lv.	0	16	0	0	0	0	0	0	0	0	96	48	32	112	0	0	0	0	0
Co	Oulimnius tuberculatus Ad.	144	16	384	144	560	16	80	0	0	96	240	320	80	0	0	128	0	128	0
Co	Oulimnius tuberculatus Lv.	32	96	128	48	64	0	48	144	0	64	0	64	16	112	32	112	32	112	0
Co	Platambus maculatus Lv.	0	0	0	0	112	0	0	48	0	0	0	0	0	0	0	0	0	0	0
Di	Antocha sp.	0	0	0	0	0	0	0	0	0	80	0	0	0	0	0	16	16	0	0
Di	Atherix/Ibisia sp.	0	16	0	16	0	0	32	0	0	96	256	0	48	0	0	64	0	880	0
Di	Ceratopogoninae Gen. sp.	0	0	16	0	16	0	0	0	0	0	48	48	16	16	0	48	0	0	0
Di	Chironomidae Gen. sp.	16	304	272	1	1024	336	256	1	1264	1600	448	928	464	1	16	1104	208	3920	0
Di	Chironomini Gen. sp.	16	2208	528	0	128	0	1680	37248	0	0	112	0	0	192	16	0	384	203	0
Di	Chrysops sp.	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Di	Dicranota sp.	0	0	64	0	0	0	0	0	0	16	1392	64	1168	2704	112	32	0	48	0
Di	Limnophora sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	0
Di	Pilaria sp.	0	0	0	0	0	0	0	0	0	0	16	16	0	0	0	0	0	0	0
Di	Prodiamesa olivacea	0	96	272	0	0	0	128	576	0	0	0	0	0	0	0	0	0	0	0
Di	Psychodidae Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0
Di	Simulium sp.	0	0	0	0	0	16	0	0	16	0	480	16	16	0	0	720	0	208	0
Di	Tabanidae Gen. sp.	0	0	64	0	2176	0	0	0	0	0	0	0	0	0	0	16	0	0	0
Di	Tanypodinae Gen. sp.	48	576	128	16	16	256	688	384	0	48	0	2432	32	0	0	48	128	464	0
Di	Tanytarsini Gen. sp.	176	4320	384	0	1152	688	320	768	0	272	2160	30288	496	3248	80	720	144	4005	0
Di	Tipula sp.	0	0	16	0	0	0	0	0	0	0	0	32	0	0	0	0	0	192	0

**Appendix 6.** Taxa lists of substrate samples: Lahn-LH, single- and multiple-channel section (Ind. m<sup>-2</sup>). Information on sample code and abbreviations see p 129.

Taxa group	Taxon	Lahn-LH_1_block1	Lahn-LH_1_cobble1	Lahn-LH_1_cg gravel1	Lahn-LH_1_fg gravel1	Lahn-LH_1_sand1	Lahn-LH_1_lptp1	Lahn-LH_1_cpom1	Lahn-LH_2_block1	Lahn-LH_2_cobble1	Lahn-LH_2_cg gravel1	Lahn-LH_2_fg gravel1	Lahn-LH_2_sand1	Lahn-LH_2_lptp1	Lahn-LH_2_subm1	Lahn-LH_2_subm2	Lahn-LH_2_wood1	Lahn-LH_2_wood2	Lahn-LH_2_cpom1	Lahn-LH_2_mud1	Lahn-LH_2_mud2
Tu	Polycelis sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0
Ga	Ancyclus fluviatilis	0	0	0	16	0	16	32	16	0	0	0	0	0	0	0	0	0	0	0	0
Ga	Gyraulus albus	0	0	16	0	0	0	16	0	0	0	0	0	0	0	64	0	0	0	0	0
Ga	Potamopyrgus antipodarum	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0
Ga	Radix balthica	0	0	0	192	0	16	112	144	0	0	16	64	0	0	208	0	0	0	0	0
Bi	Pisidium sp.	0	0	16	192	48	16	64	0	0	16	16	48	0	0	0	0	0	32	0	0
Bi	Sphaerium sp.	0	16	32	0	0	0	0	0	16	0	0	16	0	0	0	0	0	0	128	0
Ol	Eiseniella tetraedra	16	64	0	0	0	0	0	0	144	16	0	0	0	0	0	0	0	0	0	0
Ol	Naididae/Tubificidae Gen. sp.	0	64	32	64	16	0	0	16	0	80	0	32	176	0	0	32	0	0	0	0
Ol	Oligochaeta Gen. sp.	1	1312	112	1088	144	0	0	1	144	16	176	48	1	0	0	1	0	48	0	0
Ol	Stylodrilus heringianus	0	0	0	256	16	0	0	0	0	0	128	16	0	0	0	0	0	0	0	0
Hi	Erpobdella octoculata	16	64	0	112	16	16	0	16	0	464	16	64	0	32	64	0	0	64	256	96
Hi	Glossiphonia complanata	0	0	16	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0
Hi	Glossiphonia sp.	0	0	1	64	0	0	32	0	0	0	0	32	0	0	0	0	0	48	0	32
Hi	Helobdella stagnalis	0	0	0	16	16	0	16	0	16	16	0	48	0	0	0	0	0	208	192	32
Cr	Asellus aquaticus	0	0	192	128	16	16	208	304	112	384	287	0	448	48	112	0	16	2016	0	64
Cr	Gammarus sp.	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	16	256	0	0
Cr	Proasellus coxalis	0	0	0	0	16	0	0	0	0	0	17	0	16	0	16	0	0	128	0	0
Ep	Baetis fuscatus	0	0	32	0	32	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0
Ep	Baetis fuscatus/scambus	16	1	64	0	1	1	32	0	16	48	0	0	0	1	0	0	0	0	0	0
Ep	Baetis lutheri	96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ep	Baetis rhodani	1360	928	32	0	32	37	0	0	48	416	0	0	32	0	0	0	32	0	0	0
Ep	Baetis scambus	64	192	64	0	32	110	0	0	0	336	0	0	0	32	0	0	0	0	0	0
Ep	Baetis sp.	768	896	16	48	32	110	96	16	288	288	0	0	1	144	0	0	16	0	0	0
Ep	Caenis beskidensis/pseudorivulorum	0	0	48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ep	Caenis luctuosa	0	0	80	16	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ep	Centroptilum luteolum	0	0	0	0	80	0	0	16	0	0	0	0	0	32	32	0	0	0	0	0
Ep	Cloeon dipterum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3872	16	0	0	64	0
Ep	Ecdyonurus venosus-Gr.	0	0	0	0	0	0	64	0	0	0	0	0	0	0	0	0	0	0	0	0
Ep	Ephemera danica	0	0	64	80	0	0	0	0	0	0	16	32	0	0	0	0	0	0	0	0
Ep	Procloeon pennulatum	0	0	0	0	0	0	0	0	0	80	0	0	0	0	0	0	0	0	0	0
Ep	Procloeon sp.	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	16	0	0	0	0
Ep	Serratella ignita	96	640	672	560	144	1600	1184	640	64	80	848	0	368	32	32	0	352	1696	0	0

Appendix 6 continued.

Taxa group	Taxon	Lahn-LH_1_block1	Lahn-LH_1_cobble1	Lahn-LH_1_cg gravel1	Lahn-LH_1_fg gravel1	Lahn-LH_1_sand1	Lahn-LH_1_lptp1	Lahn-LH_1_cpom1	Lahn-LH_2_block1	Lahn-LH_2_cobble1	Lahn-LH_2_cg gravel1	Lahn-LH_2_fg gravel1	Lahn-LH_2_sand1	Lahn-LH_2_lptp1	Lahn-LH_2_subm1	Lahn-LH_2_subm2	Lahn-LH_2_wood1	Lahn-LH_2_wood2	Lahn-LH_2_cpom1	Lahn-LH_2_mud1	Lahn-LH_2_mud2
Pl	Leuctra geniculata	0	192	32	16	0	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0
Pl	Leuctra sp.	0	16	64	16	0	0	0	0	480	128	96	0	0	0	0	0	0	32	0	0
Pl	Nemoura sp.	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Me	Sialis fuliginosa	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0
Me	Sialis sp.	0	0	0	0	0	16	1	16	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Anomalopterygella chauviniana	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Athripsodes cinereus	0	0	0	0	0	16	32	0	16	0	64	32	0	0	0	0	0	16	64	0
Tr	Hydropsyche siltalai	0	16	0	48	0	16	0	0	0	0	0	0	48	0	0	0	0	0	0	0
Tr	Hydropsyche sp.	0	432	0	48	0	16	48	0	0	0	0	0	16	0	0	0	0	0	0	0
Tr	Lepidostoma hirtum	0	0	0	0	0	0	64	0	0	0	0	0	0	0	0	0	16	16	0	0
Tr	Mystacides azurea	0	0	0	0	16	0	96	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Oecetis testacea	0	16	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Polycentropus flavomaculatus	0	16	0	0	0	48	192	0	0	0	0	0	16	0	0	0	0	48	0	0
Tr	Rhyacophila dorsalis/nubila	208	352	16	32	0	0	32	32	0	0	0	0	80	0	0	0	32	64	0	0
Tr	Sericostoma flavicorne/personatum	0	0	48	48	32	0	0	0	0	0	16	16	0	16	0	0	0	0	0	0
Co	Elmis aenea Ad.	0	0	0	0	0	0	0	0	0	26	0	0	0	0	0	0	0	0	0	0
Co	Elmis maugetii Ad.	16	80	16	16	0	16	0	0	608	205	0	0	0	16	0	0	16	32	0	0
Co	Elmis rioloides Ad.	0	0	0	0	0	0	0	0	0	26	0	0	0	0	0	0	0	0	0	0
Co	Elmis sp. Lv.	0	272	16	32	0	160	32	64	288	160	0	80	16	0	0	0	32	48	0	16
Co	Esolus angustatus Ad.	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0
Co	Esolus parallelepipedus Ad.	16	464	32	80	0	16	0	0	1344	832	112	0	0	32	0	0	0	0	0	0
Co	Esolus sp. Lv.	32	48	0	112	0	0	16	0	288	400	16	160	0	32	32	0	0	0	0	0
Co	Halipus sp. Lv.	0	0	0	0	0	0	0	0	0	0	0	32	0	0	32	0	0	0	0	0
Co	Hydraena dentipes Ad.	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0
Co	Hydraena gracilis Ad.	0	0	0	0	0	0	0	16	352	32	0	0	0	0	0	0	0	0	0	0
Co	Hydraena sp. Ad.	0	16	16	0	0	16	0	1	480	48	0	0	0	0	16	0	0	0	0	0
Co	Hydroporinae Gen. sp. Lv.	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0
Co	Laccobius sp. Lv.	0	0	0	0	0	0	0	0	192	112	0	0	0	0	16	0	0	0	0	0
Co	Laccophilus sp. Lv.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	0	0	0	0	0
Co	Limnius volckmari Ad.	0	48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	Limnius volckmari Lv.	0	0	0	16	0	0	0	0	352	16	0	0	0	0	0	0	0	16	0	0
Co	Oulimnius tuberculatus Ad.	0	64	32	80	0	128	0	48	288	144	80	0	0	16	16	16	0	80	0	0
Co	Oulimnius tuberculatus Lv.	0	144	128	272	0	336	16	144	0	240	16	496	16	48	48	0	48	80	0	0

Appendix 6 continued.

Taxa group	Taxon	Lahn-LH_1_block1	Lahn-LH_1_cobble1	Lahn-LH_1_cggravel1	Lahn-LH_1_fggravel1	Lahn-LH_1_sand1	Lahn-LH_1_lptp1	Lahn-LH_1_cpom1	Lahn-LH_2_block1	Lahn-LH_2_cobble1	Lahn-LH_2_cggravel1	Lahn-LH_2_fggravel1	Lahn-LH_2_sand1	Lahn-LH_2_lptp1	Lahn-LH_2_subm1	Lahn-LH_2_subm2	Lahn-LH_2_wood1	Lahn-LH_2_wood2	Lahn-LH_2_cpom1	Lahn-LH_2_mud1	Lahn-LH_2_mud2
Di	Antocha sp.	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Di	Atherix/Ibisia sp.	0	496	32	0	0	0	16	0	0	0	0	16	16	0	0	0	0	32	0	0
Di	Ceratopogoninae Gen. sp.	0	0	0	0	16	0	0	0	0	0	16	0	0	0	0	16	0	16	0	0
Di	Chironomidae Gen. sp.	384	1792	128	1	384	3296	320	880	2944	1776	432	448	2064	2224	176	416	80	1024	1	1
Di	Chironomini Gen. sp.	32	960	3168	832	896	1360	1280	368	0	16	336	4336	224	0	128	2112	112	1472	704	208
Di	Dicranota sp.	0	320	16	0	0	0	0	0	192	0	0	0	0	0	0	0	0	0	0	0
Di	Prodiamesa olivacea	0	0	0	0	384	0	0	0	0	0	0	128	0	0	0	0	0	0	0	0
Di	Psychodidae Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0
Di	Simulium sp.	992	64	16	0	0	304	16	16	144	32	48	0	128	0	0	0	32	0	0	0
Di	Tabanidae Gen. sp.	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0
Di	Tanypodinae Gen. sp.	16	96	480	192	384	384	640	672	0	0	432	128	0	0	0	0	64	384	0	0
Di	Tanytarsini Gen. sp.	192	3520	2800	3008	9488	11040	2752	976	304	976	2256	896	576	1216	208	128	320	2560	256	16
Di	Tipula sp.	0	0	0	0	0	0	0	0	32	0	16	0	0	0	0	0	0	0	0	0

**Appendix 7.** Taxa lists of substrate samples: Eder, single- and multiple-channel section (Ind. m<sup>-2</sup>). Information on sample code and abbreviations see p 129.

Taxa group	Taxon	Eder_1_block1	Eder_1_cobble1	Eder_1_cg gravel1	Eder_1_lptp1	Eder_1_subm1	Eder_1_wood1	Eder_1_mud1	Eder_2_block1	Eder_2_cobble1	Eder_2_cg gravel1	Eder_2_fg gravel1	Eder_2_fg gravel2	Eder_2_sand1	Eder_2_sand2	Eder_2_lptp1	Eder_2_subm1	Eder_2_wood1	Eder_2_mud1
Tu	Dugesia sp.	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tu	Polycelis sp.	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ga	Ancylus fluviatilis	0	32	16	0	0	0	0	0	32	128	80	0	16	0	0	0	0	0
Ga	Gyraulus albus	0	0	32	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0
Bi	Pisidium sp.	0	0	0	0	0	0	80	0	0	0	0	0	0	32	0	0	0	224
Ol	Eiseniella tetraedra	80	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0
Ol	Naididae/Tubificidae Gen. sp.	0	64	0	16	0	0	96	0	0	0	0	0	0	48	0	0	0	0
Ol	Oligochaeta Gen. sp.	1	112	0	1	16	0	1	0	0	32	0	128	0	160	0	0	0	128
Ol	Stylodrilus heringianus	0	0	0	0	0	0	0	0	0	0	0	16	0	32	0	0	0	0
Hi	Erpobdella octoculata	0	32	16	0	112	0	96	0	64	0	16	0	0	0	0	64	0	64
Hi	Glossiphonia verrucata	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0
Hi	Glossiphonia sp.	0	0	0	0	0	1	0	0	0	0	0	0	0	32	0	0	0	0
Hi	Helobdella stagnalis	0	0	32	0	0	0	0	0	0	0	16	0	0	0	0	16	0	32
Cr	Asellus aquaticus	0	0	0	80	0	0	1056	0	0	0	0	0	0	128	288	16	0	32
Cr	Gammarus fossarum	0	0	0	0	0	16	0	0	0	0	0	0	0	0	16	0	0	0
Cr	Gammarus pulex	0	16	0	0	0	16	0	0	0	0	0	0	0	0	0	16	0	0
Cr	Gammarus sp.	16	16	0	272	16	128	224	0	16	0	16	0	0	0	112	1	0	0
Cr	Proasellus coxalis	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ep	Baetis buceratus/vernus	1	0	0	0	128	0	0	1	0	0	16	0	0	0	0	0	0	0
Ep	Baetis fuscatus	48	0	0	0	992	0	0	64	192	640	0	0	0	19	0	0	0	0
Ep	Baetis fuscatus/scambus	16	32	16	0	672	0	0	1	128	192	16	464	0	77	0	0	0	0
Ep	Baetis liebenauae	0	0	0	0	736	0	0	0	0	0	0	0	0	0	0	0	0	0
Ep	Baetis lutheri	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0
Ep	Baetis rhodani	0	0	16	0	0	0	0	96	0	32	32	0	0	0	0	0	0	0
Ep	Baetis scambus	32	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0
Ep	Baetis vernus	16	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0
Ep	Baetis sp.	32	32	1	0	1568	0	0	80	32	128	1	112	0	1	0	32	0	0
Ep	Caenis luctuosa	0	672	736	0	224	0	64	0	176	0	0	16	208	96	0	0	0	64
Ep	Centroptilum luteolum	0	0	0	208	32	144	0	0	0	0	0	16	0	0	176	0	0	0
Ep	Ecdyonurus venosus-Gr.	0	0	0	0	128	16	0	0	96	96	0	32	0	0	0	0	0	0
Ep	Ephemera danica	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0
Ep	Procloeon sp.	0	16	0	0	0	0	64	0	0	0	0	0	0	0	0	0	0	0
Ep	Serratella ignita	400	16	48	0	6304	16	0	32	288	480	32	96	32	32	80	0	0	0

Appendix 7 continued.

Taxa group	Taxon	Eder_1_block1	Eder_1_cobble1	Eder_1_cgravel1	Eder_1_lptp1	Eder_1_subm1	Eder_1_wood1	Eder_1_mud1	Eder_2_block1	Eder_2_cobble1	Eder_2_cgravel1	Eder_2_fgravel1	Eder_2_fgravel2	Eder_2_sand1	Eder_2_sand2	Eder_2_lptp1	Eder_2_subm1	Eder_2_wood1	Eder_2_mud1
Pl	Leuctra geniculata	0	48	224	0	0	0	0	0	288	96	0	0	0	0	0	0	0	0
Pl	Leuctra sp.	0	0	64	0	0	0	0	0	176	800	80	48	0	0	0	0	0	0
He	Micronectinae Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0
Me	Sialis fuliginosa	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Me	Sialis lutaria	0	0	0	0	0	0	64	0	0	0	0	0	16	0	0	0	0	64
Me	Sialis sp.	0	0	1	0	0	0	224	0	0	0	0	0	1	0	0	0	0	736
Tr	Allogamus auricollis	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0
Tr	Anabolia nervosa	0	0	0	48	0	0	32	0	0	0	0	0	0	0	0	0	16	0
Tr	Athripsodes albifrons	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0
Tr	Athripsodes aterrimus	0	0	0	96	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Athripsodes cinereus	0	0	0	0	16	0	0	0	0	0	0	0	0	48	16	0	0	0
Tr	Brachycentrus maculatus	0	0	0	0	16	0	0	0	0	0	16	0	0	0	0	0	0	0
Tr	Brachycentrus subnubilus	0	0	0	0	16	0	0	0	336	0	0	0	0	0	0	32	0	0
Tr	Ceraclea dissimilis	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Chaetopteryx villosa	0	0	0	48	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Goera pilosa	0	0	0	0	0	0	0	0	0	304	432	0	80	0	0	0	0	0
Tr	Hydropsyche incognita	48	0	0	0	0	0	0	0	224	16	0	0	0	0	0	0	0	0
Tr	Hydropsyche pellucidula	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0
Tr	Hydropsyche siltalai	0	0	0	0	0	0	0	0	0	64	0	0	0	0	0	0	0	0
Tr	Hydropsyche sp.	224	0	0	0	16	0	0	32	320	144	16	0	0	0	0	64	0	0
Tr	Hydroptila sp.	64	48	0	0	0	0	0	0	16	16	0	0	0	16	0	0	0	0
Tr	Lepidostoma hirtum	0	0	0	0	16	0	0	0	16	0	0	0	0	0	0	0	0	0
Tr	Leptocerus interruptus	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Lype reducta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0
Tr	Mystacides azurea	0	0	16	48	0	0	0	0	0	0	0	0	32	0	0	0	0	0
Tr	Mystacides longicornis/nigra	0	0	0	16	0	0	128	0	0	0	0	0	0	0	0	0	0	0
Tr	Oecetis sp.	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Polycentropus flavomaculatus	0	192	16	21	352	0	0	0	352	16	0	0	16	0	32	48	0	0
Tr	Polycentropus irroratus	0	0	0	43	0	16	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Psychomyia pusilla	16	0	0	0	0	0	0	16	0	16	0	0	0	0	0	0	0	0
Tr	Rhyacophila dorsalis/nubila	48	0	0	0	0	0	0	0	32	80	0	0	0	0	0	32	16	0
Tr	Sericostoma flavicorne/personatum	0	0	0	0	0	0	0	0	32	0	0	0	0	16	0	0	0	0

Appendix 7 continued.

Taxa group	Taxon	Eder_1_block1	Eder_1_cobble1	Eder_1_cg gravel1	Eder_1_lptp1	Eder_1_subm1	Eder_1_wood1	Eder_1_mud1	Eder_2_block1	Eder_2_cobble1	Eder_2_cg gravel1	Eder_2_fg gravel1	Eder_2_fg gravel2	Eder_2_sand1	Eder_2_sand2	Eder_2_lptp1	Eder_2_subm1	Eder_2_wood1	Eder_2_mud1
Co	Elmis maugetii Ad.	0	0	16	0	24	0	0	0	80	64	16	32	0	0	0	32	80	0
Co	Elmis rioloides Ad.	224	0	0	0	72	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	Elmis sp. Lv.	368	32	32	0	192	0	0	0	80	240	112	0	0	0	0	16	16	0
Co	Esolus angustatus Ad.	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0
Co	Esolus parallelepipedus Ad.	0	0	0	0	0	0	0	0	80	288	112	0	0	0	0	0	0	0
Co	Esolus sp. Lv.	16	16	16	0	0	0	0	0	144	112	272	0	16	0	0	0	0	0
Co	Haliphus sp. Lv.	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	Hydraena gracilis Ad.	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0
Co	Hydraena reyi Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0
Co	Hydraena sp. Ad.	0	0	0	0	0	0	0	0	0	16	0	16	0	0	0	0	1	0
Co	Laccobius sp. Lv.	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0
Co	Laccophilus sp. Lv.	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	Limnius opacus Ad.	0	0	0	0	0	0	0	0	48	0	0	0	0	0	0	0	0	0
Co	Limnius opacus Lv.	0	0	0	0	0	0	0	0	16	16	0	0	0	0	0	0	0	0
Co	Longitarsus sp. Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0
Co	Nebrioporus elegans Ad.	0	0	0	0	48	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	Oulimnius tuberculatus Ad.	0	208	80	16	64	32	0	32	16	128	144	144	96	0	96	16	0	0
Co	Oulimnius tuberculatus Lv.	256	144	144	0	32	0	0	0	16	16	144	0	64	0	0	32	0	0
Co	Platambus maculatus Ad.	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0
Di	Antocha sp.	16	0	0	0	0	0	0	0	16	16	0	0	0	0	0	0	0	0
Di	Atherix/Ibisia sp.	64	0	0	0	0	0	0	0	0	80	0	0	0	0	0	0	0	0
Di	Ceratopogoninae Gen. sp.	16	0	0	0	0	0	0	0	0	48	64	16	32	0	0	0	0	0
Di	Chelifera sp.	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Di	Chironomidae Gen. sp.	528	944	96	1	272	1	1	1472	304	32	256	1	400	1	0	112	1	1
Di	Chironomini Gen. sp.	64	352	512	80	512	32	288	16	288	16	1408	32	3152	160	0	32	0	160
Di	Chrysops sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0
Di	Clinocerinae Gen. sp.	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Di	Dicranota sp.	0	0	0	0	0	0	0	0	0	144	224	0	0	0	0	0	0	0
Di	Prodiamesa olivacea	0	0	0	0	0	0	512	0	0	0	0	0	64	0	0	0	0	0
Di	Simulium sp.	0	0	0	0	1744	0	0	0	0	0	0	0	0	0	0	1568	0	0
Di	Tabanidae Gen. sp.	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0
Di	Tanypodinae Gen. sp.	240	16	16	16	352	96	0	0	48	0	0	96	0	0	0	0	16	32
Di	Tanytarsini Gen. sp.	1152	368	432	16	784	16	0	0	432	352	6864	128	352	32	0	0	0	0
Di	Tipula sp.	0	0	0	0	0	0	0	0	0	0	0	16	32	0	0	0	0	0

**Appendix 8.** Taxa lists of substrate samples: Nims, single- and multiple-channel section (Ind. m<sup>-2</sup>). Information on sample code and abbreviations see p 129.

Taxa group	Taxon	Nims_1_block1	Nims_1_cobble1	Nims_1_cgravel1	Nims_1_fgravel1	Nims_1_sand1	Nims_1_loam1	Nims_1_lptp1	Nims_1_wood1	Nims_1_cpom1	Nims_1_mud1	Nims_2_block1	Nims_2_cobble1	Nims_2_cgravel1	Nims_2_fgravel1	Nims_2_sand1	Nims_2_loam1	Nims_2_lptp1	Nims_2_wood1	Nims_2_cpom1	Nims_2_mud1
Tu	Dugesia sp.	0	16	16	0	0	0	0	0	0	0	0	112	0	0	0	0	0	0	0	0
Ga	Ancylus fluviatilis	0	0	192	16	0	0	0	0	0	0	80	16	16	0	0	0	0	16	64	176
Ga	Potamopyrgus antipodarum	0	32	80	16	0	16	0	0	1552	1088	48	80	304	0	0	0	0	16	160	4784
Ga	Radix balthica	0	0	0	0	0	32	0	0	192	0	16	0	48	0	0	32	0	16	128	304
Bi	Pisidium sp.	0	0	64	240	112	192	0	0	5808	272	0	0	16	0	0	0	0	0	0	400
Ol	Naididae/Tubificidae Gen. sp.	0	0	64	432	448	0	0	0	272	80	0	16	272	0	64	160	0	0	0	0
Ol	Oligochaeta Gen. sp.	0	0	224	304	32	0	0	0	240	1	0	1	112	0	1	1	0	0	0	0
Ol	Stylodrilus heringianus	0	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hi	Erpobdella octoculata	0	0	32	0	0	0	0	0	32	0	0	0	64	32	16	0	0	0	32	64
Hi	Glossiphonia complanata	0	0	0	0	0	0	0	0	32	0	0	0	0	16	0	0	0	0	0	0
Hi	Glossiphonia sp.	0	0	0	0	0	0	0	0	16	0	0	0	0	1	0	0	0	16	0	64
Hi	Helobdella stagnalis	0	0	0	128	0	0	0	0	64	0	0	0	0	0	0	0	0	0	0	128
Cr	Asellus aquaticus	0	0	16	0	0	0	0	0	0	0	0	0	176	0	0	0	0	0	480	0
Cr	Gammarus fossarum	0	0	0	0	0	0	32	0	32	0	0	48	0	0	0	80	16	0	2464	0
Cr	Gammarus pulex	0	0	0	0	0	0	0	0	16	0	0	0	16	0	0	0	0	0	0	0
Cr	Gammarus sp.	0	80	736	1440	0	32	144	0	224	48	368	592	736	0	0	560	688	208	3264	0
Ep	Baetis buceratus/vernus	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	1	0	0	0
Ep	Baetis fuscatus/scambus	0	32	32	64	0	16	0	0	0	0	1	0	0	0	0	1	0	0	1	0
Ep	Baetis lutheri	112	0	0	0	0	0	16	0	0	0	224	53	0	0	0	16	0	0	0	0
Ep	Baetis rhodani	144	32	16	80	0	0	128	0	0	0	224	142	0	0	0	80	0	0	288	0
Ep	Baetis scambus	0	80	208	0	0	0	0	0	0	0	32	0	0	0	0	48	0	0	32	0
Ep	Baetis vernus	16	0	0	0	0	0	128	0	0	0	0	18	0	0	0	16	32	0	0	0
Ep	Baetis sp.	304	80	16	16	0	1	208	0	0	0	448	283	0	0	0	32	0	16	64	0
Ep	Caenis beskidensis/pseudorivulorum	0	16	64	64	0	0	0	0	112	0	0	16	0	0	0	0	0	16	0	0
Ep	Centroptilum luteolum	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ep	Ecdyonurus venosus-Gr.	0	0	16	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0
Ep	Ephemera danica	0	64	0	208	0	0	0	16	304	64	0	0	48	112	80	16	0	0	0	384
Ep	Habroleptoides confusa	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0
Ep	Serratella ignita	160	160	112	544	0	32	736	16	16	32	560	272	48	0	0	16	416	112	1056	0
Od	Calopteryx sp.	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	32	48	0	0
Pl	Leuctra geniculata	0	64	144	48	0	32	0	0	128	0	0	144	16	0	0	0	0	0	16	0
Pl	Leuctra sp.	0	32	416	16	0	0	0	0	0	0	0	32	16	0	0	0	0	0	160	0
Pl	Protonemura sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0
Pp	Osmylus fulvicephalus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	64	0

Appendix 8 continued.

Taxa group	Taxon	Nims_1_block1	Nims_1_cobble1	Nims_1_cgravel1	Nims_1_fgavel1	Nims_1_sand1	Nims_1_loam1	Nims_1_lptp1	Nims_1_wood1	Nims_1_cpom1	Nims_1_mud1	Nims_2_block1	Nims_2_cobble1	Nims_2_cgravel1	Nims_2_fgavel1	Nims_2_sand1	Nims_2_loam1	Nims_2_lptp1	Nims_2_wood1	Nims_2_cpom1	Nims_2_mud1
Me	<i>Sialis lutaria</i>	0	0	0	0	0	0	0	0	64	0	0	0	0	0	0	0	0	0	0	448
Me	<i>Sialis</i> sp.	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Tr	<i>Anomalopterygella chauviniana</i>	0	0	16	16	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0
Tr	<i>Athripsodes cinereus</i>	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0
Tr	<i>Brachycentrus maculatus</i>	288	2112	0	0	0	0	3152	0	0	0	64	208	0	0	0	0	896	0	0	0
Tr	<i>Chaetopteryx villosa</i>	0	0	0	0	0	0	0	0	112	16	0	0	0	32	16	0	0	0	64	0
Tr	<i>Goera pilosa</i>	0	0	32	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0
Tr	<i>Halesus digitatus/tesselatus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	192	0	64	0
Tr	<i>Halesus radiatus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	192	0	0	0
Tr	<i>Hydropsyche siltalai</i>	0	0	0	0	0	0	64	0	0	0	32	176	0	0	0	0	0	0	64	0
Tr	<i>Hydropsyche</i> sp.	400	192	0	0	0	0	1376	0	112	0	1088	112	0	0	0	32	320	144	1232	0
Tr	<i>Hydroptila</i> sp.	0	0	0	0	0	0	0	0	0	0	144	0	0	0	32	112	0	32	0	0
Tr	<i>Lasiocephala basalis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	960	0	0	0
Tr	<i>Lepidostoma hirtum</i>	0	0	0	0	0	0	32	48	688	0	0	0	0	0	0	0	0	0	400	0
Tr	<i>Lype reducta</i>	0	0	0	0	0	0	0	0	240	0	0	0	0	0	0	0	0	16	0	0
Tr	<i>Mystacides azurea</i>	0	0	0	0	0	0	0	0	112	32	0	0	0	0	0	0	0	0	0	0
Tr	<i>Mystacides longicornis/nigra</i>	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0
Tr	<i>Odontocerum albicorne</i>	0	0	16	192	0	32	0	0	0	0	0	64	32	16	32	0	0	0	0	0
Tr	<i>Polycentropus flavomaculatus</i>	0	192	0	0	0	0	16	0	688	16	0	0	0	0	0	0	0	0	0	0
Tr	<i>Psychomyia pusilla</i>	0	64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	<i>Rhyacophila dorsalis/nubila</i>	0	192	16	0	0	0	64	0	0	0	48	64	0	0	0	16	320	0	176	0
Tr	<i>Rhyacophila fasciata</i>	0	64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	<i>Sericostoma flavicorne/personatum</i>	0	192	80	48	0	0	0	16	944	0	0	144	0	64	416	0	192	0	160	0
Co	<i>Elmis aenea</i> Ad.	92	0	0	0	0	0	64	0	0	0	979	0	0	0	32	28	373	0	0	0
Co	<i>Elmis maugettii</i> Ad.	276	64	16	0	0	0	512	0	0	0	109	304	0	0	0	84	507	112	1776	0
Co	<i>Elmis</i> sp. Lv.	16	208	128	16	0	16	96	0	48	16	320	256	0	0	16	80	80	16	720	0
Co	<i>Esolus parallelepipedus</i> Ad.	0	32	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	<i>Esolus</i> sp. Lv.	0	16	16	0	0	0	0	0	0	0	0	16	0	48	0	0	0	0	0	0
Co	<i>Hydraena gracilis</i> Ad.	0	0	48	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0
Co	<i>Hydraena reyi</i> Ad.	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	<i>Hydraena</i> sp. Ad.	0	0	32	0	0	0	1	0	0	0	0	32	0	0	0	0	32	0	0	0
Co	<i>Hydroporinae</i> Gen. sp. Lv.	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	80	0	0	0	0
Co	<i>Laccobius</i> sp. Lv.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	80	0	0	16	0
Co	<i>Limnius volckmari</i> Ad.	0	0	16	0	0	0	0	0	0	0	0	16	16	0	0	0	0	0	128	0
Co	<i>Limnius volckmari</i> Lv.	0	144	224	32	0	0	0	0	0	0	0	128	16	16	0	0	0	0	0	0

Appendix 8 continued.

Taxa group	Taxon	Nims_1_block1	Nims_1_cobble1	Nims_1_cgravel1	Nims_1_fgravel1	Nims_1_sand1	Nims_1_loam1	Nims_1_lptp1	Nims_1_wood1	Nims_1_cpom1	Nims_1_mud1	Nims_2_block1	Nims_2_cobble1	Nims_2_cgravel1	Nims_2_fgravel1	Nims_2_sand1	Nims_2_loam1	Nims_2_lptp1	Nims_2_wood1	Nims_2_cpom1	Nims_2_mud1
Co	Orectochilus villosus Ad.	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0
Co	Oulimnius tuberculatus Ad.	0	16	224	96	0	0	64	0	0	16	1120	32	176	0	0	928	320	32	848	0
Co	Oulimnius tuberculatus Lv.	0	32	48	128	0	48	0	0	192	0	0	0	16	32	0	32	0	0	0	128
Co	Platambus maculatus Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0
Di	Antocha sp.	0	0	0	0	0	0	0	0	0	0	80	0	0	0	0	320	0	0	0	0
Di	Atherix/Ibisia sp.	0	80	64	16	0	0	0	0	16	0	0	16	0	0	0	0	0	0	0	0
Di	Ceratopogoninae Gen. sp.	0	0	16	48	16	0	0	0	224	0	0	0	32	0	16	48	0	16	0	0
Di	Chelifera sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0
Di	Chironomidae Gen. sp.	112	240	16	64	16	1	464	1	208	16	272	48	16	448	80	2272	48	96	1824	1
Di	Chironomini Gen. sp.	48	768	128	80	0	0	720	16	112	48	48	128	16	4576	1408	0	128	64	4547	512
Di	Dicranota sp.	0	16	128	32	0	0	0	0	0	0	0	0	0	0	0	32	16	0	0	0
Di	Hemerodromia sp.	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0
Di	Limnophora sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	80	0
Di	Pilaria sp.	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0
Di	Prodiamesa olivacea	0	0	0	0	48	0	0	0	0	160	0	0	16	384	320	0	0	0	0	768
Di	Psychodidae Gen. sp.	0	0	0	0	32	0	0	0	16	0	0	0	0	0	0	0	0	0	48	0
Di	Simulium sp.	272	64	0	32	0	0	352	0	0	0	144	96	0	16	0	0	96	0	448	0
Di	Tabanidae Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	128
Di	Tanypodinae Gen. sp.	0	0	48	112	16	0	32	0	288	256	64	16	16	320	976	192	32	80	480	448
Di	Tanytarsini Gen. sp.	48	608	96	48	16	16	368	0	160	80	432	48	0	0	368	640	80	128	493	0
Di	Tipula sp.	0	0	0	16	0	0	0	0	48	0	0	0	0	0	0	32	0	0	32	0

**Appendix 9.** Taxa lists of substrate samples: Bröl, single- and multiple-channel section (Ind. m<sup>-2</sup>). Information on sample code and abbreviations see p 129.

Taxa group	Taxon	Bröl_1_block1	Bröl_1_cobble1	Bröl_1_fgravel1	Bröl_1_sand1	Bröl_1_lptp1	Bröl_1_wood1	Bröl_1_mud1	Bröl_2_block1	Bröl_2_cobble1	Bröl_2_cgravel1	Bröl_2_cgravel2	Bröl_2_fgravel1	Bröl_2_sand1	Bröl_2_loam1	Bröl_2_loam2	Bröl_2_lptp1	Bröl_2_wood1	Bröl_2_cpom1	Bröl_2_cpom2	Bröl_2_mud1
Ga	Ancylus fluviatilis	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0
Ga	Potamopyrgus antipodarum	0	0	32	0	0	0	112	0	0	32	0	0	16	0	32	0	0	16	32	0
Ga	Radix balthica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	16	0
Bi	Pisidium sp.	0	0	0	32	0	0	144	0	0	0	0	0	16	0	16	0	0	0	64	16
Bi	Sphaerium sp.	0	0	0	48	0	0	256	0	0	0	0	0	0	0	0	0	0	0	16	0
Ol	Eiseniella tetraedra	0	0	0	0	0	0	0	16	0	0	32	0	0	0	0	0	0	0	0	0
Ol	Naididae/Tubificidae Gen. sp.	32	0	272	64	0	0	2304	80	16	80	0	928	384	0	256	0	0	176	32	288
Ol	Oligochaeta Gen. sp.	96	144	208	304	0	0	192	1	64	288	336	640	272	0	496	0	48	16	1	256
Ol	Stylodrilus heringianus	0	64	32	96	0	0	0	0	16	32	96	32	64	0	400	0	0	16	0	32
Hi	Erpobdella octoculata	0	0	16	0	0	0	16	0	16	48	48	32	0	0	16	16	32	16	48	32
Hi	Erpobdella vilnensis	0	0	0	0	0	0	0	0	0	0	80	0	0	0	0	0	16	0	0	0
Hi	Glossiphonia sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0
Cr	Asellus aquaticus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	0	0	64	48	0
Cr	Gammarus fossarum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	16	0	0	32	0
Cr	Gammarus sp.	48	64	96	48	368	16	32	32	32	80	48	0	0	0	512	256	0	16	16	0
Ep	Baetis fuscatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0
Ep	Baetis fuscatus/scambus	1	32	1	16	0	0	0	1	1	80	1	1	0	1	0	1	0	0	0	1
Ep	Baetis lutheri	0	0	0	0	0	0	0	96	0	0	0	0	0	0	0	0	0	0	0	0
Ep	Baetis rhodani	128	528	48	0	128	880	0	640	304	0	112	0	0	32	0	32	704	0	0	0
Ep	Baetis scambus	16	384	304	0	0	0	0	16	544	96	48	16	0	48	0	0	0	0	0	48
Ep	Baetis sp.	1	288	1	1	1	16	0	416	16	32	1	16	0	1	0	1	80	0	0	1
Ep	Centroptilum luteolum	0	0	0	64	0	0	16	0	0	0	0	0	0	0	64	0	0	32	0	16
Ep	Ecdyonurus venosus-Gr.	0	288	0	0	0	0	0	0	176	48	80	16	0	0	16	0	0	0	0	0
Ep	Ephemera danica	0	32	48	64	0	16	272	0	0	16	0	0	32	0	0	0	0	128	0	16
Ep	Habrophlebia lauta	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	16	0
Ep	Serratella ignita	784	336	160	32	2064	304	0	288	128	256	400	0	0	48	16	784	208	144	112	0
Pl	Leuctra geniculata	0	192	128	0	0	16	0	64	496	432	160	0	0	0	32	0	0	16	16	0
Pl	Leuctra sp.	0	416	192	0	0	0	0	112	512	400	1168	176	0	0	16	32	16	0	48	32
He	Velia sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0
Me	Sialis sp.	0	0	0	16	0	0	16	0	0	0	0	0	0	0	80	0	0	16	0	16

Appendix 9 continued.

Taxa group	Taxon	Bröl_1_block1	Bröl_1_cobble1	Bröl_1_fgravel1	Bröl_1_sand1	Bröl_1_lptp1	Bröl_1_wood1	Bröl_1_mud1	Bröl_2_block1	Bröl_2_cobble1	Bröl_2_cgravel1	Bröl_2_cgravel2	Bröl_2_fgravel1	Bröl_2_sand1	Bröl_2_loam1	Bröl_2_loam2	Bröl_2_lptp1	Bröl_2_wood1	Bröl_2_cpom1	Bröl_2_cpom2	Bröl_2_mud1
Tr	Anabolia nervosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	16	16
Tr	Anomalopterygella chauviniana	0	96	32	0	0	0	0	0	0	64	128	32	0	0	0	0	0	0	16	0
Tr	Athripsodes albifrons	0	16	0	0	0	0	0	0	16	0	48	0	0	0	0	0	0	0	0	0
Tr	Chaetopteryx villosa	0	0	0	0	0	0	0	0	0	32	0	0	0	0	32	0	0	96	1104	0
Tr	Cheumatopsyche lepida	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0
Tr	Goera pilosa	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0
Tr	Halesus digitatus/tesselatus	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	16	0	0	160	0
Tr	Halesus radiatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	16	32	0
Tr	Hydropsyche incognita	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Hydropsyche pellucidula	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Hydropsyche siltalai	16	32	0	0	304	16	0	128	0	32	144	0	0	0	0	48	0	0	0	0
Tr	Hydropsyche sp.	16	1	0	16	384	1	0	64	16	16	512	0	16	0	0	656	32	0	0	0
Tr	Hydroptila sp.	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0
Tr	Lasiocephala basalis	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Lepidostoma hirtum	0	0	0	0	16	0	0	16	0	0	0	0	0	0	0	48	0	16	144	0
Tr	Odontocerum albicorne	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tr	Oecetis sp.	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0
Tr	Polycentropus flavomaculatus	16	0	16	0	64	0	0	0	16	0	0	0	16	0	0	32	0	32	0	0
Tr	Polycentropus irroratus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	0
Tr	Rhyacophila dorsalis/nubila	16	80	0	0	112	16	0	96	0	0	16	0	32	16	0	112	0	0	0	0
Tr	Sericostoma flavicorne/personatum	0	32	48	0	0	0	0	16	80	192	128	16	0	0	0	0	16	112	192	16
Co	Cyphon sp. Lv.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0
Co	Elmis maugetii Ad.	96	112	0	0	464	64	0	208	32	16	272	48	0	0	0	544	96	0	0	0
Co	Elmis sp. Lv.	0	16	16	0	64	0	16	32	32	16	64	16	0	0	0	64	0	16	0	0
Co	Esolus parallelepipedus Ad.	0	32	0	0	0	0	0	0	16	0	80	16	0	0	0	0	0	0	0	0
Co	Esolus sp. Lv.	0	32	16	0	0	0	0	0	0	16	0	16	0	0	0	0	0	0	0	0
Co	Hydraena gracilis Ad.	0	0	0	0	0	0	0	0	0	0	112	0	0	0	0	0	0	0	0	0
Co	Hydraena sp. Ad.	0	0	0	0	0	0	0	16	16	0	128	0	0	0	16	32	0	0	0	0
Co	Limnius opacus Lv.	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	Limnius volckmari Ad.	0	16	0	0	0	0	0	16	32	16	64	0	0	0	0	0	0	0	0	0
Co	Limnius volckmari Lv.	0	48	16	0	0	0	0	0	32	0	32	144	0	0	0	0	0	0	0	0
Co	Oulimnius tuberculatus Ad.	112	48	144	0	320	0	0	48	96	176	288	0	0	0	0	384	16	0	0	0
Co	Oulimnius tuberculatus Lv.	0	16	32	0	0	0	0	0	0	32	0	0	0	0	32	16	0	0	0	0
Co	Stictotarsus duodecimpustulatus Ad.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0

## Appendix 9 continued.

Taxa group	Taxon	Bröl_1_block1	Bröl_1_cobble1	Bröl_1_fgravel1	Bröl_1_sand1	Bröl_1_lptp1	Bröl_1_wood1	Bröl_1_mud1	Bröl_2_block1	Bröl_2_cobble1	Bröl_2_cgravel1	Bröl_2_cgravel2	Bröl_2_fgravel1	Bröl_2_sand1	Bröl_2_loam1	Bröl_2_loam2	Bröl_2_lptp1	Bröl_2_wood1	Bröl_2_cpom1	Bröl_2_cpom2	Bröl_2_mud1
Di	Atherix/Ibisia sp.	0	0	0	0	0	0	0	48	0	0	16	0	0	0	0	0	0	0	0	0
Di	Atrichops crassipes	0	0	0	0	0	0	48	0	0	0	0	0	0	0	0	0	0	0	0	0
Di	Ceratopogoninae Gen. sp.	16	0	48	0	0	0	48	0	0	0	0	0	0	0	32	0	0	0	0	16
Di	Chelifera sp.	16	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0
Di	Chironomidae Gen. sp.	160	64	16	112	1520	16	368	1248	1	64	96	1	64	16	96	3440	144	48	1	112
Di	Chironomini Gen. sp.	0	32	32	64	64	0	288	96	16	16	0	32	128	0	240	672	0	48	0	160
Di	Chrysops sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0
Di	Dicranota sp.	0	32	16	0	16	0	0	16	64	48	80	96	16	0	48	16	0	0	0	0
Di	Prodiamesa olivacea	0	0	16	208	0	0	224	0	0	0	0	0	48	0	0	0	0	0	0	0
Di	Ptychoptera sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16
Di	Simulium sp.	32	0	0	16	2752	32	0	304	0	0	0	0	96	0	16	544	144	0	16	16
Di	Tabanidae Gen. sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16
Di	Tanypodinae Gen. sp.	0	0	0	128	32	0	208	0	0	0	0	32	0	0	144	64	0	96	32	48
Di	Tanytarsini Gen. sp.	80	0	32	224	64	0	176	0	0	16	0	0	16	0	656	0	0	64	16	64
Di	Tipula sp.	112	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

**Appendix 10.** Physico-chemical parameters of multiple-channel samples; values for single-channel samples identical; n.d. = no data available (device failed).

	Date	Dissolved Oxygen content (mg l <sup>-1</sup> )	Oxygen saturation (%)	pH	Conductivity (µS cm <sup>-1</sup> )
Lahn-W	11.07.2005	9.8	103.6	7.9	211
Lahn-LH	10.07.2005	n.d.	n.d.	n.d.	n.d.
Lahn-C	30.06.2004	9.3	98.6	7.77	322
Orke	01.07.2004	10.5	101.7	8.5	319
Eder	11.07.2005	9.3	107.3	8.4	166
Nims	06.07.2005	9.2	93.5	8.1	463
Bröl	07.07.2005	9.8	98.5	7.75	259

**Appendix 11-A.** Spearman rank correlation: Input hydromorphological metrics; abbreviations see Table 4-2.

	Lahn-W		Lahn-LH		Lahn-C		Orke		Eder		Nims		Bröl	
	single	multiple	single	multiple	single	multiple	single	multiple	single	multiple	single	multiple	single	multiple
sect_ha	0.29	0.62	0.31	1.14	0.48	1.24	0.43	0.92	0.73	0.74	0.35	0.55	0.45	1.04
shore	301.00	1001.00	381.00	1605.00	432.00	1408.00	415.00	785.00	509.00	715.00	382.00	862.00	403.00	1021.00
av_width	18.50	56.00	15.80	67.30	25.50	57.80	22.90	49.20	34.60	39.30	17.90	31.40	19.00	54.20
aquatic_width	11.98	5.33	9.78	5.63	15.26	24.75	14.87	16.07	22.16	11.76	9.91	5.88	11.62	6.14
cf_no	2.00	10.00	4.00	12.00	4.00	8.00	4.00	8.00	7.00	9.00	3.00	10.00	3.00	13.00
cf_swi	0.65	1.95	1.04	2.15	0.99	1.79	1.04	1.56	1.23	1.91	0.89	2.05	0.82	2.17
cv_depth	0.44	0.69	0.41	0.85	0.59	0.97	0.35	0.52	0.69	0.71	0.81	0.67	0.45	0.90
cv_veloc	0.46	1.21	0.63	1.38	0.67	1.02	0.61	0.77	0.99	1.00	0.96	1.06	0.67	1.09
su_no	7.00	10.00	7.00	11.00	8.00	11.00	11.00	10.00	8.00	9.00	10.00	10.00	8.00	9.00
su_swi	0.80	1.50	0.76	1.74	1.24	1.47	1.70	1.14	1.06	0.94	1.18	1.16	0.95	1.19
su_sdi	0.99	5.05	1.91	5.94	4.14	5.98	6.38	5.28	2.74	3.38	2.60	3.28	2.93	3.22
block-cobble_A	45.02	35.89	46.58	53.34	28.01	23.99	34.54	63.27	76.43	84.12	42.48	42.72	55.03	59.60
gravel_A	0.65	18.38	0.68	29.77	41.60	71.81	28.06	6.18	8.33	8.03	2.33	3.78	0.83	9.50
sand-loam_A	0.46	4.45	1.00	8.55	1.33	19.91	3.67	5.10	0.56	1.03	0.49	2.91	0.72	3.07
lptp-wood_A	0.72	3.25	0.13	2.92	2.94	3.55	4.95	1.51	0.50	0.60	1.22	1.22	0.59	1.82
cpom-mud_A	1.05	0.71	0.23	8.68	2.39	4.02	2.70	4.28	2.33	4.08	3.03	8.17	0.93	7.41

**Appendix 11-B.** Spearman rank correlation: Input biological metrics; abbreviations see Table 4-3.

	Lahn-W		Lahn-LH		Lahn-C		Orke		Eder		Nims		Bröl	
	single	multiple												
abund	6109.91	7419.68	9674.61	8306.31	4451.76	6132.49	4433.74	3023.41	4815.53	4123.16	4919.01	5059.28	3064.07	3006.36
# taxa	91	96	78	81	95	95	111	111	98	100	91	91	77	79
EPTCBO	59	61	47	49	60	60	67	67	62	63	55	55	48	49
evenness	0.58	0.62	0.66	0.65	0.64	0.59	0.51	0.68	0.69	0.70	0.75	0.75	0.71	0.73
[%] pel	22.03	19.76	21.10	21.27	16.57	16.47	16.35	13.22	12.35	15.59	8.63	11.07	13.03	7.83
[%] psa	24.12	17.17	8.18	12.66	8.73	9.59	43.55	25.42	9.12	11.80	11.37	14.22	6.64	10.43
[%] Aka	4.18	4.11	5.89	4.73	12.66	15.30	4.03	6.48	10.72	9.04	5.76	5.55	11.15	14.77
[%] lit	18.97	23.58	30.34	26.87	29.83	27.78	15.04	26.54	36.92	33.67	43.92	39.61	35.13	35.31
[%] phy	23.98	26.19	25.90	26.04	22.54	21.09	15.77	21.32	25.24	22.21	24.61	23.00	28.16	26.51
[%] aka+lit+psa	47.26	44.85	44.41	44.25	51.21	52.66	62.62	58.45	56.76	54.51	61.04	59.37	52.92	60.52
[%] grazers_scrapers	27.05	30.76	37.19	34.01	24.51	19.26	13.60	24.05	30.77	28.91	31.65	27.39	36.99	37.33
[%] miners	2.00	1.49	2.40	2.22	1.74	1.75	0.30	0.50	1.26	1.77	0.56	0.48	1.33	0.38
[%] xylophag	0.05	0.05	0.00	0.01	0.05	0.04	0.06	0.41	0.05	0.05	0.22	0.25	0.05	0.03
[%] shredders	2.89	3.14	1.46	1.99	6.17	7.51	7.35	10.88	2.18	2.73	8.94	10.40	7.17	10.84
[%] gatherers_collectors	48.70	40.32	36.33	41.32	31.99	30.28	66.21	46.04	38.77	39.25	25.84	26.33	38.48	40.83
[%] active filtfeed	4.29	3.42	5.03	5.05	5.26	5.51	3.29	3.26	2.22	3.18	3.45	4.64	3.13	2.23
[%] passive filtfeed	0.67	1.67	3.39	2.08	21.26	26.46	0.92	2.00	12.75	9.26	12.55	11.21	5.18	2.16
[%] predators	12.18	17.43	11.74	10.98	6.96	6.78	6.44	10.74	10.74	13.11	13.55	14.71	6.02	5.37
[%] parasites	1.99	1.48	2.40	2.22	1.72	1.74	0.29	0.49	1.07	1.49	0.38	0.40	1.32	0.38
[%] other feedtyp	0.17	0.24	0.05	0.10	0.35	0.67	1.54	1.64	0.20	0.24	2.86	4.19	0.34	0.44
[%] xsap	5.66	5.70	8.02	6.91	28.18	29.90	10.44	15.18	15.67	13.30	23.72	24.98	14.96	14.35
[%] hypocrenal	2.20	2.81	3.45	2.98	1.95	2.14	3.63	4.04	1.80	1.77	3.47	3.83	3.38	4.00
[%] epirhithral	11.05	12.18	12.81	12.13	10.64	10.40	12.46	13.26	7.87	7.73	9.59	9.01	14.06	16.19
[%] metarhithral	21.37	21.93	20.87	19.97	17.52	16.15	21.03	22.16	18.92	16.98	27.69	25.56	24.21	25.43
[%] hyporhithral	23.87	24.70	22.78	22.08	23.44	22.03	24.35	24.82	25.62	24.11	34.13	34.35	26.36	27.63
[%] epipotamal	14.51	15.48	15.00	15.51	19.21	18.69	19.54	18.74	24.10	24.61	13.99	13.87	16.28	17.38
[%] metapotamal	5.35	4.53	4.74	5.15	6.11	6.87	4.17	3.80	5.50	6.20	2.87	3.64	3.00	2.22
[%] littoral	10.09	10.14	9.87	11.34	11.91	13.33	9.57	8.25	9.74	10.27	5.04	5.59	6.88	3.78
[%] LP	2.23	4.42	0.18	0.15	0.14	0.12	0.26	0.30	0.04	0.04	0.12	0.26	1.00	0.15
[%] LR	0.32	0.51	1.29	2.75	0.94	1.17	1.48	1.35	0.29	0.23	0.43	0.94	0.00	0.00
[%] RL	16.48	22.47	15.65	14.09	18.60	18.54	26.03	27.95	19.97	22.36	16.48	14.40	18.29	22.55
[%] RP	26.38	31.12	37.84	34.71	51.29	51.03	42.76	47.12	54.90	43.20	63.04	57.27	50.88	50.71
[%] RB	18.23	14.00	11.77	11.53	2.75	1.97	6.75	6.98	3.31	4.21	4.76	4.21	14.47	20.34
[%] IN	36.36	27.49	33.27	36.77	26.29	27.17	22.71	16.31	21.48	29.98	15.17	22.92	15.36	6.26
even-curr	0.80	0.83	0.75	0.76	0.65	0.64	0.73	0.71	0.62	0.67	0.59	0.63	0.79	0.74

**Appendix 11-C.** Spearman rank correlation: A priori formulated correlation direction. Positive (grey) = 1; negative (white) = -1; abbreviations see Table 4-2 and Table 4-3.

	sect_ha	shore	av_width	aquatic_width	cf_no	cf_swi	cv_depth	cv_veloc	su_no	su_swi	su_sdi	block-cobble_A	gravel_A	sand-loam_A	lptp-wood_A	cpom-mud_A
abund	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
# taxa	1	1	1	1	1	1	1	1	1	1	1	-1	1	1	1	1
EPTCBO	1	1	1	1	1	1	1	1	1	1	1	-1	1	1	1	1
evenness	1	1	1	1	1	1	1	1	1	1	1	-1	1	1	1	1
[%] pel	1	1	1	1	1	1	1	1	1	1	1	-1	-1	1	1	1
[%] psa	1	1	1	1	1	1	1	1	1	1	1	-1	-1	1	1	1
[%] aka	1	1	1	1	1	1	1	1	1	1	1	1	1	-1	-1	-1
[%] lit	1	1	1	1	1	1	1	1	1	1	1	1	1	-1	-1	-1
[%] phy	1	1	1	1	1	1	1	1	1	1	1	-1	-1	1	1	-1
[%] aka+lit+psa	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-1	-1
[%] grazers_scrapers	1	1	1	1	1	1	1	1	1	1	1	1	1	-1	1	-1
[%] miners	1	1	1	1	1	1	1	1	1	1	1	-1	-1	-1	1	1
[%] xylophag	1	1	1	1	1	1	1	1	1	1	1	-1	-1	-1	1	1
[%] shredders	1	1	1	1	1	1	1	1	1	1	1	-1	-1	1	1	1
[%] gatherers_collectors	1	1	1	1	1	1	1	1	1	1	1	-1	-1	1	1	1
[%] active filtfeed	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1	1	-1	1	-1
[%] passive filtfeed	1	1	1	1	-1	-1	1	-1	-1	-1	-1	-1	1	1	1	-1
[%] predators	1	1	1	1	1	1	1	1	1	1	1	1	-1	-1	1	1
[%] parasites	1	1	1	1	1	1	1	1	1	1	1	-1	-1	1	1	1
[%] other feedtyp	1	1	1	1	1	1	1	1	1	1	1	-1	-1	1	1	1
[%] xsap	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
[%] hypocrenal	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	1
[%] epirhithral	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	-1	-1
[%] metarhithral	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	-1	-1	-1
[%] hyporhithral	1	1	1	1	1	1	1	1	1	1	1	-1	1	1	1	1
[%] epipotamal	1	1	1	1	1	1	1	1	1	1	1	-1	1	1	1	1
[%] metapotamal	1	1	1	1	1	1	1	1	1	1	1	-1	1	1	1	1
[%] littoral	1	1	1	1	1	1	1	1	1	1	1	-1	-1	1	1	1
[%] LP	1	1	1	1	1	1	1	1	1	1	1	-1	-1	1	1	1
[%] LR	1	1	1	1	1	1	1	1	1	1	1	-1	-1	1	1	1
[%] RL	1	1	1	1	1	1	1	1	1	1	1	-1	-1	1	1	1
[%] RP	1	1	1	1	1	1	1	1	1	1	1	1	1	-1	1	-1
[%] RB	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	-1	1	-1
[%] IN	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
even-curr	1	1	1	1	1	1	1	1	1	1	1	-1	1	1	1	1

## Lebenslauf Sonja Jähmig

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### Ausbildung

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- 09/01 – 06/03 DAAD-Stipendiatin: '2 Jahre Sprache & Praxis in China 2001 –2003'.
- 08/01 Abschluss, Universität Essen: Diplom-Umweltwissenschaftlerin.
- 11/00 – 08/01 Diplomarbeit Universität Essen, Abteilung Hydrobiologie: 'Bestimmung saprobieller Leitbilder für ausgewählte Fließgewässer-Typen Deutschlands'. Beitrag zu einem Projekt des Umweltbundesamtes.
- 04/99 – 08/01 Universität-Gesamthochschule Essen: Studium der Ökologie im Hauptstudium.
- 02/98 – 11/98 University of Newcastle, Australia: Environmental Sciences.
- 10/95 – 02/98 Universität-Gesamthochschule Essen: Studium der Ökologie.
- 09/85 – 07/94 Allgäu-Gymnasium Kempten: Abschluss Abitur.
- 08/81 – 07/85 Erbsenlachen-Grundschule Villingen.

### Berufserfahrung / Projektmitarbeit

- Seit 01/04 Wissenschaftliche Mitarbeiterin, Abteilung Hydrobiologie; Projekt 'Euro-Limpacs'; Teil: 'Paired studies of straight and braided channels' (WP2 Task 4.1).
- 09/02 – 12/03 Water Experts Berlin Brandenburg (WEBB e.V.) / WASY GmbH: Betreuung 'Guanting-Projekt' in Beijing.
- 11/99 – 08/01 Studentische Hilfskraft Universität Essen, Abteilung Hydrobiologie in Projekten 'Historisches Leitbild der Fischfauna von NRW' und 'AQEM'.
- 08/99 Teilnahme am 'Nature Project' der Firma Red Prince Nature – Modea Marketing (Essen) in der Barentsregion (Russland).
- 02/97 – 03/97 Praktikum: Biologische Station List, Sylt.
- 09/94 – 08/95 Freiwilliges soziales Jahr, Astrid-Lindgren-Haus, Verein für Körper- und Mehrfachbehinderte Kinder und Jugendliche, Kempten.

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### **Erklärung**

Hiermit erkläre ich, gem. § 6 Abs. 2, Nr. 8 der Promotionsordnung der Math.-Nat.-Fachbereiche zur Erlangung der Dr. rer. nat., dass ich das Arbeitsgebiet, dem das Thema "Comparison between Multiple-channel and Single-channel Stream Sections – Hydromorphology and Benthic Macroinvertebrates" zuzuordnen ist, in Forschung und Lehre vertrete und den Antrag von Frau Sonja Jähnig befürworte.

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Hiermit erkläre ich, gem. § 6 Abs. 2, Nr. 6 der Promotionsordnung der Math.-Nat.-Fachbereiche zur Erlangung des Dr. rer. nat., dass ich die vorliegende Dissertation selbständig verfasst und mich keiner anderen als der angegebenen Hilfsmittel bedient habe.

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Hiermit erkläre ich, gem. § 6 Abs. 2, Nr. 7 der Promotionsordnung der Math.-Nat.-Fachbereiche zur Erlangung des Dr. rer. nat., dass ich keine anderen Promotionen bzw. Promotionsversuche in der Vergangenheit durchgeführt habe und dass diese Arbeit von keiner anderen Fakultät abgelehnt worden ist.

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