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Effects of an Experimental Enrichment of Instream Habitat Heterogeneity on the Stream Bed Morphology and Chironomid Community of a Straightened Section in a Sandy Lowland Stream

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ABSTRACT / A straightened stream stretch with poor habitat heterogeneity was divided into a ‘‘control’’ section with a low amount of submerged woody debris and an experimentally ‘‘wood-enriched’’ downstream section to study the effect of enhanced habitat diversity on the benthic invertebrate community. The downstream section was enriched by fixing 25 wood packages constructed from 9–10 branches on the stream bottom. Succession processes occurring in the two stream sections were compared by chironomid exuviae drift from July to November 2000 and from April to August 2001. During the first sampling period, more drifting chironomid exuviae (medians of control vs. wood-enriched: 446 vs. 331, no significant difference) and total number of taxa (44 vs. 36, Wilcoxon signed-rank test $P = 0.019$) were recorded for the control section. Although species compositions of both stream sections were highly similar (Sørensen index: 0.83) the diversity in the wood-enriched section was distinctly lower compared to the control section (Shannon–Weaver index: 1.19 vs. 1.50). During the second sampling period, exuviae numbers remained higher in the control section (median: 326 vs. 166), but total numbers of taxa were nearly equal (51 vs. 49), as well as species diversity (Shannon–Weaver index: 1.67 vs. 1.64). The lower chironomid diversity observed during the first sampling period coincided with a gradual but significant change of the streambed morphology in the wood-enriched section. There, the initially more U-shaped profile (V/U = 0.81 ± 0.37) had turned into a pronounced V shape (V/U = 1.14 ± 0.21), whereas the control section retained its unaltered U shape (V/U = 0.62–0.75). This small-scale study on experimental of woody debris in sandy lowland streams showed that the negative impact of increased hydraulic disturbance of the existing streambed more than outweighed any positive impact resulting from the increase in woody debris.

Sandy lowland streams in Central Europe often are severely impacted by human activities, such as channelization, flow regulation, removal of natural riparian vegetation, or other structural alterations. The amount of coarse woody debris (CWD) deposited and left in streams can be estimated as a measure of their ‘‘near natural’’ state (Dahlström and Nilsson 2004). However, the number of undisturbed streams is low in Central Europe compared to other parts of the world (Hering and others 2000).

Management plans often include an alteration of the flow regime (Bunn and Arthington 2002), resulting in an impoverishment of the benthic invertebrate community (Boon 1988), which is mostly accompanied by the dominance of euryoecious species (Verdonschot 2000). Sandy streams are characterized by a low bed stability (Mangelsdorf and others 1990). Thus, the inhabiting invertebrate fauna is frequently subjected to mechanical stress, in particular during spates (Waters 1995; Palmer and others 1996). Under these conditions, accumulations of woody debris play an important ecological role as refugia for the benthic fauna (Palmer

KEY WORDS: Habitat enrichment; Woody debris; Chironomid community; Pupal exuviae; Drift; Stream restoration

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*Author to whom correspondence should be addressed; *email:* bernd.spaenhoff@uni-jena.de and others 1996; Hax and Golladay 1998; Negishi and others 2002) and as spots of high secondary production (Benke and others 1984).

In our study, we investigated the effect of woody debris enhancement in a straightened section of a sandy lowland stream on the species diversity of Chironomidae (Diptera). Woody debris was exposed in small packages, due to the specific significance of such structures for stream ecosystems (e.g., Smock and others 1989; Muotka and Laasonen 2002). For assessing the effect of the wood enrichment, the drift of chironomid pupal exuviae was sampled simultaneously in both the study section (wood enriched) and a control section, located directly upstream. This sampling method was chosen for the following advantages:

1. Larvae of Chironomidae are among the first colonizers of freshly submerged wooden substrates (Nilsen and Larimore 1973), rapidly reaching high abundances (Spänhoff and others 2000) and exhibiting more than one generation per year (e.g., Lindegaard and Mortensen 1988; Spänhoff and others 2004), making it possible to estimate the immediate community response.
2. Pupal exuviae of chironomids can be sampled easily and provide a good overview on the local species composition in term of abundance and taxonomic composition (Coffman 1973).
3. Sampling of drifting pupal exuviae integrates emergence numbers from different substrates in a stream (Ruse and Davison 2000). This allowed us to estimate not only the effect of the newly exposed habitats (submerged wood) but also their impacts on the existing chironomid community.
4. Sampling of pupal exuviae is the most sparing method with a very low impact on the habitat.
5. Identification of pupal exuviae provides taxonomic information up to the genus or species level (except heavily damaged or disrupted ones). Adult identification, however, allows species identification only in male specimens, and larvae in most cases only to the genus level.

Using natural substrates, such as woody debris, to restore the original instream habitat heterogeneity especially for sandy lowland streams could be a very useful tool for stream management and restoration purposes, but monitoring the effects of small-scale restoration projects in streams is rare (Bash and Ryan 2002).

We hypothesized that enhancing the amount of woody debris and the retention of coarse particulate organic matter would lead to an increase in chironomid species diversity, through an increase in the abundance and the types of food resource and an increase in habitat diversity.

Methods

Study Site

The study was conducted at the Ladberger Mühlenbach, a sandy lowland stream in Northrhine-Westphalia (Germany). The study sections were located in the upper reach of the stream (52°7′38′ N, 7°52′48′ E), in a straightened channel flowing through farmland. Both bank sides were bounded by native trees and shrubs, mainly black alder (*Alnus glutinosa*), common oak (*Quercus robur*), and willow species (*Salix* spp.). The interchange of stream water and groundwater is strongly reduced by a hard pan layer beneath the sediment. The sandy sediment is subject to erosion and bedload movements during spates (Cleven and Meyer 2003) and peak discharges originating from flow regulation. The discharge regime of the stream was measured by a stationary gauge during the study periods (Figure 1). Additional information on the study stream can be obtained from Spänhoff and Gessner (2004) and Spänhoff and Meyer (2004).

Experimental Enhancement of Woody Debris Amount

The studied stream stretch was divided into an upstream control section and a downstream experimental section. The surface area of woody debris originally present in both stream sections was estimated prior to the experiment by measuring the surface area of all submerged woody debris from two areas of about 20 m^2 (5 m length, 4 m stream width) per section. The overall surface areas of woody debris per section were approximated by summing the areas of all single wood pieces, determined by its length and diameter, assuming a cylindrical shape and extrapolation on the corresponding section.

Enrichment of woody debris in the experimental section took place in May 2000. Twenty-five packages made of wood branches were fixed on the streambed. The branches were derived from different deciduous tree species, with diameters of 3–6 cm and lengths between 44 and 164 cm. The basic construction of each package was made of three straight sticks arranged in the shape of a triangle and fixed at the corners by plasticized wires. Six to seven smaller sticks were fixed by wire densely wound on the triangle base to keep the construction flat, matched for low water depths during summer months and, being submerged, not forming drift obstacles. The packages were fixed in the stream

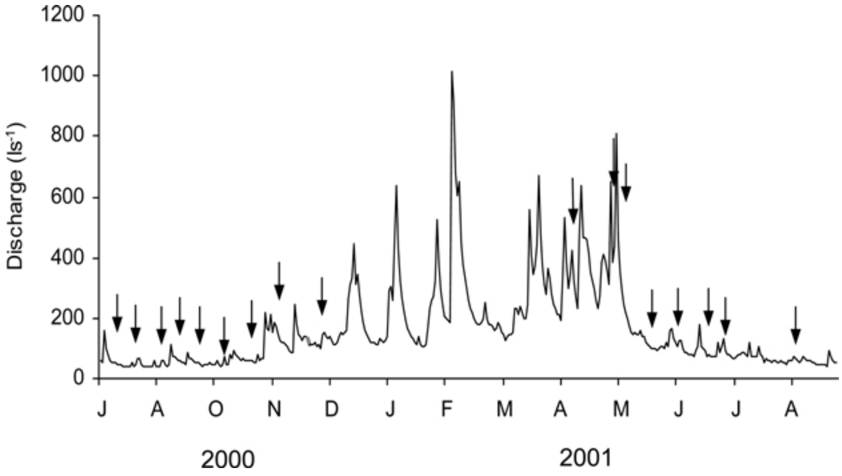

Figure 1. Discharge regime of the Ladberger Muehlenbach during the study period (June 2000–July 2001). Arrows indicate the sampling dates.

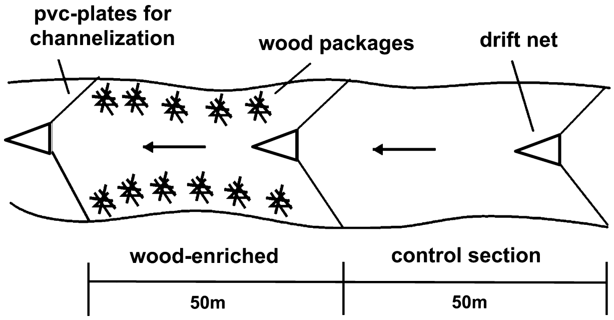

Figure 2. Scheme of the study sections and drift sampling design. Arrows show the direction of the stream current.

at three long wooden poles, which were driven vertically into the streambed. Overall, the exposed woody debris covered about 4.2% of the total stream bottom area in the wood-enriched section.

We refrained from using a BACI (before-after-control-impact) study design, including pretreatment investigations of chironomid pupal exuviae drift from the two sections because of the high annual fluctuation within chironomid communities in stream subjected to frequent flow disturbances (see Ruse and Davison 2000), which definitely occur in the study stream (Spänhoff and others 2004). Due to these fluctuations caused by infrequent openings of an impoundment, the applicability of the BACI design seems to be limited, considering the additional time and effort of implementing a complete sampling season (to get a representative overview on the chironomid communtity in the two sections) prior to the experimental restoration activity. We refer to several other studies on the effect of stream restoration practices on invertebrate or fish communities using adjacent control sections to assess the success of the restoration (Friberg and others 1998; Gørtz 1998; Pretty and others 2003; Harrison and others 2004).

Drift Sampling Procedure

Chironomid pupal exuviae were obtained from the surface drift by use of specifically constructed sampling sets, each consisting of a drift net, which was made up of a metal frame (50 cm wide and 10 cm high) attached to it, a gossamer net (mesh aperture: 250 μm), and two polyvinyl chloride (PVC) panels fixed in the streambed on metal rods at a 45° angle toward the drift net (Figure 2). By the design and positioning of the panels, the catch efficiency was enhanced considerably by collecting pupal exuviae from the entire stream width. Drift samples were taken for 30 min beginning at sunset at biweekly intervals. Sampling comprised three stages:

1. Drifting exuviae from upstream reaches were kept off the study stretch by mounting one sampling net at the beginning of the upper study section. According to preceding tests, 30 min were sufficient to have the vast majority of pupal exuviae float off the study section and, thus, to ensure that exuviae collected in the study sections had emerged solely from the latter.
2. Thereafter, two more sampling nets were positioned, one downstream of the control section and the other downstream of the wood-enriched section. This arrangement was chosen to attain a maximum degree of comparability of the two drift samplings.
3. After a sampling time of 30 min, the sampling sets were removed from behind the two study sections simultaneously. Finally, the uppermost sampling

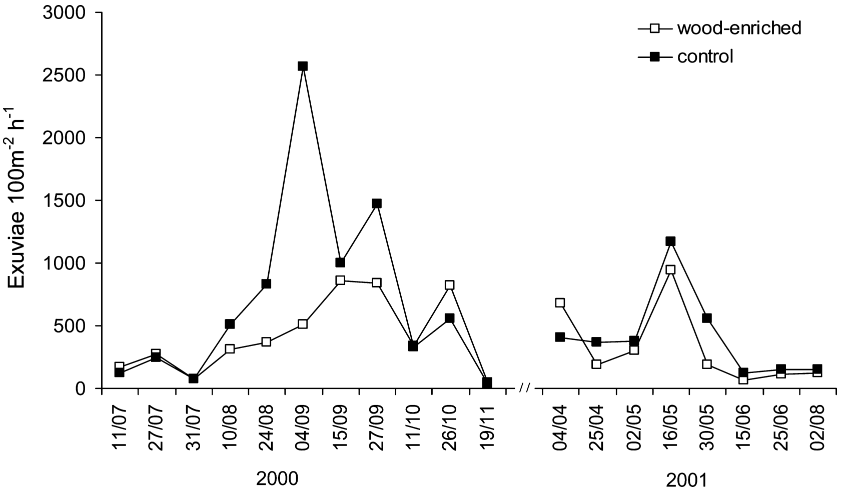

Figure 3. Total number of chironomid exuviae caught during the study period.

set was removed. The content of the drift nets were preserved in 98% ethanol for subsequent analyses.

In the laboratory, chironomid pupal exuviae were collected from the samples under a stereomicroscope. All exuviae were mounted in Euparal® on microscopic slides and identified mostly to species level using the keys of Wilson and McGill (1982) and Langton (1991) under a light transmission microscope.

Monitoring of the effects of wood enrichment on the chironomid community was split into two periods due to the intervening winter, when few chironomids were expected to emerge. Additionally, we separated direct effects of the exposition procedure of the wood packages (11 sampling dates from July to November 2000) that had surely caused a disturbance to this stream section from the effects of chironomid life-cycle traits, like reproduction and dispersal (8 sampling dates from April to July 2001).

Channel Morphology Measurement

Accompanying the drift survey, four transects were located within the wood-enriched section and two within the control section (due to its uniform U-shaped morphology) to map channel profiles from June 2000 to November 2001. Individual bottom levels were measured at 10-cm distances. The dynamics were given for each channel profile as the average temporal variation of all bottom levels per transect. Changes of the profile shape were assessed most precisely by the ratio of the V and U shape parameters, which were attained through the correlation of the bottom levels with symmetric templates basedon two adjoining linear functions(Equation 1) and, derived from the latter, a polynomial function (Equation 2):

$$V_{\mathrm{d}} = \{2 \cdot d \cdot \frac{h}{b} \text{ for all } d < \frac{b}{2} \text{ and } 2 \cdot (\mathrm{b} - d) \cdot \frac{h}{b} \text{ for all } d \geq \frac{b}{2}\}$$

$$U_d = -(V_{\mathrm{d}} - \mathrm{h})^4 .10^{-4} + \mathrm{h},$$

with $V_{\mathrm{d}} = V -$ shape function
d = distance from one bank side,
b = channel width,
h = maximum water depth,
U_d = U − shape function.

According to the formula, V/U ratios smaller than 1 point out a U-shaped stream bed; V/U ratios larger than 1 correspond to V-shaped channels.

Statistics

Similarity of chironomid communities of the two stream sections was determined by the Sørensen index ($S' = (2G/S_1 + S_2)$), where G is the number of species found in both stream stretches and S_1 and S_2 are the number of species in stream stretches 1 and 2, respectively). The Shannon diversity index ($H' = -\sum_i p_i \ln p_i$, with p_i the proportion of all chironomids belonging to the ith species) was used to describe community diversity. Differences in total numbers of drifting exuviae and number of taxa between the control section and wood-enriched section were tested using a Wilcoxon signed-rank test. After ensuring a Normal distribution of the data, a Student's t-test was performed to compare the V/U ratios of the study sections.

Table 1. Taxa list of all caught pupal exuviae (n = number of samplings per month, w = wood enriched, c = control). Significant differences ($P < 0.05$) are denoted with *(all sampling dates of the two sites were tested against each other).

	July 2000 ($n = 3$)		Aug. 2000 ($n = 2$)		Sept. 2000 ($n = 3$)		Oct./Nov. 2000 ($n = 3$)		April 2001 ($n = 2$)		May 2001 ($n = 3$)		June/July 2001 ($n = 3$)	
	w	c	w	c	w	c	w	c	w	c	w	c	w	c
Tanypodinae														
Apsectrotanypus trisfacipennis		1									1		3	
Conchapelopia melanops											2	2		
Procladius (Holotanypus) choreus												1		
Zavrelimya barbatipes											1			
Prodiamesinae														
Odontamesa fulva *				1					4	6	9	60	1	1
Prodiamesa olivacea					1	4			10	13	8	4		1
Orthocladiinae										1	1			
Brillia longifurca		1	1			2	2	1	4	1	1			
Brillia modesta	1			1								1	1	
Corynoneura spp.	334	273	310	469	1283	2288	1014	759	566	467	71	102	158	199
Cricotopus fuscus						2						1		
Diplocladius cultriger									1					
Epoicocladius flavens	10	11		2							32	48	3	9
Eukiefferiella claripennis												1		
Heterotanytarsus apicalis											1			
Heterotrissocladius marcidus						2			3	1				
Limnophyes sp.	2	1			1	2			2	4	2	1		1
Nanocladius rectinervis *	10	9	11	26	52	67	5	3	4	5	4	14	23	30
Orthocladius oblidens											1	11		
Orthocladius sp.										3	5	12		
Parakiefferiella smolandica *	18	23	5	49	38	92		2	6	15	18	20	6	17
Parametriocnemus stylatus	1	1	1	1	5	4		2	38	29		3		1
Paraphaenocladius irritus	1	1							12	8				
Paratrichocladius rufiventris *		2	1			3			1	4	3	5		1
Paratrissocladius excerptus	1	4	2		2	15					2		2	1
Rheocricotopus effuses									5	3		1		
Rheocricotopus fuscipes	1	1		1	12	16	18	19	28	40	22	39	4	3
Rheoorthocladius sp. A								1						
Rheosmittia species B	1										95	172	3	6
Rheosmittia spinicornis	2	1	1							1	421	722	15	30
Synorthocladius semivirens				1	1									
Thienemanniella spp.	6	6	5		20	19	13	9	36	21	19	6	13	19
Tvetenia calvescens										1				1
Tvetenia discoloripes									1	4	3		1	4
Chironominae														
Chironomini														
Chironomus plumosus gr.		1												
Kiefferulus tendipediformes						1								
Microtendipes pedellus *		6				1			2	2	81	118		
Paracladopelma camptolabis					1	2				1	13	15		
Paracladopelma nigritulu		1												
Phaenopsectra flavipes	2		1	1	3	8					2	1	2	2
Polypedilum aegyptilum													3	9
Polypedilum albicorne											4	8		
Polypedilum convictum			1		2	1					7	5	3	
Polypedilum cultellatum				1		1								
Polypedilum pedestre											1			
Polypedilum sp.	2	1			1	1					1	5	3	1
Polypedilum tritum		1		1	6	7	2					6		
Stictochironomus crassiforceps											2			
Stictochironomus pictulus											8	15		

Table 1. Continued

	July 2000 (*n* = 3)		Aug. 2000 (*n* = 2)		Sept. 2000 (*n* = 3)		Oct./Nov. 2000 (*n* = 3)		April 2001 (*n* = 2)		May 2001 (*n* = 3)		June/July 2001 (*n* = 3)	
	w	c	w	c	w	c	w	c	w	c	w	c	w	c
Tanytarsini														
Cladotanytarsus vanderwulpi	20	15	60	189	201	1105		1			67	61	1	23
Micropsectra atrofasciata					1				4	6	1			
Micropsectra bidentata						1								
Micropsectra contracta/apposita		2			1	8	6	6	4	6				1
Micropsectra sp.					3	8		3	22	13		1		
Paratanytarsus dissimilis			1		1	2								
Paratanytarsus lauterbornia						1					1			
Rheotanytarsus curtistylus *	17	12	99	189	157	362	2	1	1	2	209	259	6	9
Rheotanytarsus muscicola	3	3	6	27	13	58					9	15	5	2
Stempellina bausei				1	13	15					10	9		
Stempellinella minor					1									
Tanytarsus ejuncidus			1		3	10					3	1	1	
Tanytarsus heusdensis	13	9	83	204	86	252			2	15	118	96	4	4
Tanytarsus multipunctatus	6		2	6	31	47								
Tanytarsus spp.	2	1	1	1	1						2			
Total	453	387	592	1171	1940	4407	1062	807	756	672	1261	1841	261	375

Results

Pupal Exuviae Drift

During the first monitoring period, 4048 exuviae (median: 301) comprising 36 taxa were caught from the wood-enriched section and, simultaneously, 6774 exuviae (median: 446; 44 taxa) were obtained from the control section (Figure 3). The chironomid community of the two stream sections comprised 4 subfamilies in different proportions: very few Tanypodinae (4 species, making up 0.1% of the total exuviae number) and Prodiamesinae (2 species, 0.8%). Orthocladiinae (27 taxa, 69.4%) and Chironominae (30 taxa, 29.7%) were dominant and showed higher numbers of drifting exuviae in the control section compared to the wood-enriched section, especially in samples with high total exuviae numbers (Figures 4a and 4b). This pattern was more prominent during the first sampling period (2000) than in 2001 (Table 1). Taxa numbers from the control section were significantly higher than from the wood-enriched section ($P = 0.019$). Species composition was very similar in the two stream sections, as indicated by a Sørensen index of 0.83. However, community diversity was distinctly higher in the control (Shannon–Weaver index: 1.50) compared to the wood-enriched section (1.19). The main reason for this very low diversity in the wood-enriched section was the absolute dominance of *Corynoneura* species throughout this first sampling period (72.7% of all caught exuviae numbers; Table 1).

Exuviae numbers were slightly higher in the wood-enriched section at the first two and the last sampling dates. Much higher differences between the two sections occurred during periods of species peak emergences in August and September, with distinctly higher exuviae number caught in the control section (Figure 3).

During the second sampling period, the differences between the two sections were smaller, which was evidenced by more balanced taxa numbers (51 from the wood-enriched section and 49 from the control section), a high Sørensen index (0.87), and equal Shannon diversities (1.67 vs. 1.64). Additionally, differences of total exuviae numbers caught in the two sections were not as distinct as during the first sampling period (Figure 3). Taxa numbers no longer differed significantly during the second sampling period ($P = 0.553$).

Combining the results of both study periods, the number of exuviae ($P = 0.044$) as well as taxa numbers ($P = 0.031$) from the control section were significantly higher in comparison to the wood-enriched section (Table 1).

Changes of Channel Morphology

Transects mapped during the study period showed the high dynamics of the stream sediments. Bottom levels varied spatiotemporally by 31.5 ± 6.5% in the study section and by 29.3 ± 6.7% in the control section. On the basis of variability therein, neither of the simple morphometric parameters (the average depth and hydraulic radius) was significantly different between the two sections. However, the change that became

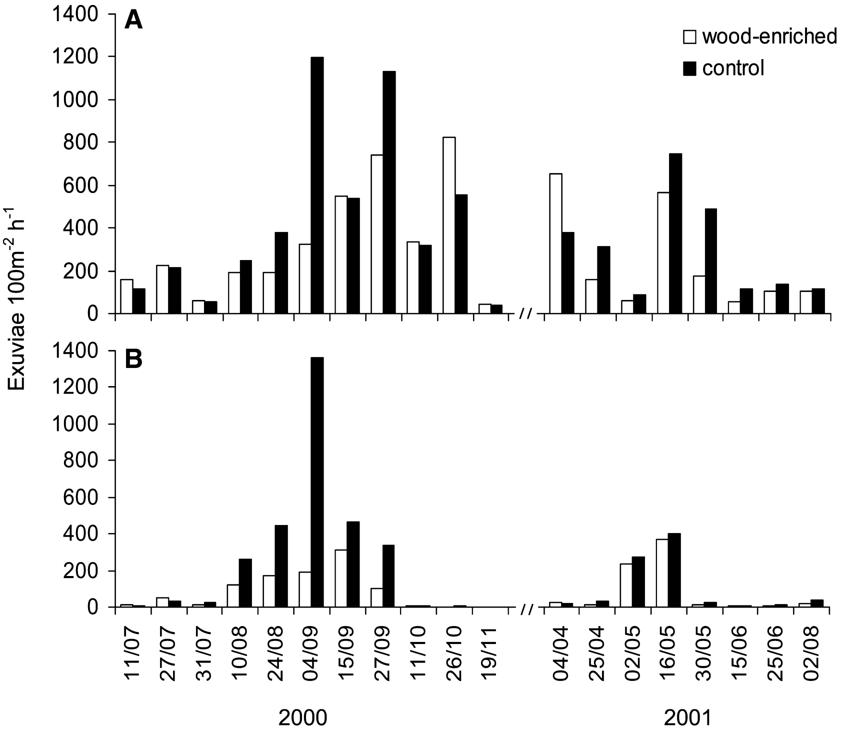

Figure 4. Total number of (a) Orthocladiinae and (b) Chironominae pupal exuviae caught during the study period.

visible was a central deepening of the channel in the wood-enriched section. Indeed, the increasing V/U ratio of the transects reflected this transition clearly. After the beginning of the survey during Summer 2000, the V/U ratio was 0.81 ± 0.37 in the wood-enriched section and 0.75 ± 0.05 in the control section, which illustrated that the channel was originally more U-shaped (Figure 5). In the following year, the wood-enriched section showed V/U ratios of 1.18 ± 0.18, which were significantly different than those of the preceding year ($t = -3.3$, $df = 33$, $P < 0.002$). In contrast, the change of the V/U ratios at the control section was not significantly different between the two years ($t = 1.1$, $df = 9$, $P = 0.3$).

Discussion

Effects of Restoration Practices on Aquatic Biocoenoses

The main goal of this study was the enhancement of biodiversity by increasing the instream habitat heterogeneity in a habitat-poor section of a sandy lowland stream. The benefit of instream structures in lowland streams has been discussed critically for fish (e.g., Pretty and others 2003) and macroinvertebrate (e.g., Harrsion and others 2004) communities. In both cases (fish and invertebrate assemblages), the effects of artificially introduced riffles and flow deflectors were shown to be minimal. It is argued that the positive ecological effect of artificial instream habitat enrichment on the aquatic animal communities is highly dependent on the design and spatial arrangement of artificial structures, especially in sand-bed streams (Mutz 2000; Shields and others 2004). Studies on stream rehabilitation using large wood reported similarly minor effects of stream restoration on macroinvertebrate and fish communities (e.g., Gerhard and Reich 2000; Shields and others 2003), and Frissel and Nawa (1992) reported a physical failure of artificial habitats in many studies. Nevertheless, the important role of woody debris for invertebrate communities in aquatic systems has been often stressed (e.g., Harmon and others 1986; Benke and Wallace 2003). Woody debris is colonized by a variety of aquatic invertebrate species (Hoffmann and Hering 2000; Benke and others 2003) serving as a food source and protection against drift and predations. Large woody debris can create stable sediment patches in its surroundings, which were used as refugia, increasing the resistance of invertebrates against drifting during spates (Palmer and others 1996; Hax and Golladay 1998; Negishi and others 2002). Benke and others (1984) reported higher secondary production of snag-inhabiting inver-

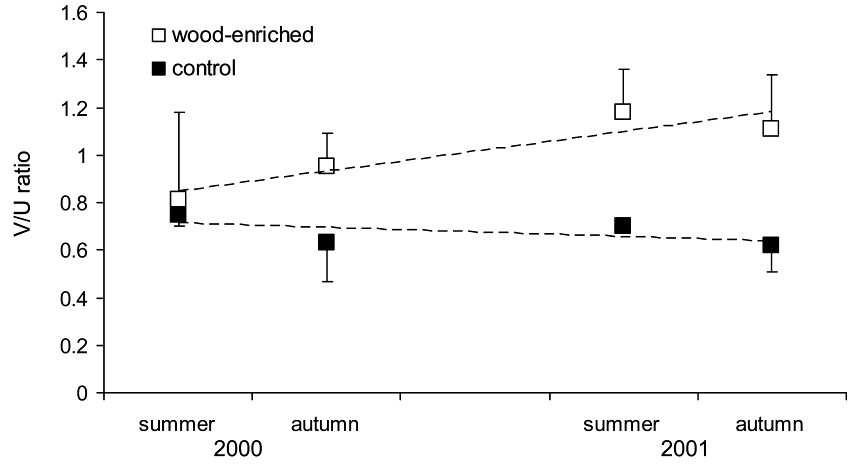

Figure 5. Average V/U-shape ratios for the studied stream sections (mean values with standard deviations: wood-enriched section, 4 transects; control section, 2 transects; 46 mappings in total).

tebrate communities compared to mud and sand dwellers in a blackwater stream dominated by unstable fine particulate bed sediments.

Our approach of using small wood packages for small-scale restoration practices should prevent drastic effects on stream morphology and bank erosion (which would have led to severe problems for adjacent land-users) but should provide additional habitats for settlement and stable patches acting as refugia for aquatic invertebrates. A further important effect of instream woody debris is the retention of drifting coarse particulate matter such as detritus and leaf litter, which might alter the nutritional basis and thus the food web in these stream sections (Wallace and others 1995; Muotka and Laasonen 2002). Indeed, a higher retention of leaf litter in the wood-enriched section could be observed in our study, but was not investigated in detail.

Effects of Wood Enrichment on the Chironomid Community

The results of the two study periods revealed that the enhancement of woody debris in the experimental stretch had little positive influence on the chironomid communities. The increase in woody debris in the experimental stretch was accompanied by changes in streambed morphology and increases in bed erosion, particularly during peak flow periods. The positioning of the wood packages at both banksides in alternating arrangement created an artificial flow channel in the middle of the stream, whereas the water velocity around the accumulations was reduced. This resulted in completely changed hydraulic conditions of unexpected magnitude, resulting in heavy erosion in the stream middle (leading to a V-shaped bed profile), especially during peak discharge periods (winter and spring), and increased sedimentation of sand, leaf litter, and fine organic matter around the packages after recovery to base flow discharge. Increased scouring of the streambed center obviously impacted the sand-dwelling chironomid larvae as well those living in the still deposition areas in between the wood packages. Psammophilic species such as *Odontomesa fulva*, *Microtendipes pedellus*, *Nanocladius rectinervis*, and *Rheotanytarsus curtistylus* are typical representatives of the Central European sand streams (Lindegaard and Mortensen 1988; Böttger and Rudow 1995), but at the same time (according to our findings) are the most susceptible to sediment erosion during spates. Unfortunately, we did not sample the chironomid assemblage inhabiting the sand sediment, which would had enabled us to analyze the effect of the changed hydraulic conditions on the psammophilic fauna.

During the second study period in 2001, the expected positive effects of the habitat enrichment such as a significant increase of total exuviae number and the settlement of closely wood-associated species were still not ascertainable. We had expected a rapid colonization of the newly introduced wood habitats, which has been shown in several studies incubating wood into streams (Nilsen and Larimore 1973; Phillips and Kilambi 1994) and which was also found in a former study on the Ladberger Mühlenbach (Spänhoff and others 2000). The smooth bark covering the branches used for the wood packages seemed to be an unsuitable habitat for the settlement of chironomid larvae. Several studies stressed the role of wood surface complexity for the colonization of aquatic invertebrates, reporting higher invertebrate densities on rough wood surfaces (O'Connor 1991; Mathooko and Otieno 2002). Preconditioned alder and oak wood with altered surfaces were more rapidly colonized and reached higher colonization densities of invertebrates than fresh wood of the same species covered by a smooth bark (Spänhoff and others 2000).

The chironomid community found on naturally submerged wood of the same stream in a former study (Spänhoff and others 2004) corresponded well to the overall exuviae drift collected during the present study. Few species, such as *Corynoneura* spp., *Rheocricotopus fuscipes*, *Cladotanytarsus vanderwulpi*, and *Rheotanytarsus curtistylus*, all known to be ubiquitous species without closer association to a special habitat, dominated the emergence from woody debris (Spänhoff and others 2004) comparable to the drift samplings.

We supposed that after the initial disturbances caused by the bed movement, and leading to a reduced population density of chironomid larvae in the wood-enriched section, the population recovered after stabilization of the altered streambed morphology. Recolonization of the wood-enriched section was likely facilitated by downstream drift from upstream reaches, which explains the high similarity of the chironomid assemblages in the control and wood-enriched section. Immigration and establishment of new species with a close association to woody debris in the wood-enriched stretch could not be found.

Comparison to Other Stream Restoration Activities

The success of recent stream restoration projects has been mainly assessed by the investigation of macroinvertebrate assemblages and the diversity of the restored stream sections compared to unaltered upstream sections after different recovery periods (e.g., Friberg and others 1998; Gørtz 1998; Laasonen and others 1998). Some studies on stream restoration projects reported a distinct decline in invertebrate numbers, especially shredders and detritivores (Biggs and others 1998; Laasonen and others 1998), or taxa numbers (Friberg and others 1998) immediately after completion of large-scale restoration procedures. These faunal depletions were surely caused by the heavy physical disturbance associated with the constructional restoration procedures. Therefore, the establishment of the aquatic faunal community in restored stream sections is often subjected to long lag periods, in which an invertebrate community recovers from initial disturbances depending on the magnitude of the interference (e.g., Biggs and others 1998; Laasonen and others 1998; Muotka and Laasonen 2002). Several current studies reporting the failure of restoration practices that did not achieve the desired goal led to a critical discussion about the usefulness of invertebrate or fish community data to assess the success of restoration practices (Brooks and others 2002; Moerke and Lamberti 2004).

Conclusion

Large woody debris (LWD) has been shown to be a useful and inexpensive tool for structural restoration of sand-bed streams (Gerhard and Reich 2000; Shields and others 2004), but several problems in using LWD structures must be considered (Frissel and Nawa 1992; Shields and others 2003). Small woody debris could be more useful in small-scale restoration practices to enhance the habitat diversity of streams that cannot be structurally changed on a larger scale due to the use of the adjacent landscape, especially in densely populated regions like Central Europe. The present study was a small-scale project restricted to a very short stream section and with little physical interference to the stream morphology. Nevertheless, the initial effect of the experimental habitat enrichment was a depletion of the chironomid community. The main reason for missing of the desired result was likely (1) the positioning of the wood packages near both stream banks, leading to a detrimental changing of hydraulic conditions and sediment shifting, (2) the use of freshly cut branches covered by a smooth bark, making it unsuitable for chironomid settlement, (3) the partially burying of the wood structures, and (4) the short timescale of monitoring, overlooking the fact that immigration and establishment of chironomid species might need longer timescales. However, in morphologically degraded streams, retention structures are often absent; thus, introduced wood packages will serve as invertebrate habitat as well as retention structure for transported coarse particulate organic matter (CPOM). These effects are supposed to increase the habitat heterogeneity in structurally poor stream stretches, resulting in an increased biodiversity of the macrozoobenthos. We strongly believe that, despite the inappropiate positioning of the wood packages, the habitat enhancement will lead to an increased biodiversity in the wood-enriched stretch when the sediment fauna has adapted to the changed hydraulic conditions and the decomposition of the wood proceeds, offering more suitable habitats for invertebrates.

In future projects, we recommend the use of woody debris with an altered surface (tree species with a structured bark or preconditioned wood that is still stable enough to withstand the hydraulic stress of flowing water), providing microhabitats for invertebrates. The woody debris should be placed in a way that it prevents extensive hydraulic disturbance of the streambed sediment, but it should create new habitats (e.g., pools and backwater zones) in a structurally poor stream section. More study replicates either in one stream or in neighboring streams would be desirable to obtain more detailed informations on general patterns of such habitat enhancement projects if the sampling effort can be managed. The timescale of monitoring to assess the success of such a small-scale project should be adjusted to the desired goal of the practice, considering the species pool for immigration into the enhanced stream section from upstream and downstream reaches and neighboring stream systems. We used chironomids for monitoring, because they rapidly colonize new habitats, and a sampling method that allowed us to estimate the changes of the chironomid community structure in a reach scale. However, we could not detect positive effects of the habitat enhancement after 1 year, so we recommend a longer monitoring period.

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