Evaluation of small rivers by combining biological sampling with a structure analysis of river beds

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Abstract Macroinvertebrates are useful in the evaluation of the condition of a river. This study presents the results of two biological sampling approaches to assess river condition. The first involves the direct sampling of all habitats present at a site and this allows inferences to be made between species composition and the condition of the river-bed substratum. The second is a standardized method that uses artificial substrates. This enables comparisons to be made between different sites by producing results independently from the actual substrates. It also permits correlations between the quantity and quality of accumulated fine sediment in the basket samplers and composition of macroinvertebrates in the artificial substrate samples.

Key words macroinvertebrates; water quality assessment; substrate diversity; direct sampling; artificial substrates; southwest Germany

INTRODUCTION

The presence and composition of macroinvertebrates can be used to evaluate the quality or condition of river systems. Macroinvertebrates respond to disturbances in catchment land use, discharge and the structure of river-bed sediment. Species have different habitat preferences and can adapt to structural differences in the texture and composition of river-bed sediment (Minshall, 1984). Increased loads of fine sediment in river systems have an impact on macroinvertebrate assemblage. Fine sediment can smother instream habitat and alter habitat conditions, but not necessarily water quality. However, fine sediment does occur naturally in rivers. For example, Hering *et al.* (2001) argue that under natural conditions rivers in low mountain areas and hilly ranges are dominated by stony substrate, riffles, pools and beaver dams. They also have periodic accumulations of fine sediment naturally. Often, river beds that are rich in fine sediments are misclassified as being polluted especially when using the occurrence of organisms as an indication of water quality or river condition. Therefore establishing sampling methods that are able to reflect the substrate conditions are important (Beisel *et al.*, 1998). The main problem at the moment seems to be how to compare different sites and different methods of sampling. This paper contributes to this discussion by presenting the results of a comparison of two different sampling methods for river-bed sediments and macroinvertebrates.

STUDY AREA AND METHODS

Twenty-three sites were studied on several tributaries of the Moselle River, in southwest Germany near Trier (Fig. 1, Table 1). The geology of the area is mainly

Devonian bedrock comprised of quartzite and schist while the Kartelbornsbach area north of Trier is limestone. Sampling at sites 1 to 12 has been undertaken since the autumn of 1999 and at sites 13 to 23 since spring 2001. The autumn 1999 survey was used to assess a range of appropriate sampling methods for the collection of macroinvertebrates. Two types of sampling methods were used on the results of this survey; direct sampling of a range of habitats present at each site and the use of basket or artificial substrate samplers. Direct sampling of all substrates present at a site was restricted to a 30-min period as recommended by Klemm *et al.* (1990). To remove the influence of substrate texture on the overall macroinvertebrate composition and later analysis of the these biological data substrate types were classified as either "rough" and "fine" for the spring 2001 sampling survey and were investigated separately at selected sampling sites. The substrate types were divided into those coarser or finer than 20 mm as used by the Bavarian state water authority (Bayerisches Landesamt für Wasserwirtschaft, 1996).

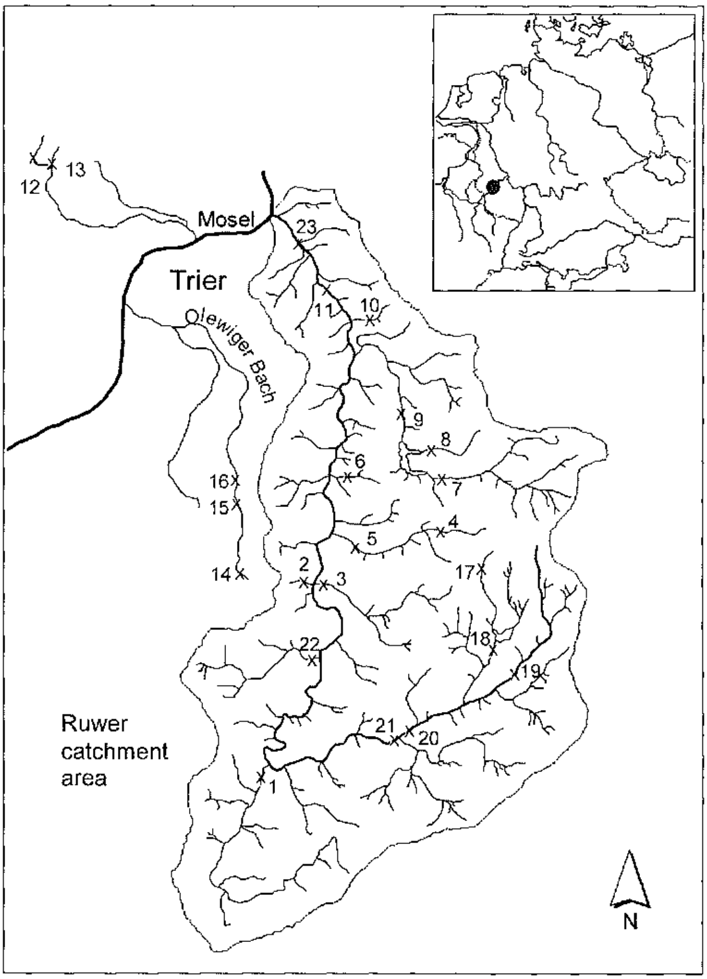

Fig. 1 Map of the area under investigation, region of Trier, southwestern Germany.

The basket samplers were 10 × 15 × 20 cm cages, filled with cleaned river-bed material present at each site. At each sampling site, two baskets were exposed on the river bed in riffle areas for periods of three and six weeks, respectively, where they were colonized by macroinvertebrates (Rosenberg & Resh, 1982). After the exposure period the cages were removed, stones washed and the macroinvertebrates and fine sediment collected for analysis. The accumulated fine sediment was analysed for carbonate, nitrogen, major cations and the heavy metals: lead (Pb), zinc (Zn), copper (Cu), iron (Fe), manganese (Mn), magnesium (Mg) and potassium (K). Heavy metals were determined using AAS (atomic absorption spectrometry) following digestion with 5 ml of 65 % nitric acid. Carbonate and nitrogen were determined by oxidation of freeze-dried and homogenized sediment samples using an element analyser.

The amount of fine material in the basket samplers was estimated on a scale from 0 (no accumulation) to 3 (much material). Collected taxa were identified down to the lowest possible level and the evaluation of their composition calculated via various biological indices and multivariate statistics using the program SPSS. The following indices were used:

- Saprobic index according to DIN EN ISO 38 410 (1990), where an indication value is allocated to selected taxa. The water quality value is calculated by the indicator value and the abundance of these organisms. The index is sensitive to organic loads.

Table 1 List and short characteristics of sampling sites (br = bedrock, cob = cobble, gra = gravel, peb = pebble, sa = sand).

Site	Geomorphology	Land use	Size*	Main substrate	Possible pollution sources
1	Wide valley, shallow incline	Agriculture/settlement	3	gra/sa	Eutrophication
2	V-shaped, steep incline	Forest	1	br/gra	
3	Dell, intermediate incline	Forest	2	br/peb	
4	Dell, intermediate incline	Forest	1	peb	Acidification
5	Wide valley, shallow incline	Forest	2	cob	Acidification
6	V-shaped, steep incline	Forest	1	gra/sa	
7	Wide valley, shallow incline	Forest	3	cob	Acidification
8	Wide valley, shallow incline	Forest	1	peb/gra	
9	Wide valley, shallow incline	Forest	3	peb	Reservoir
10	V-shaped, steep incline	Agriculture	1	gra/sa	Vineyard
11	Wide valley, shallow incline	Agriculture/settlement	4	cob	
12	Dell, intermediate incline	Agriculture	1	peb	Sewage plant
13	Dell, intermediate incline	Forest	1	peb/loam	Eutrophication
14	Dell, intermediate incline	Agriculture	1	silt/gra	Agriculture
15	Wide valley, shallow incline	Agriculture	2	gra/sa	
16	Wide valley, shallow incline	Agriculture	2	gra/sa	Sewage plant
17	Dell, intermediate incline	Forest	1	peb	Acidification
18	Wide valley, shallow incline	Forest	2	gra/silt	Reservoir
19	Wide valley, shallow incline	Agriculture/fallow land	2	cob/silt	Sewage water
20	Wide valley, shallow incline	Agriculture	3	cob	
21	Wide valley, shallow incline	Agriculture	4	cob	Sewage plant
22	Wide valley, shallow incline	Agriculture	3	peb	
23	Wide valley, shallow incline	Agriculture	4	cob/silt	Sewage plant

* According to Strahler.

- For the ASPT (average score per taxon) different families are allocated with index values in order to receive an average value according to their presence at a sampling site.
- The TBI (Trent biotic index, Woodiwiss, 1964) combines the presence of indication orders, their diversity and the total amount of taxa.
  The EPT index describes the relative share of the families of Ephemeroptera, Plecoptera and Trichoptera in the total number of families. The families of these orders predominantly need good water quality and a stony substrate.

Analyses of the water quality was also calculated according to the chemical index (CI) from Bach (1980), derived from Brown *et al.* (1970). The index was calculated from chemical and physical parameters like water temperature, oxygen content, conductivity, pH-value, ammonium, nitrate and orthophosphate and describes the content of organic material.

To monitor the influence of the habitat, different river-bed structural parameters were mapped, especially the composition of the river-bed sediment. The proportions of stones, pebble, sand and detritus as well as organic material like leaves and branches were recorded *in situ*. The substrate diversity was calculated using the formula of Shannon and Wiener (Shannon, 1948) from these data:

$$H_S = -\sum_{i=1}^{s} p_i \ln p_i$$

where H_S = diversity, p_i = relative coverage of the substrate types, and s = total number of substrate types.

RESULTS AND DISCUSSION

Direct sampling

In spring 2001 the total number of taxa collected by hand sampling was 77. The most common species were *Gammarus fossarum* (Amphipoda, Crustacea), *Simulium* spp. (Diptera), Orthocladiinae (Chironomidae, Diptera), *Baetis vernus* (Ephemeroptera) and *Rhithrogena semicolorata* (Ephemeroptera). A comparison between CI and ASPT suggested an impact of poor water quality on macroinvertebrate composition (Table 2). Classification of the sampling sites indicated two groups, according to the abundance of *Gammarus fossarum* (Crustacea).

The results from the preliminary study suggested substrate diversity was highly correlated with macroinvertebrate composition along with land use. There was a significant correlation between substrate diversity and the saprobic index (Pearson correlation, level of significance of 0.05%). In particular, the amount of fine material was highly correlated with the water quality index CI—low water quality was perhaps a factor of higher amounts of fine material in the river bed. It was assumed that the amount of fine material was a consequence of the anthropogenic influence, at least in the study area. It is also possible that the decreasing values of the biological indices are consequences either of the increasing amount of fine material in the rivers or of the lower water quality.

Table 2 List of the biological indices of the direct samples in spring 2001, the substrate diversity and the chemical index.

Sampling site	Saprobic index	Class (SI)	ASPT	TBI	EPT	Number of taxa	Substrate diversity	Chemical index	Class (CI)
1	1.7	I–II	6.7	9	0.59	23	1.11	92	I
5	1.3	I	7.3	8	0.68	8	1.24	86	I
6	1.5	I–II	6.5	9	0.64	15	1.14	83	I–II
7	1.8	I–II	6.0	7	0.50	3	0.86	88	I
8	1.5	I–II	6.1	9	0.50	18	1.14	88	I
9	1.5	I–II	7.3	10	0.67	21	0.69	89	I
10	1.6	I–II	6.7	7	0.56	9	0.82	85	I
11	2.1	II	5.6	9	0.33	11	0.69	86	I
12	2.4	II–III	3.4	7	0.09	12	0.71	47	II–III
13	1.7	I–II	6.5	8	0.57	8	1.04	59	II
14	1.7	I–II	6.1	9	0.40	15	1.39	81	I–II
15	1.7	I–II	6.1	10	0.50	22	1.17	82	I–II
16	1.6	I–II	6.5	8	0.75	14	1.22	77	I–II
17			5.4	8	0.50	7	0.90	76	I–II
18	1.9	II	7.0	9	0.55	13	1.16	91	I
19	2.1	II	5.3	7	0.43	10	0.61	78	I–II
20	1.8	I–II	5.9	10	0.50	16	0.52	87	I
21	1.8	I–II	6.5	10	0.50	16	0.80	89	I
22	1.7	I–II	7.2	10	0.67	29	0.80	75	I–II
23	2.1	II	4.6	5	0.33	5	0.50	74	I–II

The next stage of the analysis indicated a correlation between these factors in the absence of low water quality. A highly significant correlation (Pearson correlation, level of significance of 0.05%) was found between the amount of fine material and the saprobic index. Higher amounts of fine material increased the abundance of species.

The sampling of different substrate types was carried out at a number of sampling sites. Because of the small size of most of the streams under investigation, substrates found often belonged to only one class, and a further division was not possible. A cluster analysis between the samples of coarse material, fine material and the basket samplers resulted in a differentiation of the sampling methods, but not in a subdivision of the sampling sites. Discriminant analysis confirmed no separation by sampling site, but the groups of the sampling methods were verified. A comparison between the biological indices of the coarse and the fine material samples showed that except at sites 19 and 22 the evaluation of the fine material was worse than that of the coarse material samples. At site 19 the ground substrate was covered with a mud layer, and therefore ideal conditions for species that prefer hard substrates did not exist. Furthermore, better evaluation of the fine material was based mainly on rare taxa. At site 22 the fine substrate consisted mostly of gravel and not of sand, so that many taxa that prefer stony substrates were also sampled within the fine substrate.

Artificial substrates

The results of the exposure of artificial substrates are comparable to those from direct sampling with regard to the relative faunal distribution and the calculated biological

Table 3 List of the biological indices of the basket samplers, spring 2001.

Sampling site	Saprobic index	Class (SI)	ASPT	TBI	EPT	Number of taxa
1	1.6	I–II	5.5	10	0.40	25
5	1.6	I–II	7.0	9	0.56	11
6	1.5	I–II	5.9	7	0.36	13
7	1.2	I	5.9	8	0.38	9
8	1.5	I–II	6.5	10	0.57	24
9	1.5	I–II	6.3	10	0.59	19
10	1.6	I–II	6.3	9	0.60	15
11	1.8	I–II	6.0	10	0.47	20
12	2.3	II–III	4.7	7	0.38	12
13	1.7	I–II	6.0	8	0.55	11
14	1.7	I–II	5.6	9	0.36	13
15	1.6	I–II	6.6	10	0.64	18
16	1.6	I–II	6.8	8	0.53	15
17	1.3	I	5.8	9	0.50	12
18	1.9	II	6.3	8	0.57	6
19	2.0	II	5.0	8	0.29	14
20	1.8	I–II	6.9	10	0.60	21
21	1.7	I–II	7.0	9	0.67	14
22	1.7	I–II	6.6	10	0.52	24
23	1.7	I–II	6.5	10	0.35	20

indices (Table 3). Some differences in the number of taxa were recorded but this may have been a problem of access to the sampling sites and small macroinvertebrate species were not recorded in the field work with the direct sampling, leading to lower TBI values. Both methods achieve a similar evaluation of sampling sites. A cluster analysis resulted in a splitting into two groups according to the abundance of *Gammarus fossarum* (Crustacea) that corresponded to the results of the direct sampling. Both methods are considered to be appropriate for biological sampling and the evaluation of sampling sites. However, at the species level differences between the two methods were noted as shown by the Sörensen index. The Sörensen index indicates the similarity between two samples by dividing the number of taxa occurring in each with the total number of taxa of both samples. The maximum value is 1 and a value of 0.6 suggests similar biological composition. The differences between direct sampling and the basket sampler ranges from 0.3 to 0.6. Hence, the methods appear to complement each other.

Direct sampling of all habitats present showed correlations between the river-bed substrate and biological indices whereas the basket samplers showed no significant relationships between the structure and macroinvertebrate composition. This emphasizes that artificial substrates can be used as a standardized method for comparing two sampling sites independent of the structure of the river. Changes in flow velocities within and near the vicinity of the baskets may result in enhanced sedimentation of transported fine material to take place. In the spring 2001 sampling period, the amount of fine material in the basket samplers correlated with the ASPT, TBI and the saprobic index of the biological sampling. Higher amounts of fine sediment lead to an inferior assessment of river condition.

Accumulated fine sediment was also analysed to establish the content of carbonate (C) and nitrogen (N) as well as of Cu, Mn, Pb, Zn, Fe, Mg. Concentrations of carbonate and nitrogen and the ratio between them was associated with the land use. High amounts of organic material, like leaves, results in a reduction of the C:N ratio. This occurs in mainly forested areas. In areas with a higher anthropogenic influence the C:N ratio increases because of lower N values. These results suggest the saprobic index is correlated to the C:N ratio and carbonate concentrations correlate well to the number of taxa. Hence, high C values are directly associated with lower numbers of taxa. Metal concentrations in the fine sediment were not correlated to macroinvertebrate composition except for copper that show a relationship to *Atherix* spp. (Diptera), *Potamophylax* spp. and *Sericostoma personatum* (Trichoptera).

CONCLUSIONS

A relationship between the composition of the river-bed substrate and macroinvertebrate composition was established in this study. It was shown that a high amount of fine sediment leads to a relatively poorer biological condition of a site independent of its water quality. This was proved by the analyses of sites with good water quality and with the separate sampling of fine and coarse substrates. This sampling method can be used to indicate the combined influence of water quality and river structure.

Artificial substrate samplers were also used and deemed to be independent of the condition of the river-bed substrate. An assessment of the standard basket samplers highlighted issues of enhanced accumulation of fine sediment which may partly reduce the applicability of their use in river condition assessment studies. However, this sedimentation is a consequence of a higher amount of transported material due to anthropogenic changes and this may be used in an evaluation of river condition. Moreover, chemical analysis of the accumulated fine material is another possible means to evaluate rivers and the relationship between sediment, pollution and macroinvertebrates. Overall, both methods are suitable for recording macroinvertebrate composition, depending on the aim of the survey. Direct sampling yields an overview of the taxa at a sampling site and therefore describes the river. For comparisons between sampling sites basket samplers are the preferable option.

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