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Practicability of the Index of Trophic Completeness for running waters

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Abstract

Effects of stress caused by anthropogenic activities in rivers negatively act on the intricate system of trophic links within invertebrate communities and other components of the aquatic ecosystem. These effects can be made visible with the Index of Trophic Completeness (ITC), which was developed as an indicator for the functioning of the river ecosystem, based on the trophic classification of benthic macroinvertebrates. We tested the index using data collected from rivers exposed to different degree of anthropogenic pressure. In undisturbed rivers, all trophic guilds distinguished are present irrespective the part of the river studied and its geographical region. No significant seasonal effect on the outcomes was observed. Disturbances cause the extinction of specific trophic guilds, however due to overlap of effects, the result of an ITC outcome does not indicate the type of anthropogenic pressure. The ITC can be applied to the results of each combination of biotopes sampled, although one has to consider a varying biotope-density relation for species in the trophic guilds. Although the outcomes are projections of trophic guilds present, they can be arranged into quality classes.

Introduction

Effective river management takes into account ecological information, specifically geared to the water manager and decision maker (Van der Velde & Leuven, 1999). Compression of this information is facilitated by use of relatively simple indices. In rivers, the community structure of benthic macroinvertebrates has become an important quality element in many of the water quality assessment procedures (Rosenburg & Resh, 1993; Canfield et al., 1994; Chapman, 1994). Advantages of the use of macroinvertebrate assemblages in biological assessments include their abundance, sedentary nature, suitable life span, biodiversity and trophic levels, sensitivity and swift response to various stress types (Metcalfe-Smith, 1994). They play an important role in aquatic ecosystems by the primarily mechanical breakdown of coarse particulate organic material (CPOM), the consumption of fine organic matter (FPOM), including microbes and algae, and their preying and parasitizing on other invertebrates. Benthic macroinvertebrates also constitute a major food source for other invertebrates, fish and waterfowl, making them an important link between microbes and vertebrates (Cummins, 1992), and thus important for the transfer of energy and the transformation of substances.

Disturbance caused by anthropogenic activities (e.g., water pollution, river engineering) has an impact on substance and energy flows, because any significant stress to the ecosystem has a negative effect on macroinvertebrate communities. That results in the disappearance of food web links if lost species with the same trophic function are not replaced by others belonging to the same guild. To make this visible the Index of Trophic Completeness (ITC) was developed (Pavluk et al., 2000), based on their trophic classification (Fig. 1) (e.g., Konstantinov, 1967; Cummins,

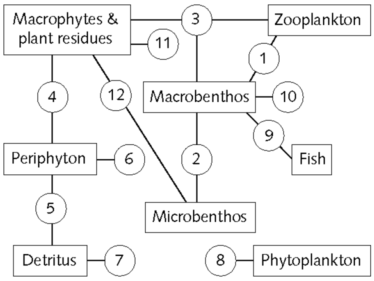

Figure 1. Relations between the twelve trophic guilds (Table 1) of macroinvertebrates, distinguished in the ITC, and their food sources.

1973; Miroshnichenko, 1983). The ITC indicates the presence of twelve trophic guilds. These guilds were distinguished after data examination from geographically diverse rivers (Pavluk et al., 2000). Trophic characteristics of the animals in these guilds are listed in Table 1.

Our objective was to study the practicability of the ITC. Effects of variables, like (a) sampling strategy (number of biotopes sampled), (b) sampling season, (c) river section, (d) climate, (e) water pollution and (f) sediment pollution, were made visible. The variables a-d are natural variables used to test the hypothesis that in a healthy ecosystem all guilds are always present, e and f are anthropogenic variables used to test the hypothesis that in an unhealthy ecosystem some guilds have disappeared.

Material and methods

Trophic characteristics of the macroinvertebrate species were put together into a taxa database which is part of the index calculation program MaTros (http//www.riza.nl/itc/). The database is still growing and contains already information on 920 species (situation on January 1, 2002). However, the number of taxa per trophic guild differs considerably due to unequal food supply in trophic niches.

The practicability of the ITC was tested with data sets from selected rivers (Fig. 2): (a) rivers subjected to different types of anthropogenic activity (Rhine and Meuse Rivers, The Netherlands; Chusovaya, Salda and Iset Rivers, Russia), (b) a pristine river (Sylva River, Russia), and (c) bottom substrates with a different pollution degree (Rhine distributary called Waal River, The Netherlands). Those data sets were accompanied by data on pollutants. The t-test for independent variables was applied to conclude statistically differences between data sets (Fowler et al., 1998). Conclusions were checked for statistical significance at a 95% level.

Data of the Chusovaya (1994 and 1995), Rhine (1995) and Meuse (1996) Rivers were used to study the contribution of the sampled biotopes on the outcome of an ITC-calculation. For the Chusovaya River, a tributary of the Kama River in the Volga basin that is undisturbed from point of view of river engineering (Fig. 2), macrozoobenthos data sets were taken into account from two natural biotopes (sandy bottom and pebbles), sampled with a handnet (Pashkevich et al., 1996), including data sets from a standardised artificial substrate sampling (glass marbles) (De Pauw et al., 1994; Pashkevich et al., 1996). The benthic macroinvertebrate community was collected in the vicinity of Stauroutkinsk and Kharionky, in a decreasing gradient caused by an upstream chromium pollution source (Leslie et al. 1999). Another dataset was obtained from the Rhine delta in which five biotopes were sampled in 1995 and 1999 in the framework of the Netherlands biological monitoring program in the Rhine delta. The Rhine River is an example of a heavily modified river due to long term (>1000 years) anthropogenic activity in its densely populated floodplain (Kalweit, 1993; Van de Ven, 1993). In 1995 and 1999 three free flowing distributaries in the Rhine delta were sampled in the same period each year.

A crosscheck with another climate zone was made, using data from the Greek rivers Strymon, Aliakmon and Axios (data kindly made available by Dr. Konstantinos Gritzalis, National Centre for Marine Research, Athens, Greece), all situated in a subtropical climate zone. These first order rivers (total length 310–390 km) are situated in the north of Greece flowing southwards The Strymon and Alaikmon Rivers discharge into the Aegean Sea, the Axios River discharges into the Gulf of Thermiakos. Average discharge of these rivers is 95 (max. 336, min. 18), 32 (max. 66, min. 2) and 118 (max. 870, min. 24) m3 sec-1 respectively. Samples were taken with a standard handnet in June and September 1997 (Gritzalis et al., 1998). The results of all samplings in each river were joined for the ITC-calculation.

Common practice is to group results of index outcomes into quality classes, indicating the status of the surface water monitored. No linear relation is present between the number of trophic guilds and quality classes since the guilds represent different trophic levels. Therefore an indication value (or weight factor) 'C', based on the number of species in each trophic guild, was introduced for each guild for compensa-

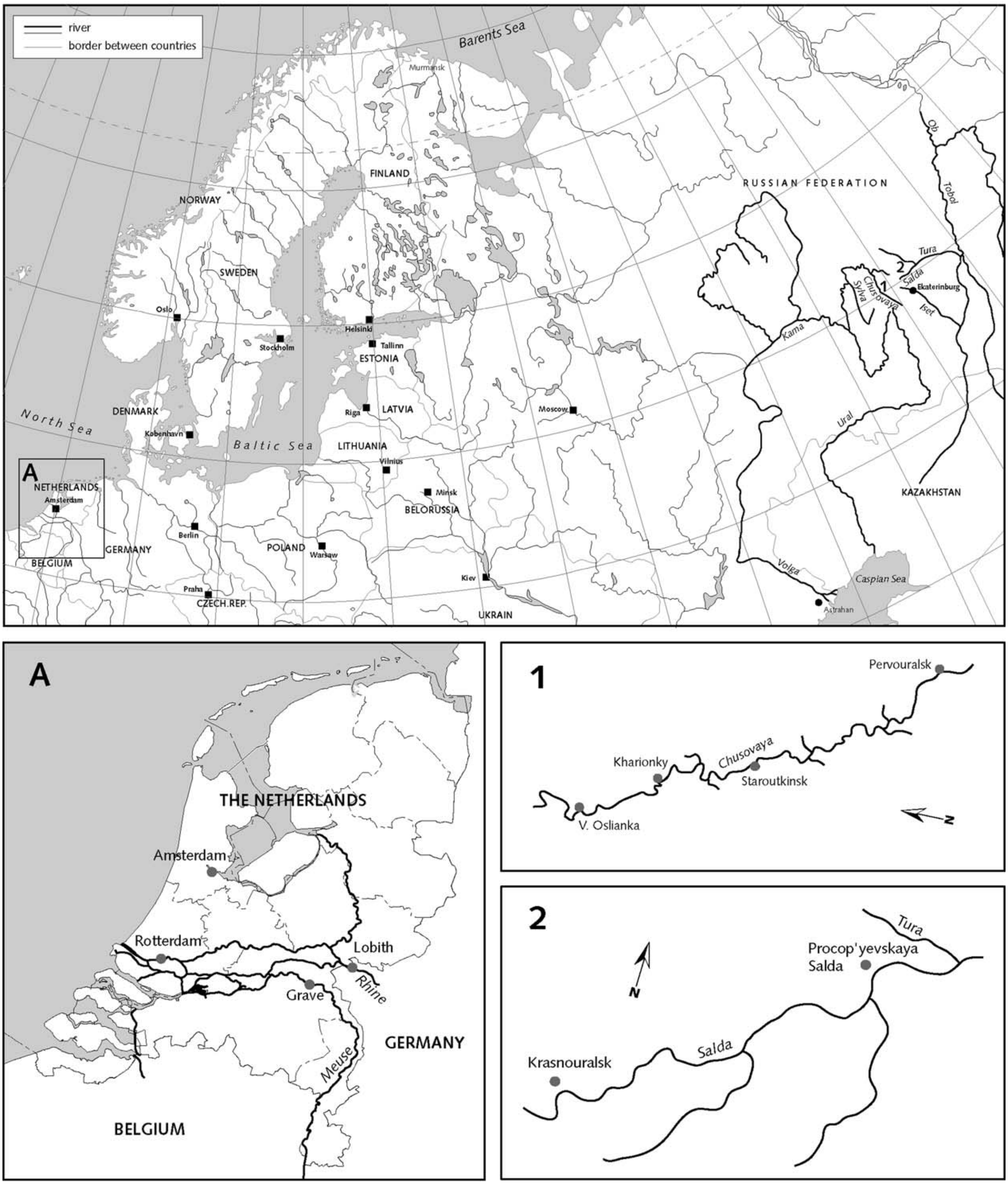

Figure 2. Sampling stations in the investigated rivers. Top: overview; A: sampling stations in the Rhine and Meuse Rivers, The Netherlands; 1: sampling stations along the Chusovaya River, Russia; 2: sampling stations along the Salda River, Russia.

Table 1. Characteristics of the macroinvertebrate guilds distinguished in the ITC (Pavluk et al., 2000), including relative number of taxa per guild present in the database.

Guild no.	Diet	Feeding behavior	Food size (mm)	Relative number (%)
1	Carnivory	Active shredder/chewer	>1	9.8
2	Carnivory	Passive shredder/chewer	>1	3.6
3	Omnivory	Shredder/chewer/collector	>1	5.9
4	Herbivory	Shredder/chewer	>1	7.8
5	Herbivory	Shredder/chewer	<1	2.6
6	Herbivory	Scraper	<1	26.3
7	Herbivory	Collector	<1	22.7
8	Herbivory	Filtrator	<1	8.7
9	Carnivory	Sucker (incomplete food ingestion)	>1	6.6
10	Carnivory	Sucker (total food ingestion)	>1	2.4
11	Herbivory	Sucker	>1	1.9
12	Omnivory	Shredder/chewer	<1	1.7

Table 2. Indication value (C) of the trophic guilds.

Trophic guild	C	Ln C
1	10.2	2.3
2	27.6	3.3
3	16.9	2.8
4	12.8	2.6
5	39.2	3.7
6	3.8	1.3
7	4.4	1.5
8	11.5	2.4
9	15.2	2.7
10	41.4	3.7
11	53.2	4.0
12	57.3	4.1
Total		34.4

Table 3. Quality class score for an assessment system with five quality classes.

Quality class	C_{tot}	Quality description
I	≥28	High
II	21–28	Good
III	14–21	Moderate
IV	7–14	Poor
V	0–7	Bad

tion, being $C = 100/A$, in which A is the relative number of species per trophic guild (Table 2). The quotient of the sum of the Ln transformations of these values (Table 2) and the number of classes gives the class width. In the case of five classes, width is 7 ($34.4/5 = 6.9$ (≈ 7)). Quality class score is calculated with the formula:

$$C_{tot} = \sum_{i=1}^{n} C_i,$$

in which: C_{tot} is the total score, n is number of trophic guilds present in the data-set, and C_i is the ln transformed indication value of trophic guild i. The relation between C_{tot} and the quality classes is given in Table 3 for an assessment system with five quality classes.

Results

A reliable survey of the aquatic ecosystem status, e.g., in the process of improving its ecological values, directly depends on the design of an appropriate monitoring program in which sampling methods and sampling period are very important. Ecological assessment, in general, is based on species richness which strongly depends on the number of microhabitats sampled, the time of the year, and the water type.

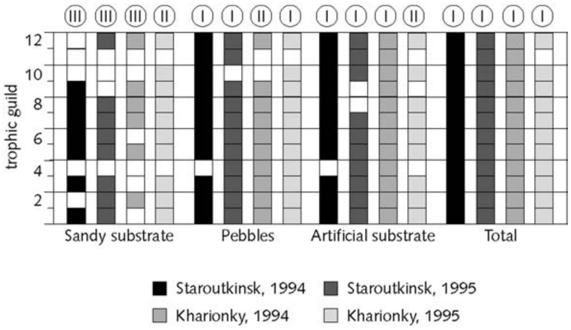

Figure 3. Number of trophic guilds in different biotopes sampled in the Chusovaya River in the vicinity of Stauroutkinsk and Kharionky in 1994 and 1995. For the ITC calculations the total number of species found in August each year (three samplings) was used; white squares indicate absent guilds. Numbers in the circles represent the calculated quality class (Table 3).

For testing the applicability of the ITC, natural and anthropogenic variables were studied that could influence the outcome of an ITC-calculation: (a) sampling strategy, (b) season, (c) river stretch (e.g., up-, downstream section), (d) climate zone, (e) water and (f) sediment pollution.

Influence of the sampling strategy

Data of the Chusovaya (1994 and 1995), Rhine (1995) and Meuse (1996) Rivers were used to study the contribution of the sampled biotopes on the outcome of an ITC-calculation. The most complete trophic structure was observed on pebbles and on the artificial substrate (Fig. 3). Statistical analysis (*t*-test) of the data showed that the number of trophic guilds found in the sandy biotope and on pebbles differed significantly ($p < 0.05$). Such was not shown between the sandy biotope and the artificial substrate and between the pebbles and the artificial substrate ($p < 0.05$). In the sandy biotope the trophic guilds 4 and 11 (herbivorous shredder/chewers and suckers respectively) were absent in both years, while guild 10 (carnivorius suckers) was only present at Kharionky in 1995. All twelve guilds were met in the samples from the pebbles as well as from the artificial substrate, although guild 11 was absent in all samples taken at Kharionky in 1995. If the results of the sampled biotopes are put together, the results from the sandy substrate samplings do not contribute to the ITC outcomes. No significant differences were observed between the results of the pebbles and artificial substrate samplings. The combined results of all samplings per location and per year indicate a high ecosystem quality.

In the Dutch part of the Meuse River in the vicinity of Grave (Fig. 2), comparable biotopes were sampled in 1992, 1996 and 2000. However, instead of pebbles, stones in the littoral zone were sampled. These stones in this normalised and dammed stretch in the downstream section of the Meuse River are in fact an artificial substrate for the macrozoobenthos community because they were introduced for bank protection. The results (Fig. 4) show that either with the stone or the artificial substrate sampling the maximum number of trophic guilds was found. Also no differences were observed in the quality classes calculated from the ITC outcomes of each sampling method. Results from sandy substrate samplings did not contribute to the ITC outcomes. Herbivorous small and large size particle shredder/chewers, and omnivorous shredder/chewers (guilds 4, 5 and 12, respectively) were absent in all three years; passive carnivorous and omnivorous shredders/chewers, and herbivorous suckers (guilds 2, 3 and 11, respectively) were only present with one species in relatively low densities.

The number of trophic guilds found in five biotopes, sampled in 1995 and 1999 in the Rhine, delta was compared, using the results of the Netherlands biological monitoring program (Fig. 5). It is evident that this number guilds varied between the biotopes sampled, but the differences between the ITC scores were not statistically significant ($p < 0.05$). In all biotopes sampled the herbivorous shredder/chewers (trophic guilds 4 and 5), the herbivorous suckers (trophic guild 11) and the omnivorous shredder/chewers (trophic guild 12) were absent in 1995. In 1999 trophic guild 5 was the only absent guild, the other guilds absent in 1995 were present with two species at maximum. In both years the monitoring results of the profundal sand bottom did not contribute to the total number of trophic guilds observed in all distributaries.

Seasonal influence

Species composition and the density of macroinvertebrates varies in the course of the year depending on their life cycles. In an ideal situation, season dynamics should not have any influence on the assessment outcomes. Influence of sampling date on species composition and subsequently on the ITC outcomes was examined with time series gathered with artificial substrate sampling only in the 1992, 1996 and 2000 monitoring programs from the Rhine (sampling location Lobith) and Meuse Rivers (sampling location

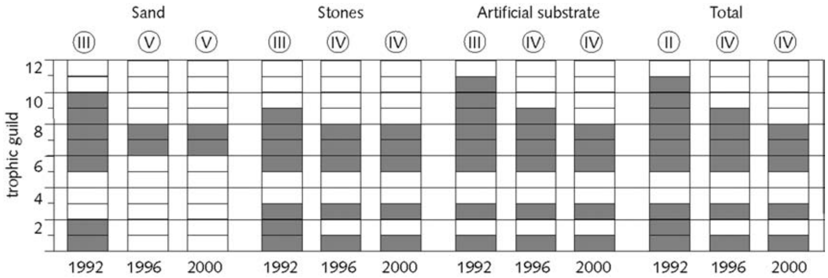

Figure 4. Trophic guilds present (white squares indicate absent guilds) in different biotopes sampled in the Meuse River in the vicinity of Grave in September/October 1992, 1996 and 2000 (only one sampling in the given years). Numbers in the circles represent the calculated quality class (Table 3).

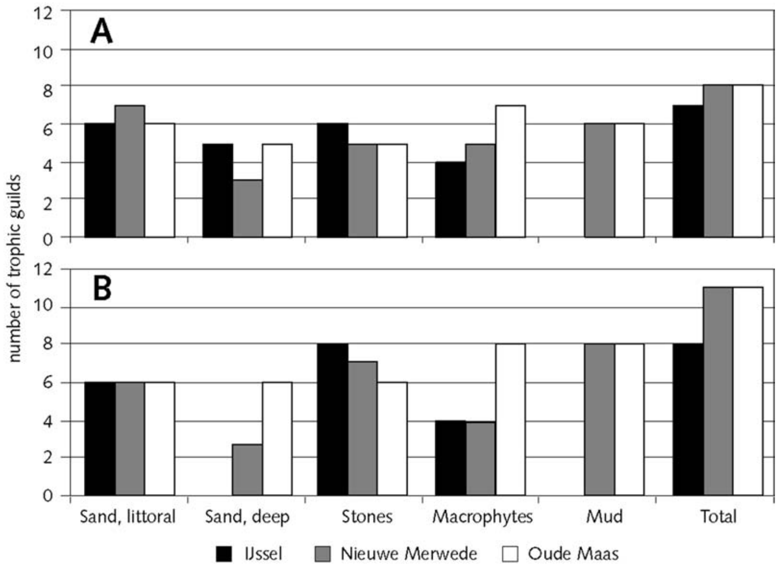

Figure 5. Number of trophic guilds found in the most important biotopes in three free flowing distributaries in the Rhine delta in 1995 (A) and 1999 (B).

Grave). In general, the ITC outcomes seem to be more stable with the number of trophic guilds presented in the samples (Fig. 6). This can be explained by the low number of trophic guilds present containing >2 species ($n = 4$ and 6 for the Rhine and Meuse Rivers, respectively). In addition, when trophic guilds were present with <2 species, the density of these species in the samples was relatively low.

No statistically significant difference ($p < 0.05$) was found between the number of trophic guilds present in spring and summer at both locations in the individual years.

River section

As summarized in the River Continuum Concept, a gradual change of many stream parameters (e.g., depth, current velocity, bottom substrates, and chemical composition of the river water) takes place from the river's source to its mouth (Vannote et al., 1980). This change of environmental conditions results in a shift of the benthic macroinvertebrate community. However, a change in species composition does not necessarily result in loss of trophic guilds (Cummins, 1977). Only the number of taxa in each trophic guild will change as illustrated (Fig. 7) with results obtained from the Sylva River (Middle Urals), a 493 km long pristine tributary of the Kama River in the Volga River basin (Fig. 2). In the River Sylva stony biotopes were sampled in July and August 1996. All trophic guilds were present in the three river sections sampled. With respect to species richness, scrapers and collectors (guilds 6 and 7) were the dominant guilds in all river sections, filter-feeders (guild 8) in the lower section as well.

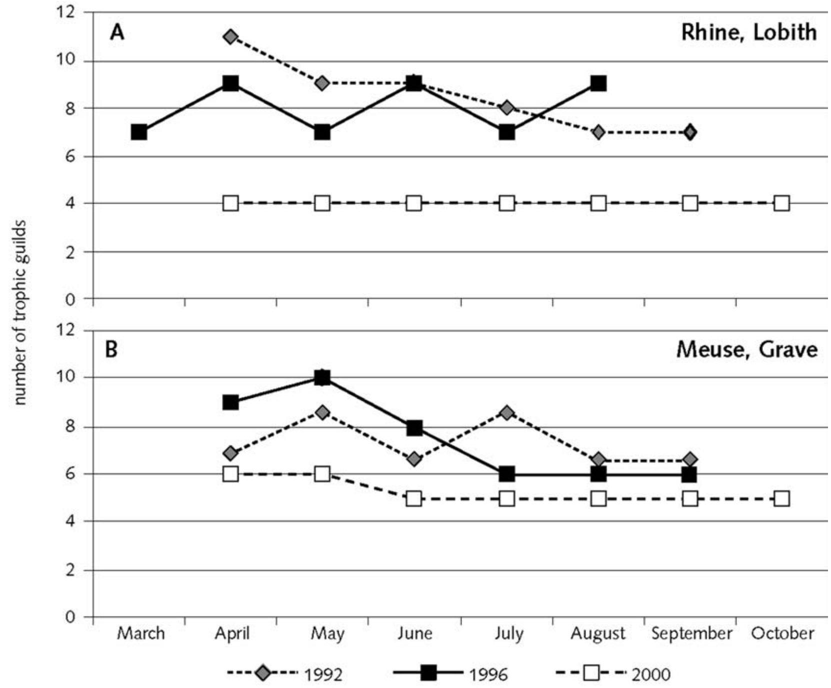

Figure 6. Number of trophic guilds found in the Rhine (A) and Meuse (B) Rivers based on artificial substrate samples taken in 1992, 1996 and 2000 in the vicinity of Lobith and Grave respectively.

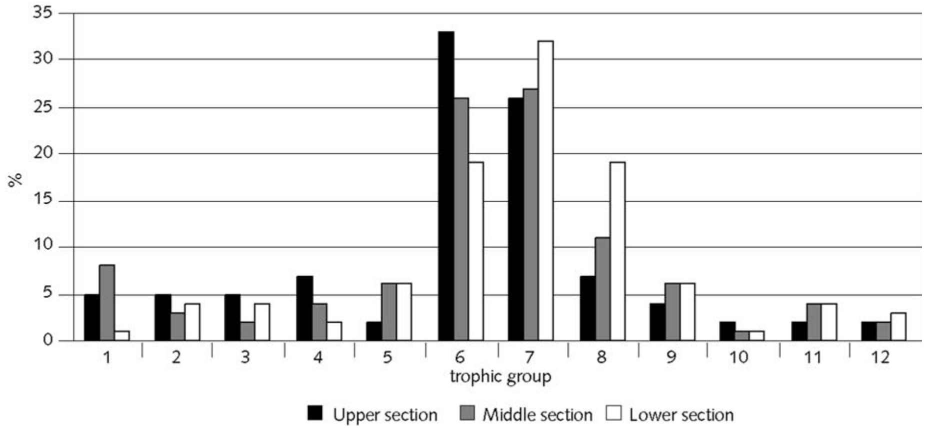

Figure 7. Relative abundance of macroinvertebrate species in stony biotopes in three sections of the Sylva River arranged by their trophic status.

In the Rhine River, macroinvertebrates were monitored in 1995 and 2000 as part of an extensive international monitoring program organised by the International Commission for Protection of the Rhine River against Pollution (ICPR, Koblenz, unpublished data). Downstream of Lake Constance, the influence of anthropogenic stress is clearly reflected by the absence of trophic guilds in the lower sections (Fig. 8). Based on the relative number of taxa per trophic guild, the diversity of scrapers and collectors (guilds 6 and 7) was relatively high in all river sections. In the lower sections this was also the case for the filter-feeders guild (guild 8). In the two most upstream sections all trophic guilds were present, despite the presence of a series of dams. In downstream direction, a gradual decrease in the relative abundance of shredders/chewers species (trophic guilds 1 and 4) was observed. Small particle shredders/chewers (trophic guilds 5 and 12) and plant suckers (trophic guild 11) were absent in the

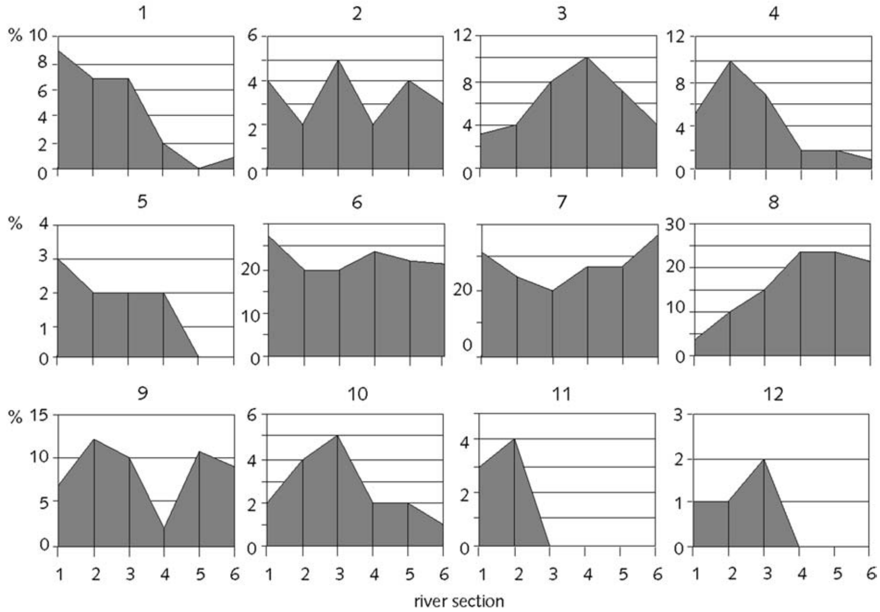

Figure 8. Relative species number, arranged per trophic guild (I-XII), present in successive sections of the Rhine River in 1995. Numbers on the X-axis refer to the river section indicated with river km's (starting at the outlet in Lake Constance and running up in downstream direction): 1: 28–64; 2: 127–168; 3: 220–316; 4: 496–696; 5: 860–951 and 6: 990–1002.

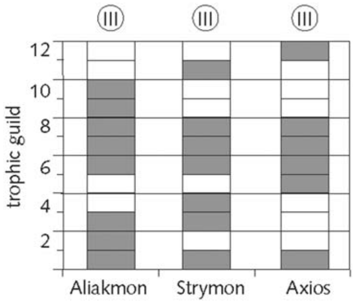

Figure 9. Trophic structure in three Greece rivers (white squares indicate absent guilds). Numbers in the circles represent the calculated quality class (Table 3).

downstream sections, the later guild most likely due to the absence of vegetation in the river channel.

Climate

According to the theoretical postulates of the ITC (Pavluk et al., 2000), the trophic structure of an aquatic ecosystem tends towards the greatest possible diversity of trophic niches present. In rivers exposed to a continental or a sea climate (respectively the Sylva and Rhine Rivers) all trophic guilds were observed. However, not all trophic guilds were present in each river due to significant differences in water pollution (Skoulikidis et al., 1998). No guild was absent when taking the three rivers into account (Fig. 9).

Types of water pollution

In the Sverdlovsk Oblast, rivers have been subjected to water pollution with specific substances like heavy metals and oil as mono-dominant pollutants. The main pollutant in the Chusovaya River is chromium, in the Salda River copper while the Iset River is subjected to oil pollution. Macroinvertebrate communities in these rivers were studied in the period 1995–1998 by means of handnet sampling and a standard artificial substrate (Pashkevich et al., 1996).

In the Chusovaya River, samples were taken in July, August and September 1995 and 1997 at a location in the vicinity of Pervouralsk downstream of an ore enrichment plant, which is the source of a diffuse and permanent chromium contamination. Total chromium concentrations in the river water measured were mostly above 0.5 mg l^{-1} (Fig. 10). Although species density was relatively low compared with downstream locations, at least eight trophic guilds were present in the combined results of handnet and artificial substrate samplings, resulting in a good quality score most of the time (Fig. 10). Sucking animals (guilds 10 and 11) and small particle shredders/chewers (guild no.12) appeared to be the most chromium sensitive.

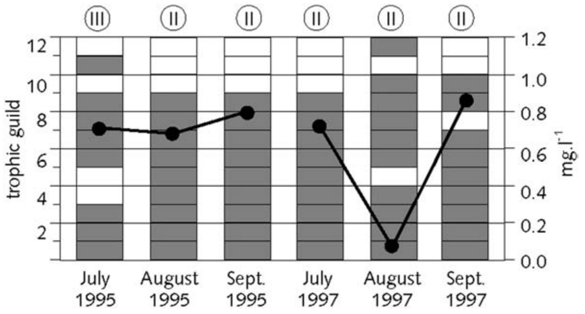

Figure 10. Trophic structure (white squares indicate absent guilds) in the chromium polluted Chusovaya River near Pervouralsk in the summer seasons of 1995 and 1997, including total chromium concentrations measured (right Y-axis). Numbers in the circles represent the calculated quality class (Table 3).

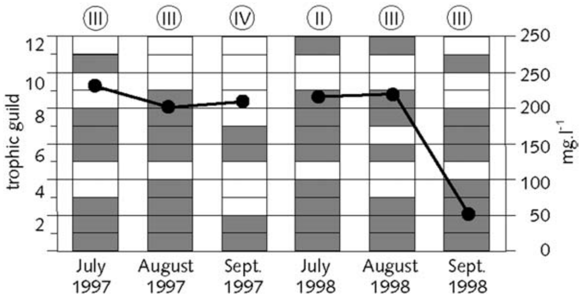

Figure 11. Trophic structure (white squares indicate absent guilds) in the copper polluted Salda River near Krasnouralsk in the summer seasons of 1997 and 1998, including copper concentrations measured (right Y-axis). Numbers in the circles represent the calculated quality class (Table 3).

Copper pollution in the Salda River has been caused by a melting plant in the vicinity of Krasnouralsk (Fig. 2). At the sampling site, copper concentration ranged between 200 and 230 mg l^{-1} in the summer of 1997 and 1998, except on the last sampling date when the concentration had dropped to 50 mg l^{-1} (Fig. 11). From the combined results of handnet and artificial substrate samplings it can be concluded that, despite low densities compared to locations further downstream, at least seven trophic guilds were present during each sampling, except in September 1997 when extremely few animals were sampled. In general the same guilds were absent as in the Chusovaya River (guilds 10, 11 and 12), including small particle herbivorous shredders/chewers (guild 5) and sucking animals with total food ingestion (guild 9). Quality score ranged between good and poor.

The effect of oil substances on macroinvertebrate communities was studied in the summer of 1997 in a free flowing section of the Iset River in the vicinity of Ekaterinburg (Fig. 2). Relatively high oil concentrations in the range of 0.3–0.4 mg l^{-1} have been the main reason for the degradation of the benthic community. The ITC, calculated from the results of all samples taken on each sampling date (Fig. 12), showed a permanent absence of three trophic guilds (no. 5, 10 and 12), resulting in a quality score being moderate or poor.

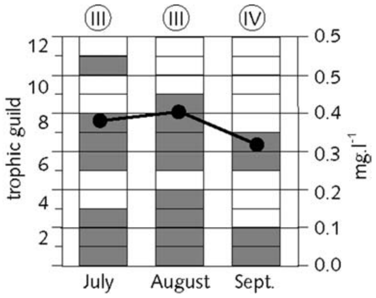

Figure 12. Trophic structure (white squares indicate absent guilds) in the oil polluted Iset River near Ekaterinburg in the summer season of 1997, including oil concentrations measured (right Y-axis). Numbers in the circles represent the calculated quality class (Table 3).

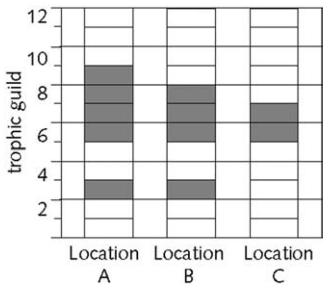

Figure 13. Trophic structure (white squares indicate absent guilds) of the sediment preferring macroinvertebrate community in side channels along the Waal River.

Polluted sediments

Chemical sediment quality is an important component of the pelephilic macroinvertebrate's habitat quality and may thus influence trophic structure of the community when they feed on sedimented particles. Effects of polluted sediments on the results of the ITC outcomes were studied in 1995 in a man-made side channel of the Waal River, the most important distributary in the Rhine delta (Fig. 1). Three identical bottom biotopes with different degrees of pollution were sampled (De Jonge et al., 1999). The bottom consisted of a mixture of sand and mud and was mainly polluted with a mixture of cadmium, chromium, lead, mercury, PCB-153 and ΣDDT. At three locations examined, situated in a gradient, an enhanced bio-availability was observed of cadmium and chromium (Fig. 13, location A); cadmium, chromium and mercury (Fig. 13, location B); and cadmium, lead, mercury, PCB-153 and ΣDDT (Fig. 13, location C) respectively. The impact of these combinations of pollutants on the benthic macroinvertebrates is reflected by a gradual disappearance of trophic guilds from location A to C. At location C only herbivorous scrapers and collectors (guilds 6 and 7 respectively) were found (Fig. 13).

Discussion

The ITC belongs to the group of indices based on functional trophic relations, taking into account the presence of trophic guilds in the benthic macroinvertebrate community (Pavluk et al., 2000). Outcomes of the index are not given in concrete numbers, but by a projection of trophic relations within a biocenosis. The index indicates the functionality of the community and is based on the functional redundancy hypothesis. If input and transfer of energy and organic matter in the ecosystem change, the composition of the macroinvertebrate community changes as well. Species will disappear and subsequently specific trophic guilds if it was the last remaining species in a functional group (Aarts & Nienhuis, 1999). The index is based on the assumption that in a healthy environment all trophic guilds will be present, irrespective the number of species per guild. The correctness of this assumption was proved in this study. From the investigations we concluded that the trophic structure is a relatively stable mark of the aquatic ecosystem condition. Planas et al. (2000) concluded that functional biodiversity of phytoplankton seems a better predictor of stability than species biodiversity. Ecosystems normally exist in a dynamic equilibrium in which structural parameters (e.g., biomass, species density, diversity) may change in different periods of the year and functional properties only will vary through anthropogenic activities (Odum, 1971). Natural fluctuations (e.g., floods, drought, ice covering) may influence the community structure, but their long term effects do not result in the extinction of trophic guilds, which was also demonstrated in our study. Results from the Sylva River with relatively long periods of ice cover, and from the Greek Aliakmon, Strymon and Axios Rivers, exposed to drought during summer and autumn, show the presence of species from all twelve trophic guilds in these rivers (Figs 7, 9). No significant seasonal changes were observed in the course of one year in the Rhine and Meuse Rivers, although the number of trophic guilds decreased from 11 to 4 and from 10 to 5 respectively in the period 1992–2000 (Fig. 6). This decrease of guilds coincides with the colonisation of both rivers by the Ponto-Caspian gammarid *Dikerogammarus villosus* which is dominantly predaceous in these new areas (Van der Velde et al., 2000; Dick & Platvoet, 2002).

In contrast to natural disturbances, anthropogenic induced stress factors have a very short history on the evolutionary scale. Aquatic organisms have not yet developed an adequate response to the heterogeneous and sometimes highly toxic stressors. Specific impact of chemical or physical stress factors on the trophic structure of macroinvertebrate communities is still difficult to indicate due to lack of information. It seemed that the application of the ITC on monitoring results of many rivers was impossible because the assessment methods prescribed in many monitoring programs do not require identification of the macroinvertebrates to species level, which is a necessity. On the other hand, effects of some physical factors on the trophic structure are clear. An excess of suspended matter, for example, affects filter-feeders negatively by blocking their filtering apparatus (Rusanov et al., 1990) and reduces growth of primary producers and thus the occurrence of their consumers (herbivorous animals). In the case of thermal pollution the decomposition rate of organic substances increases, leading to the reduction of dissolved oxygen in the water column and an accumulation of FPOM in the sediments. Under such conditions oxyphilic and thermophobic taxa are under threat, on the other hand, the number of generations per year of other taxa can increase (Allan, 2000).

Chemical stressors can act in different ways in the trophic structure. Chromium pollution in the Chusovaya River seems to lead to the disappearance of the trophic guilds 10, 11 and 12, but did not result in their extinction due to the recolonisation of some representatives of these guilds from the unpolluted river section upstream of the sampling location and the chromium discharge point in the vicinity of Pervouralsk (Fig. 10). Although the other trophic guilds were present nearly all the time, diversity and abundance of the macroinvertebrate fauna was strongly reduced. Copper pollution in the Salda River resulted in the extinction of the trophic guilds 5 and 10, whereas the guilds 11 and 12 balanced on the edge of extinction (Fig. 11). From the latter two guilds, only one species each was present in the given months in relatively low numbers (*Ititrichia lamellaris* and *Ch-*

eumatopsyche lepida respectively). Oil pollution in the Iset River has a disastrouse effect on the occurrence of most trophic guilds except the numbers 1, 2, 6 and 7 (Fig. 12) consisting of carnivorous shredders/chewers (guilds 1 and 2) and herbivorous scrappers (guild 6) and collectors (guild 7) (Table 1). Although oil was the monodominant pollutant, frequently occurring oil contaminants like PCB's also could play an important role in the disappearance of trophic guilds (Swindoll et al., 1987; Le Blanc et al., 1988). Effects of these organo-micropollutants were visible in the macroinvertebrate community of polluted sediments in the Waal River (Fig. 13). In these sediments as well as in the Iset River the guilds of predatory animals were absent, possibly due to effects of bioaccumulation in the food web.

When outcomes of the ITC-calculations are arranged into quality classes the Meuse River at Grave scores well in 1992 and poor in 1996 and 2000 (Fig. 4); all three Rhine distributaries (IJssel, Nieuwe Merwede and Oude Maas Rivers) score moderate and good in 1995 and 1999 respectively (Fig. 5). In both the Rhine and Meuse Rivers anthropogenic pressure is relatively high mainly due to river engineering and industrial pollution (Admiraal et al., 1993). Although macrozoobenthos density was relatively low in the Chusovaya River near Pervouralsk, chromium pollution did result in a much lower quality qualification compared to downstream reaches. At Pervouralsk the score ranged between moderate and good (Fig. 10), downstream at Stauroutkinsk and Kharionky between good and high (Fig. 3). Copper pollution in the Salda River resulted in quality scores ranging from poor to good (Fig. 11), while oil pollution in the Iset River near Ekaterinburg resulted in scores between poor and moderate (Fig. 12). Also in the Salda and Iset Rivers macrozoobenthos density was relatively low at the sampling locations. However, in all three Russian rivers, the macrozoobenthos community at the polluted sampling locations was positively influenced by a permanent colonisation pressure from the unpolluted upstream river stretch, resulting in elevated quality scores.

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References

Aarts, B. G. W. & P. H. Nienhuis, 1999. Ecological sustainability and biodiversity. International Journal of Sustainable Development & World Ecology 6: 89–102.

Admiraal, W., G. van der Velde, H. Smit & W. G. Cazemier, 1993. The rivers Rhine and Meuse in The Netherlands: present state and signs of ecological recovery. Hydrobiologia 265: 97–128.

Allan, J. D., 2000. Stream Ecology: Structure and Function of Running Waters. Kluwer Academic Publishers, Dordrecht, 388 pp.

Canfield, T. J., N. E. Kemble, W. G. Brumbaugh, F. J. Dwyer, C. G. Ingersoll & J. F. Fairchild, 1994. Use of benthic invertebrate community structure and the sediment quality triad to evaluate metal contaminated sediment in the Upper Clark Fork River, Montana. Environmental Toxicology & Chemistry 13: 1999–2012.

Chapman, D., 1994. Water Quality Assessments: a Guide to the Use of Biota, Sediments, and Water in Environmental Monitoring. Chapman & Hall, London, 585 pp.

Cummins, K. W., 1973. Trophic relations of aquatic insects. Annual Revue of Entomology 8: 183–206.

Cummins, K. W., 1977. From headwater streams to rivers. American Biology Teacher 39: 305–312.

Cummins, K. W., 1992. Invertebrates. In Calow, P. & G. E. Petts (eds), The Rivers Handbook, Vol. 2. Blackwell Scientific Publications, Oxford: 234–250.

De Jonge J., J. M. Brils, A. J. Hendriks & W. C. Ma, 1999. Ecological and ecotoxicological surveys of moderately contaminated floodplain ecosystems in The Netherlands. Aquatic Ecosystem Health & Management 2: 9–18.

De Pauw, N., V. Lambert, A. Van Kenhove & A. bij de Vaate, 1994. Comparison of two artificial substrate samplers for macroinvertebrates in biological monitoring of large and deep rivers and canals in Belgium and The Netherlands. Journal of Environmental Monitoring & Assessment 30: 25–47.

Dick, J. T. A. & D. Platvoet, 2000. Invading predatory crustacean *Dikerogammarus villosus* eliminates both native and exotic species. Proceedings of the Royal Society of London, Series B 267: 977–983.

Fowler, J., L. Cohen & P. Jarvis, 1998. Practical Statistics for Field Biology. John Willey & Sons, Chichester, 259 pp.

Gritzalis, K. C., N. Skoulikidis, I. Bertahas, I. Zacharias & T. Koussouris, 1998. Ecological estimation of riparian locations on the rivers Aliakmon, Axios and Strymon. Proceedings of the 20th Panhellenic Meeting, Samos, pp. 53–54.

Kalweit, H. (ed.), 1993. Der Rhein unter der Einwirkung des Menschen. Usbau, Schiffahrt, Wasserwirtschaft. Internationale Kommission für die Hydrologie des Rheingebietes, Lelystad, Report no. I–II, 260 pp.

Konstantinov, A. S., 1967. Obshaya gydrobiologiya (Principals of Hydrobiology). Vysshaya shkola, 430 pp. (in Russian).

Le Blanc, G. A., B. Hilgenberg & B. J. Cochrane, 1988. Relationships between the structures of chlorinated phenols, their toxicity, and their ability to induce glutathione S-transferase activity in *Daphnia magna*. Aquatic Toxicology 12: 147–155.

Leslie, H. A., T. I. Pavluk & A. bij de Vaate, 1999. Triad assessment of the impact of chromium contamination on benthic macroinvertebrates in the Chusovaya River (Urals, Russia). Archives of Environmental Contamination and Toxicology 37: 182–189.

Metcalfe-Smith, J. L., 1994. Biological water quality assessment in rivers: use of macroinvertebrate communities. In Calow, P. & G. E. Petts (eds), The Rivers Handbook, Vol. 2. Blackwell Scientific Publications, Oxford: 144–170.

Miroshnichenko, M. P., 1983. Znachenye oligohet v trohicheskoi struktur biotzenozov bentosa Tzimlianskogo vodohranilisha (The place of Oligochaeta in the trophic structure of benthic biocenosis in the Tzimliansky reservoir). Materialy chetvertogo vsesoiuznogo sympoziuma, Tbilisi, 5–7 October 1983, Tbilisi, Izd-vo 'Metzniereba', pp. 58–63 (in Russian).

Odum, E. P., 1971. Fundamentals of Ecology. Saunders & Co., Philadelphia.

Pashkevich, A., T. Pavluk & A. bij de Vaate, 1996. Efficiency of a standardized artificial substrate for biological monitoring of river water quality. Journal of Environmental Monitoring & Assessment 40: 143–156.

Pavluk, T. I., A. bij de Vaate & H. A. Leslie, 2000. Biological assessment method based on trophic structure of benthic macroinvertebrate communities. Hydrobiologia 427: 135–141.

Planas, D., E. Prepas & S. Paquet, 2000. Is biodiversity a good predictor of ecosystems stability in freshwater? Verhandlungen der Internationale Vereinigung für theoretische und angewandte Limnologie 27: 1138.

Rosenburg, D. M., Resh, V. H., 1993. Freshwater Biomonitoring and Benthic Macroinvertebrates. Chapman & Hall, New York, 488 pp.

Rusanov, V. V., Zusko, A. J., Olshvang, V. N., 1990. Sostoyanie otdel'nykh komponentov vodnyh biogeocenozov pri razrabotke rossypnykh mestorozhdenyi drazhnym sposobom. (The condition of separate components of the aquatic biocenosis during mining deposits by dredging.) Sverdlovsk UrO AN, SSSR (in Russian).

Skoulikidis N. T., I. Bertahas & T. Koussouris, 1998. The environmental state of freshwater resources in Greece (rivers and lakes). Environmental Geology 36: 1–17.

Swindoll, C., N. Michael & F. M. Applehans, 1987. Factors influencing the accumulation of sediment-sorbed hexachlorbiphenyl by midge larvae. Bulletin of Environmental Contamination & Toxicology 39: 1055–1062.

Van de Ven, G. P. (ed.), 1993. Leefbaar laagland: geschiedenis van de waterbeheersing en landaanwinning in Nederland. Uitgave Stichting Matrijs, Utrecht, 303 pp.

Van der Velde, G., & R. S. E. W. Leuven, 1999. Polluted river systems: monitoring and assessment of ecotoxicological risks. Acta Hydrochimica et Hydrobiologica 27: 251–256.

Van der Velde, G., S. Rajagopal, B. Kelleher, I. B. Muskó & A. bij de Vaate, 2000. Ecological impact of crustacean invaders: general considerations and examples from the River Rhine. In Von Vaupel Klein, J. C. & F. R. Schram (eds), The Biodiversity Crisis and Crustacea: Proc. 4th Int. Crustacean Congress, Amsterdam, 20–24 July 1998, Vol. 2. Crustacean Issues 12: 3–33. Brill, Leiden.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell & G. E. Cushing, 1980. The river continuum concept. Canadian Journal of Fisheries & Aquatic Sciences 37: 130–137.