Variables determining the response of invertebrate species to toxicants, A case study on the River Meuse.
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Chapter VII

CONCLUDING REMARKS

The general aim of this study was to identify key factors of water quality determining the response of invertebrate species to polluted river water. It was evaluated if toxic barriers exist for indigenous species to re-establish in rivers in the process of sanitation, and which variables determine the response of "pollution tolerant" species to deteriorated conditions. The River Meuse was used in a case study. This section contains concluding remarks on the results of this study, by discussing 1.) how invertebrate species in disturbed rivers are affected by multiple stressors, 2.) which variables determine the ranking of species according to their sensitivity to pollution, and 3.) the relevance of the findings to river management.

1. Multiple stressors

In areas where industry and land use are not very diverse, large rivers may "only" suffer from one or few kinds of pollution. For example, in a case study on the Scandinavian River Kyrönjoki, Vuori (1995) could relate mortality of hydropsychid caddisflies to the effects of acid sulphate runoff from soils. Also, Leslie (1998) related adverse effects on benthic populations to extreme chromium contamination in the Russian Chusovaya River. In many cases, however, large rivers run through areas with highly diverse industries and through cultivated land with different kinds of crops. Consequently, river water is polluted with a mixture of numerous pollutants from different sources. Only a relatively small part of such cocktails of pollutants can be identified, even if extensive monitoring programmes are carried out, like by the Dutch government on the Rivers Meuse and Rhine. Consequently, it is difficult to relate observed effects on organisms to specific compounds that occur in these rivers. In a study on the Rhine, Hendriks et al. (1994) monitored the effect of concentrated river water on daphnids, and attempted to relate the observed toxicity to compounds identified in the river water. Even though many chemicals were measured and many toxicity data on Daphnia magna exist, only 10% of the observed toxicity could be attributed to identified compounds. Also in the present study, effects of the river water on macrofauna
were not causally related to the measured compounds in 1995, even though many chemicals were analysed in the Meuse. During the field experiments with *Hydropsyche* caddisflies in 1996, various reports were made of strongly elevated toxicant levels in the River Meuse (RIWA, 1997a). On one occasion complete mortality was observed when elevated concentrations of numerous unidentified compounds were reported. These findings illustrate the difficulty to relate effects on aquatic macrofauna to individual substances in rivers with complex pollution, even when high concentrations of compounds are detected.

Which stressors determine the response of species to pollution? Toxicants in a mixture can mutually influence toxicity (*mixture toxicity*), but there are also other abiotic and biotic stress factors that may modify toxic effects (*multiple stressors*). For example, oxygen can alter *(bio)chemical reactions, which may modify negative effects of toxicants. Oxygen can also directly influence individuals; low oxygen levels may affect their condition, resulting in a higher vulnerability towards toxicants (Eriksson and Weeks, 1994). There are, however, also factors in polluted rivers that may positively interact with the response of organisms to toxicants. In the present study, midges were expected to be inhibited by the local toxicant levels, but actually showed stimulated growth during exposure to polluted site water. Positive effects of polluted river water on invertebrates have also been observed for daphnids in Meuse water (De Ruiter and Hendriks, 1996) and for species in rivers suffering from other mixed sources of pollution (Lowell et al., 1995; Dubé and Culp, 1996).

How can these discrepancies between expected and actual performances of test species be explained? In all these studies, the input of toxicants coincided with an increase of nutrients or organic waste. It was demonstrated in the present study that for *C. riparius* particulate organic matter in river water reduces negative effects of pollution by serving as a supplementary, superior food source. This observation was recently confirmed by observations on *C. riparius* in Irish streams subject to complex pollution (Curran, unpublished). Thus, the input of nutritive compounds directly or indirectly mitigates or even completely masks the effects of toxicants for some species. This observation may lead to the conclusion that macrofauna species are not at risk as long as there is organic enrichment. However, the opposite effect may occur for species that are sensitive to organic waste products, as illustrated by the performance of *D. polymorpha* in polluted river water. The results of the present study suggest that filtration rates of the zebra mussel were inhibited by the unfavourable "taste" (due to organic waste) of the water. Hence, certain compounds can act as stressors for one species (type 1, Fig. 7.1), but may benefit another species (type 2, Fig. 7.1) under the same conditions. This implies that the reduction of eutrophication and organic pollution in rivers will have strong but divergent effects on macrofauna species.
CONCLUDING REMARKS

It has been argued (Diamond et al., 1997) to apply a factor to correct for differences in bioavailability, in order to account for differences between effects of toxicants in standard laboratory tests and effects in site water. However, the present study demonstrated that such a “correction factor”, applicable to a case of pollution with a single toxicant, is not appropriate to predict the in situ response of an organism to pollution, because mostly multiple factors (like oxygen and organic enrichment) affect the response of organisms to toxicants. A species specific response to multiple toxicant stress is a further obstacle to predict realistically the consequences of pollution.

2. Ranking of species sensitivity

How is the ranking of species sensitivity to pollution determined? Classifications of pollution “tolerant” and “sensitive” species are often based on the occurrence of species in the field. The ranking order of sensitivity to pollution that follows from these classifications seems analogous to observations under (semi-)controlled conditions reported in this study. This order of sensitivity can, however, not be deduced from standard toxicity tests: species considered to be tolerant of pollution in field surveys are not necessarily most tolerant of toxicants. For example, “pollution tolerant” species (the crustacean Paracallope fluviatilis and snail Potamopyrgus antipodarum) were more sensitive to the (natural) toxicant
ammonia than "pollution sensitive" species like mayflies (Zephlebia dentata) and stoneflies (Zealandobius furcillatus) (Hickey and Vickers, 1994). Accordingly, C. riparius (present study) and Daphnia magna (De Ruiter and Hendriks, 1996) seemed not be affected by the pollution levels in the Meuse while both species appear more sensitive in toxicity tests. D. polymorpha, on the other hand, performed worse in Meuse water than expected from toxicity tests.

Which factors contribute to the observed inconsistencies between rankings of species sensitivities in the laboratory and rankings based on field observations? First, chemical water quality characteristics (other than toxicants) play a role: as discussed above, certain compounds can act as stressors for one species, but may benefit another species under the same conditions. Second, physical water quality characteristics co-determine the occurrence of populations. Field observations indicate that characteristic riverine insects, like caddisflies, mayflies and stoneflies require current flow and high oxygen levels. Due to water abstractions subsequent falls in current velocities and oxygen levels occur. As a result, especially riverine species become more vulnerable to pollution than species that are generalistic. Third, life cycle characteristics play a significant role in determining the occurrence of populations in the field. The present study demonstrated that responses of aquatic insects to pollution are strongly determined by their developmental stage; differences in sensitivity were observed to be larger between instars of one species than between different species. Also, the length of a species' life cycle is likely to determine the effect of pollution on populations in the field. For species that are univoltine, frequent chemical discharges are disastrous because it will take at least a year before the number of individuals will increase again. Indeed, riverine species like stoneflies, caddisflies and mayflies have been observed to take longer to recover from a disturbance than e.g. dipteran species, as demonstrated for many case studies (Fig. 7.2). Hence, characteristic riverine species are not only likely to be more affected by deteriorated water quality than generalistic species, their populations are also more susceptible because of their long life cycles.

Clearly, there are many species specific factors that may alter the response of an organism to deteriorated water quality, making it difficult to classify a species as tolerant or sensitive to specific compounds or other stress factors. The present study has identified several factors which determine the response of organisms to complex pollution. To further clarify the ranking of sensitivity to pollution as observed in the field, future research should focus on species' responses to multiple stressors rather than to establish more dose response relationships for single compounds.
3. Relevance and Implications for River Management

Ecotoxicological barriers for rehabilitation of the River Meuse

In 1994, a treaty was signed by France, The Netherlands and the Belgian regions of Wallonia, Flanders and Brussels to co-operate in the protection of the River Meuse (Anonymous, 1994). Furthermore, an international report on the water quality and ecological state of this river has been issued recently (ICBM, 1997). An outline of an action programme for the Meuse (MAP) is expected to be reviewed by the governments of the countries involved. However, an international action plan for rehabilitation has still not initiated, and more insight into the complexity of problems is required to organize a coordinated approach.

In the present study it was evaluated if toxic barriers exist for indigenous species to re-establish in rivers in the process of sanitation, and which variables determine the response of "pollution tolerant" species to deteriorated conditions. Bioassays showed that the water quality of this river has improved in recent years, yet sublethal effects were still occasionally observed on invertebrate species upon exposure to Meuse water in 1994 and 1995 (Chapter II), even when no incidental discharges were reported. In situ incubations of caddisflies showed that recovery of riverine macrofauna species is mostly hampered by incidental pollution, and less so by the prevailing water quality (Chapter V). This implies
that investments being made to improve the "overall" water quality may be (temporarily) annulled by a single serious incident. Incidents are not only caused by chemical compounds, but may also be due to oxygen limitations; especially in summer, oxygen concentrations are frequently extremely low in the Meuse.

Incidents were also pointed out as potential barriers to the rehabilitation of the River Rhine (IKSR, 1996), although the level of pollution differs from the Meuse (Baggelaar and Baggelaar, 1995). Even though the water quality of the Rhine has improved substantially, incidents are still being reported (Huijsen and Wiersma, 1995; RIWA, 1997b). Regular and incidental agricultural input have a major influence on the water quality of the Rhine (IKSR, 1996). This is consistent with the occurrence of pesticide peaks in the Meuse during springtime. The occasional wipe-out of aquatic insects, as was observed in April 1996 (Chapter V), underlines the impact of pesticidal effects. However, in contrast to the Rhine, the sources or compounds that have a (major) effect on the water quality of the Meuse vary in the course of time.

There are indications that not only chemical factors play an important role in the Meuse, but also anthropogenic alterations of morphology and hydrology hamper the return of sensitive macrofauna species, and thus ecological recovery (Chapter V). There are plans to restore habitat structures along the River Meuse. However, these mostly concern the enlargement of space for the river to meander and to prevent flooding (Anonymous, 1996; Marchand and Bresser, 1997). It is suggested that the prevention of unnaturally strong discharge fluctuations and a shortage of water due to water abstractions (by hydro-electric power stations; Chapter V) should be included in environmental plans.

Assessment of river water quality
Both in The Netherlands and abroad, there is a tradition of setting water quality standards for individual compounds on the basis of the outcome of standard laboratory toxicity tests. Several comments can be made on this approach (Van Leeuwen and Hermens, 1995; Marchand and Bresser, 1997). For example, the effective toxicity and therefore the environmental risk of a compound is related to bioavailability. In this project, experiments have shown that toxicants and organic enrichment interact strongly. Bioassays have indicated that the toxicity of a compound can be masked by suspended particles for eutrophic species like the midge Chironomus riparius (Chapter III). However, effects of interactions between organic enrichment and toxicants can differ between species. Some species may be able to benefit from organic compounds (like C. riparius), while other species may not. For example, the zebra mussel D. polymorpha was observed to be more sensitive to metal polluted river water than was expected from laboratory toxicity tests (Chapter IV). This implies that the relative sensitivities of species determined in laboratory toxicity tests may even be inversely related to their sensitivities to polluted river water. These observations suggest a strategy to evaluate a water system using chemically
defined water quality standards as well as direct biological assessments. Therefore, test species should be exposed to the total of compounds present in a river by incubating them in the river water (Chapters II-V).

The argumentation above leads to the conclusion that the selection of test species is crucial when assessing river water quality. An assessment should be based on the sensitivity of species which are representative for the river in question. A study on the river forelands of the River Waal (the main branch of the River Rhine in The Netherlands) indicated that the sediment was heavily polluted with oil. However, the selected test species were not sensitive to the contamination (Hendriks et al., 1997), while characteristic riverine species might have been. In the Meuse and Rhine, the waterflea *Daphnia magna* is currently used to monitor the water quality. However, this species does not occur in large rivers. Toxic effects on *D. magna* do not necessarily imply that indigenous species are affected, and vice versa. Therefore, it is suggested that when a specific water system is being evaluated, the sensitivity of representative species should be taken into account. The present study shows that caddisflies are suitable species for the rivers Meuse and Rhine.

Dutch standards for water quality are based on existing toxicity data, and are applied for all aquatic systems. The sensitivities of riverine species to toxicants are, however, seldomly tested in toxicity tests. Consequently, it is unknown which levels of toxicants would be hazardous for these species. To account for differences in sensitivity between species (including species that are not tested) the short-term water quality standard (Maximum Permissible Concentration: MPC) is extrapolated from the test results of standard laboratory toxicity tests by means of a statistical model with an arbitrary cut-off value set at a protection level of 95% of the species, or (in case only few toxicity data are available) by applying a standard safety factor on the most sensitive test result. To account for possible effects due to combination toxicity, a long term water quality standard (Target Value) is calculated as $1/100$ of the MPC (Van Leeuwen and Hermens, 1995). Therefore, the applied approach seems to be safe for the aquatic fauna in general, and it may even be argued that this system for setting water quality standards is overprotective. For example, the standard for diazinon is 0.4 ng/L (Anonymous, 1987), which is 3250 times below the 96 h LC$_{50}$ of diazinon for *Hydropsyche angustipennis*. However, Schulz and Liess (1995) found that emergence rates of caddisflies reduced after exposure to the insecticide lindane at concentrations below the Dutch “safe” standards. Ideally, water systems should be evaluated using regional standards, based on sensitivities of characteristic species. Since this may not be practical, an alternative would be to assess river water quality using existing standards and, if necessary, modify the evaluation using monitoring studies with characteristic species. This way, species that occur (or used to occur) in a specific water system are sufficiently protected, and environmental risks are not under- or overestimated.
Key species

The "AMOEBA" (A general Method Of Ecological and Biological Assessment) uses a number of selected animal and plant species to represent the present state and the future scenario of Dutch aquatic systems. The AMOEBA for rivers originally consisted of 12 vertebrates and 5 macroinvertebrates (among which the caddisfly Hydropsyche) (Admiraal et al., 1993), which are characteristic for a river ecosystem. Recently, adjustments have been made to this concept (Anonymous, 1996). The number of species has been enlarged, and a shift towards species which are more "appealing" has taken place. Currently, 90% of the selected animal AMOEBA species consists of vertebrates (birds, fish, mammals), and only 10% of invertebrates (one midge and one dragonfly species). This is peculiar, since it is being recognized that especially macrofauna communities are limited by the water quality of the River Meuse (Anonymous, 1996). This recognition, and the fact that the state and succession of macrofauna communities is relatively easy to monitor, lead to the premise that in particular macrofauna species are suitable for monitoring purposes. Based on this argumentation, and the observations made in this project (Chapter V), it is postulated that characteristic river insects like the caddisfly Hydropsyche are essential for monitoring ecological rehabilitation of the River Meuse, and therefore, these species should be added to the selection of AMOEBA species.

Summary of the recommendations

- River water quality should be assessed using characteristic riverine species, so that species that occur (or used to occur) in this water system are sufficiently protected, and environmental risks are not under- or overestimated. Ideally, this holds for monitoring studies as well as for the setting of water quality standards.
- Characteristic river insects like the caddisfly Hydropsyche are essential for monitoring ecological rehabilitation of the River Meuse, and therefore, these species should be added to the selection of AMOEBA species.
- Investments made to improve the water quality of the River Meuse, should focus on the prevention of incidents, next to the efforts to improve the "overall" water quality.
- Because of the interaction of organic enrichment and toxicants a coordinated reduction of both groups of pollutants is recommended.
- The prevention of unnaturally strong water discharge fluctuations due to water abstractions (by hydro-electric power stations) should be included in environmental plans.
References


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