Persistence of benthic invertebrates in polluted sediments.

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SUMMARY

The successful exploitation of sediments by benthic invertebrates is affected by numerous variables, such as grain size distribution, food availability, predator abundance, competition, and the amount of toxicants. Because the species-specific requirements or tolerances for these variables are often known incompletely, it remains difficult to identify the causes for the presence and absence of individual species. This thesis aimed, therefore, to explain the persistence of benthic invertebrate species in polluted sediments. Two benthic invertebrates species, the mayfly *Ephoron virgo* and the midge *Chironomus riparius*, with different life history characteristics and tolerances towards toxicants were selected. The specific responses of the model species to environmental variables and their biotic interactions were investigated using bioassays and it was evaluated how these responses determine the persistence of benthic invertebrates in polluted sediments.

The responses of the two models species, the mayfly *E. virgo* and the midge *C. riparius*, to natural sediments with different levels of food quality and contaminants were assessed in whole-sediment bioassays (CHAPTER 2). Seven floodplain lakes located along the River Rhine, with different levels of contamination and trophic state were selected and the species-specific preferences for these sediments were assessed using 10-day whole-sediment bioassays with both species and a 28-day emergence experiment with *C. riparius*. The two model species responded completely different. Survival and growth rate of *E. virgo* were severely affected by the sediment-bound toxicants, independent of the food quality in the sediments. In contrast, survival of *C. riparius* was only slightly affected and in highly nutritive sediments high growth rates of *C. riparius* coincided with a short time to emerge, in spite of the toxicants present. Additional feeding resulted in higher growth rates and a shortening of the time to emerge, especially in the low nutritive sediments. These results demonstrated that the trophic state of an ecosystem influences the ecological risk of toxicants to benthic invertebrates in a species-specific way.

In CHAPTER 3, the combined effect of food availability and a model toxicant, copper, on the midge *C. riparius* was analyzed. Survival, length, and dry weight of *C. riparius* and the accumulation of copper in the larvae were determined after 10 days exposure to copper and food spiked sediments in the laboratory. Lower survival and growth rates were observed at higher copper concentrations.

Elevated food suppressed the negative effects of copper on survival. And higher food levels also resulted in higher growth rates, until copper concentrations reached a critical threshold. Higher food levels resulted also in lower copper accumulation in the larvae. These results demonstrated that the combination of copper and food in the sediment determines the performance of *C. riparius* in whole-sediment bioassays. Moreover, *C. riparius* is not necessarily very tolerant to copper, but the higher food availability prevailed against the potential adverse effects of contaminants.

CHAPTER 4 examined the selection of sediments differing in food quality and toxicant levels by *C. riparius* larvae. The preference of *C. riparius* larvae was assessed using 10-day choice experiments in which the larvae could choose between two different sediments. The larvae showed a clear preference for sediments with higher food quality, which overruled the avoidance of sediments with higher toxicant concentrations. Thus, the food quality in sediments is the main driving force in the selection of a suitable habitat by *C. riparius* larvae, even if this leads to the exposure to toxicants.

In CHAPTER 5 it was examined whether sediment reworking by one of the two model species, the midge *C. riparius*, affected the performance of the other model species, the mayfly *E. virgo*. Different amounts of bioturbating *C. riparius* larvae were added to clean and polluted sediment populated with nymphs of *E. virgo*. Changes in water quality and sediment properties, and the responses of the mayfly *E. virgo* were assessed after 7 days. Chironomids increased the concentrations of metals, nutrients, and particles in the overlying water, and made oxygen penetrate deeper into the sediment. The survival and growth rates of *E. virgo* were strongly reduced in the presence of chironomids, especially in the clean sediment, where the chironomids were frequently observed outside their tubes. This suggested that the reduced performance of *E. virgo* was directly caused through the disturbance by *C. riparius* rather than by lowered water quality, overruling the potential positive effects of improved oxygen penetration. These results imply that the distribution of small insects, like *E. virgo*, can be limited by disturbance of burrowing invertebrates.

Finally, it was analyzed whether the responses of *C. riparius* in laboratory and *in situ* bioassays matched with the persistence of opportunistic chironomids in the field (CHAPTER 6). Benthic invertebrate species in historically polluted sediments, differing in toxicant level and food quality, were sampled and enumerated. Survival, growth, and frequency of mentum deformities of the *C. riparius* larvae were assessed in 10-day *in situ* and laboratory bioassays. In the sediments with higher contaminant levels, higher densities of chironomids were observed. The laboratory bioassays confirmed that the contaminant concentrations in these sediments had no effect on survival and growth rates of *C. riparius*, although higher incidences of mentum deformities were observed at higher pollution levels. The high growth rates in the *in situ* enclosures in two of the three highly polluted sediments indicated that chironomids were able to exploit these polluted sediments. Yet, the positive relation between growth rate of *C. riparius* and nutritional value of the sediments in the laboratory bioassays suggested that higher densities of chironomids might have been present in sediments with high food quality. However, in these sediments with high food quality (and low levels of contaminants) the chironomids may have suffered from competition or predation by taxa that were not able to persist at the more polluted sites. The *in situ* bioassay pointed out that predation on chironomids in the field enclosures was significant. Thus, the wide range of ecological tolerance of chironomids, such as *Chironomus* sp., combined with their rapid rate of development, enabled them to exploit polluted habitats where competition with other invertebrates is limited.

In the concluding remarks (CHAPTER 7), the species-specific responses of the two model species to several environmental variables and biotic interactions were compared. The different responses of the two model species indicated that the long-term persistence of these benthic invertebrate species under specific conditions is bound to a set of characteristics and is unlikely to be determined by single traits. Yet, this was the case in the present thesis: it was demonstrated that the pollution level in some floodplain lake sediments of the River Rhine alone is already prohibitive for benthic insects with the sensitivity of *E. virgo*. In most cases, however, a combination of conditions determines the persistence of benthic invertebrates in polluted sediments. These combined effects may cause limiting conditions to indirectly promote certain benthic invertebrate species, as was shown for *C. riparius*. Even though sediment pollution drives this species close to intoxication, the high availability of food, caused by the exclusion of less tolerant species, enables them to persist very well.

Finally, the implications for environmental management were discussed. Comparing standardized sediment-bound toxicant concentrations with current sediment quality guidelines indicated that in some sediments tested in the present thesis, the minimum sediment quality is exceeded. In these sediments survival and growth rates of the mayfly *E. virgo* were severely affected. And although no effects were observed on survival rates of *C. riparius* larvae in chronic whole-sediment bioassays, a high incidence of mentum deformities was observed in these sediments. Thus it has been shown in the present thesis that concentrations of sediment-bound toxicants close to minimum sediment quality can be responsible for distinct effects on benthic invertebrates. The mortality of the mayflies and the elevated incidence of mentum deformities of the midge were clearly observed also in some sediments with concentrations of toxicants below MPCs. Consistently, sensitive benthic invertebrate species, such as mayflies and caddisflies, were observed only in one of the investigated floodplain lakes. The present study provides evidence that current MPCs may still pose a detectable ecological effect at least for sensitive benthic invertebrates.