REVIEW OF IMPACT OF HEAVY METALS ON STREAM INVERTEBRATES WITH SPECIAL EMPHASIS ON ACID CONDITIONS

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Abstract. Studies of the accumulation and toxicity of Cd, Zn, Fe, Pb and Cu under acid conditions to stream invertebrates are reviewed. The influence of pH on metal speciation decreases in the following order: Cu > Pb > Cd > Zn. The free metal ion is one of the most toxic species and is generally taken up directly from the water by organisms. The role of food in the uptake of metals depends mainly on feeding habits of the species, body size, life span and duration of the exposure. Surface adsorption can be regarded as a form of metal 'uptake' which increases at high pH. Biomagnification of metals along aquatic trophic food chains has not been proved for many metals. Toxicity of Cd, Fe, Zn and Pb increases at low pH, however not for all invertebrates. More knowledge is needed concerning sublethal effects of metals on invertebrates at different pH values and uptake, bioconcentration and biomagnification of metals at different pH values. Future studies should include experiments in artificial streams or in the field instead of short term tests and simple recording of field data.

1. Introduction

Acidification of surface waters has been an environmental problem in Europe and North America for several decades and new areas like in China and the developmental countries are threatened (Galloway, 1989). The present state of our knowledge about the origin and the effects of acidification on aquatic organisms, mainly fish and Crustacea has been summarized in several books and reviews, (e.g. Monitor, 1986; Morris et al., 1989; Overrein et al., 1988; Schindler et al., 1988; Wren and Stephenson, 1991). Physiological studies were performed to explain the observed decrease in species diversity in acidified waters, revealing that ion regulation is disturbed by H\(^+\) and Al\(^{3+}\) ions, which were elevated in acid water (e.g. Havas et al., 1984; Havas and Likens, 1985; Herrmann, 1987). This led to the investigation of other metals in acidified lakes and a ‘comeback’ of metal toxicity studies, which so far had been mostly acute toxicity tests (LC\(_{50}\)) at neutral pH. Knowledge on the combined effects of low pH and metals on freshwater invertebrates is still very scarce, especially studies in running water ecosystems with stream invertebrates.

Several reviews summarize current knowledge on the effects of metals in freshwater. Luoma (1983) discussed the processes that control bioavailability on a theoretical basis. LaZerte (1986) reviewed studies about the sources and sinks of metals in lakes and soils with emphasis on the role of pH. Campbell and Stokes (1985) presented a comprehensive review on metal speciation, adsorption on biological surfaces and uptake in and toxicity to aquatic biota under acid and neutral conditions. Data
The aim of this review was to concentrate on summarizing current knowledge on the effects of pH on metal speciation, uptake by, adsorption on and toxicity to stream invertebrates. Only if information on stream invertebrates was lacking, other studies were discussed. Stream invertebrates were chosen because they are important food organisms for aquatic (Pisces, Coleoptera, Plecoptera) and terrestrial (Aves, Odonata) predators and they are important decomposers, being responsible for the first steps of recycling of organic matter and energy. They often link the aquatic and terrestrial environment as they need both environments to complete their life cycle. The knowledge on acidification and metals in lakes cannot be transferred to streams because these two ecosystems differ in fundamental characteristics like time for renewal of the waterbody, contact zones between the water and sediment and the water and air as well as the role of planktonic and benthic organisms in the ecosystem.

The following metals were chosen: Cd, Cu, Fe, Pb and Zn. They fulfill the criteria set up for this review: There is some information about (1) pH dependent availability in the water and (2) pH dependent toxicity to freshwater organisms. Al was not included because of the comprehensive information and reviews in the literature (Herrmann, 1987). For metals like Ni and Mn almost no information was available and metals like Hg are not likely to cause pH dependent changes in uptake and toxicity because they occur mostly as metalorganic compounds.

To obtain a complete survey of the published literature, a systematic online bibliography was set up from 1970 to 1989. The following databases have been used: Biological Abstracts, Conference Proceedings Index, Dissertation Abstracts, Pollution Abstracts, Toxicology Abstracts, Ufordsdat and Uolidat. For the recent literature Current Contents for the Environmental Sciences was used. Using several synonyms, it was asked after streams, invertebrates (and different taxa), acidification and the above mentioned metals.

2. Metal Speciation

The term ‘metal species’ is used here as the molecular representation of a physicochemical form of an element (Bernhard et al., 1986). Metal species can be grouped into different phases, e.g. the aqueous phase (free ionic species and soluble complexes), the solid phase (colloids, particles) and the biological phase (adsorbed to biological surfaces or incorporated in cells) (Flemming and Trevors, 1989). Metal speciation, partitioning and its bioavailability depend on several circumstances (Figure 1, Gerhardt, 1990b). These can be either physicochemical factors e.g. tem-