Canadian Network of Toxicology Centres
Metals In The Environment
Research Network

SCIENCE BRIEF (June 2004)

PREDICTING METAL EFFECTS ON AQUATIC ORGANISMS

ISSUE

Metals can enter aquatic environments in a chemical form, or species, which may or may not be bioavailable and toxic. And, once in the water column, metals can change into different forms depending on the site-specific conditions. Whether metals in waterbodies are actually bioavailable and toxic depends not only on their form but also on interactions with biological receptor sites ("biotic ligands") on sensitive aquatic animals such as fish and crustaceans, and on competition with natural substances in the water that may minimize or even eliminate bioavailability and thus toxicity. Because predicting effects of metals on aquatic systems has been, at best, problematic, regulatory approaches have tended to involve the Precautionary Principle, generally resulting in a high level of overprotection.

SIGNIFICANCE

This research has greatly advanced the scientific basis for predicting the effects of metals to aquatic organisms. Specifically, it has provided information for refining the existing Biotic Ligand Model (BLM) for predicting acute effects (death). It has also provided the basis for developing chronic BLMs for copper, cadmium and zinc to protect against effects on, for instance, growth and reproduction. The cost-effective BLM approach to predicting metal toxicity provides better environmental protection than presently exists, eases the regulatory burden for industry and, as precautionary approaches do not need to be applied, helps protect the internal and export markets for Canadian (and other) metal producers.

BACKGROUND

The Biotic Ligand Model (BLM) provides a mechanistic basis for predicting the acute toxicity of water-borne metals to aquatic biota. The BLM is based on toxicity occurring when the metal concentration bound to a cellular "site of action" (termed a "biotic ligand", for example salt transport cells in fish gills) exceeds a critical concentration. The model is presently based on a limited selection of animal species that are best characterized as “laboratory white rats”. These test species were chosen because they are very sensitive to metals, but they do not necessarily represent the range of species found in Canadian waters.

The BLM predicts that metal uptake by aquatic animals from water is directly proportional to the concentration of bioavailable metal that can potentially bind to biotic ligands, and that uptake can be reduced proportionally by increasing concentrations of substances that compete with metals for cell binding sites. The model was developed under controlled laboratory conditions with a limited number of test species and with a very limited amount of field validation data, and initially did not consider chronic toxicity. A separate BLM is required for chronic toxicity because there is no mechanistically or widely-applicable method to extrapolate from acute effects (death) to chronic effects.

Increasing the predictive ability of the present acute and future chronic BLM requires two major adjustments. First, because there is increasing evidence that diet is a more important source of metals for some aquatic organisms than water, dietary uptake must be considered. Second, the BLM must be extended beyond the current “laboratory white rats” to other species, especially those of importance in Canada.

FINDINGS

This research, carried out through the Metals in the Environment Research Network (MITE–RN) program, has demonstrated mechanistically how different environmental conditions (e.g., water chemistry, diet) and acclimation can produce dramatic changes in the metal binding properties of animal cells and thus in metal toxicity to those animals. Studies have involved both “laboratory white rats” such as rainbow trout and water fleas, and the common but previously unstudied yellow perch, a fish that survives in lakes moderately contaminated with metals. The BLM approach has helped us understand the differences in the gill cells of perch that provide this tolerance. Another significant finding is that diet can provide protection from metal toxicity. In cadmium and/or zinc contaminated environments, fish eating crustaceans or mollusks may gain protection from toxicity due to these metals because of the increased calcium in their diet. Calcium is one of the substances that compete with metals for biological binding sites. Similarly, dietary sodium reduces copper binding to fish gills. Overall, this research has provided necessary information to refine the acute BLM, for both sensitive and more tolerant species, in both laboratory and natural environments. And it has provided a sound mechanistic basis for the development of a chronic BLM.

CONTINUING RESEARCH

Ongoing research focuses on further refining the acute BLM (e.g., applying it to an even wider range of conditions and organisms), and on further developing a chronic BLM applicable to all metals and to a similarly wide range of organisms and environmental conditions. The primary focus of continuing research is on understanding and modeling the effects of metals (in particular copper, cadmium and zinc) on the health of aquatic animals in the natural environment.

ADDITIONAL INFORMATION

Overview Information

S. Niyogi and C. M. Wood. 2003. Effects of chronic waterborne and dietary metal exposures on gill metal-binding: Implications for the biotic ligand model. Human and Ecological Risk Assessment, volume 9, number 4, pages 813 to 846.

http://www.mite-rn.org/research/era/era.shtml

Other Information

Extensive publications in the peer-reviewed literature. For details, contact Dr. Chris Wood woodcm@mcmaster.ca