Environment Agency

Evidence

Ecological indicators for abandoned mines, Phase 1: Review of the literature

Project summary SC030136/S49

Waters released from abandoned mines are a major issue for river basin management under the Water Framework Directive. These waters are of concern because they can damage aquatic life such as fish, invertebrates and plants, and cause rivers to fail environmental quality standards (EQS) for metals (particularly cadmium, lead, zinc, copper and iron). However, EQS may be overprotective of aquatic ecosystems which may have adapted over centuries of exposure to metals.

This report forms part of a larger project to investigate the ecological impact of metals in rivers, and to develop water quality targets for aquatic ecosystems that are affected by long-term mining pollution. This report reviews the available literature on EQS failures, metal effects on aquatic biota, and the effects of water chemistry, and considers further research that might be carried out to address the problem.

A preliminary assessment of water quality and biology data for 87 sites across Gwynedd and Ceredigion (Wales) shows that Environment Agency water quality and biology data could be used to establish statistical relationships between chemical variables (such as pH and water hardness) and metrics of ecological quality (measures of ecological health). Preliminary analyses show that invertebrate diversity declines with increasing zinc concentrations in water. However, the situation is more complex because the effects of other metals are not readily apparent. Furthermore, pH and aluminium also affect streamwater invertebrates, making it difficult to establish the exact toxicity of individual mine-derived metals.

The most characteristic feature of aquatic plant communities in metal-impacted ecosystems is less diversity compared to plants in unaffected streams. Some species thrive in the presence of heavy metals, presumably because they are able to develop metal tolerance, whilst others disappear. Effects are, however, confounded by water chemistry, particularly pH.

Tolerant species are spread across a number of divisions of photosynthetic organisms, though green algae, diatoms and blue-green algae are typically the most abundant, often thriving in the absence of competition and/or grazing. Current UK monitoring focuses on community composition which may not be sensitive enough to reflect the impacts of metals. There is scope for developing new metrics, based on community-level analyses and for looking at morphological variations that are common in some species at higher metal concentrations. On the whole, community-based metrics are recommended, as these are easier to relate to ecological status.

With respect to invertebrates and fish, metals affect individuals, populations and communities but sensitivity varies among species, life stages, sexes, trophic groups and with body condition. Possible acclimation or adaptation may cause some organisms to be less sensitive to metals than others, even within the same species. Ecosystem-scale effects, for example on ecological function, are poorly understood.

Effects vary between metals such as cadmium, copper, lead, chromium, zinc and nickel in order of decreasing toxicity. Aluminium is important in acidified waters. Biological effects depend also on speciation (the different chemical forms of the metal), toxicity and availability of the metal, mixtures of metals, complexation of the metal by organic matter and exposure conditions.

Current water quality monitoring is unlikely to detect short-term increases in metal concentrations or evaluate the bioavailability of metals in sediments. These factors together create uncertainty in detecting ecological damage in metal-impacted ecosystems. Moreover, most widely used biological indicators for UK freshwaters were developed for other pressures and none distinguish metal impacts from other causes of damage.

To better regulate and manage our rivers, we need:

i) models for relating metal data to ecological data that better represent influences on metal toxicity;
ii) biodiagnostic indices to reflect metal effects;
iii) better methods to identify metal acclimation or adaptation in sensitive species;
iv) better investigative procedures for isolating metal effects from other pressures.

Laboratory data on the effects of water chemistry on the toxicity and bioaccumulation of metals in aquatic organisms show that a number of chemical parameters, particularly pH, dissolved organic carbon (DOC) and major cations (sodium, magnesium, potassium and calcium) exert a major influence on the toxicity and/or bioaccumulation of cationic metals (such as copper). The biotic ligand model (BLM) provides a framework for understanding these water chemistry effects as a combination of the influence of chemical speciation, and metal uptake by organisms in competition with hydrogen ions and other cations. In some cases where the BLM cannot accurately describe these effects, empirical bioavailability models have been successfully used. Laboratory data on the effects of metal mixtures in different water conditions are sparse, with implications for transferring understanding to mining-impacted sites where a number of metals are likely to be present.

The available field data, although sparse, shows that water chemistry influences metal effects on aquatic ecosystems. This occurs firstly through complexation reactions, notably involving dissolved organic matter and metals such as aluminium, copper and lead. Secondly, because bioaccumulation and toxicity are partly governed by complexation-type reactions, competition effects among metals, and between metals and H^+, are dependent on water chemistry. There is evidence that combinations of metals are active in the field; the main study conducted so far has found a combined effect of aluminium and zinc, and possibly copper and hydrogen (pH). Chemical speciation, that is the presence of a metal in different forms, is essential to interpret and predict observed effects of metal damage in the field. Speciation needs to be combined with a model that relates free metal ion concentrations to toxic effect. Understanding the toxic effects of heavy metals from abandoned mines requires the simultaneous consideration of the acidity-related components aluminium and hydrogen.

There are a number of reasons why organisms in waters affected by abandoned mines may experience different levels of metal toxicity than in the laboratory. This could lead to discrepancies between actual behaviour in the environment and that predicted by EQS derived from laboratory experiments. The main factors to consider are adaptation/acclimation, water chemistry, and the effects of combinations of metals. Secondary effects include metals in food, metals supplied by river sediments, and variability in stream flows.

Two of the most prominent factors, namely adaptation/acclimation and bioavailability, could justify changes in EQS, or the adoption of an alternative measure of toxic effects in the environment. Given that abandoned mines are widespread in England and Wales, and the high cost of their remediation (clean up) to meet proposed EQS criteria, further research is clearly needed.

Although ecological communities of mine-affected streamwaters might be overprotected by proposed EQS, there are clearly some conditions under which metals from abandoned mines exert toxic effects on biota. The main issue is therefore the reliable identification of chemical conditions that are unacceptable and comparison of those conditions with those predicted by EQS. If major differences can convincingly be shown, alternative standards might be needed for waters affected by abandoned mines. To help us establish whether different EQS are needed for such waters, we need more measurements/studies of metal effects under field circumstances (near mining sites). Identifying dose-response relationships between metal levels and effects on organisms, based on metal mixtures and their chemical speciation, and employing better biological tools to detect and diagnose community-level impairment, would provide the necessary scientific information.

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