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Impacts of Metals and Mining on Stream Communities

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INTRODUCTION

Studies on the effects of metal contamination on freshwater biota are well advanced in Europe and North America, but they are still in their infancy in New Zealand. One reason for this lag in research is probably the result of the relatively few sources of metal contamination in New Zealand. The primary sources of anthropogenic metal contamination in our waterways are from drainage associated with mining activities (see Chapters 9 – 13), stormwater from urban and industrial areas and seepages from landfills (see Chapter 8). New Zealand has little large-scale heavy industry (with the exception of the Bluff aluminium smelter and several pulp and paper mills), and thus few obvious metal contamination issues. However, an ignorance of the persistence of metals associated with light industry, vehicles and construction (e.g., paints) in urban areas has meant that these have remained hidden issues, until recently (Suren, 2000). In contrast, coal and gold mining have long been recognised as significant sources of metal contamination in parts of New Zealand.

Baseline information on metal concentrations in New Zealand freshwaters is sparse, and a national review of heavy metals in aquatic systems by Smith (1986) indicated that although inadequate data existed to assess metal levels it did not appear that New Zealand had a major metal problem.

A significant portion of the heavy metal problem in New Zealand streams is associated with mine drainage from historic and current coal and gold mining operations. Much of the Coromandel Peninsula, Central Otago and parts of the West Coast of the South Island have been subjected to long-term mining activities. Recent reviews by Harding et al. (2000), and Harding and Boothroyd (2004) have summarized our understanding of the effects of acid mine drainages and the associated release of metals on our inland waters. In most cases existing studies of mine-impacted systems have either not attempted to separate the effects of metals from pH, or have found the complex interactions too difficult to tease apart.

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Where they occur, heavy metals are pollutants of considerable concern because they are not usually eliminated from aquatic ecosystems by natural processes. Instead, they are either accumulated in sediments or biota, or transported to other ecosystems (e.g., from the land to streams by stormwater runoff). Thus, metals such as arsenic, cadmium, chromium, copper and mercury frequently accumulate in aquatic plants and in river and lake sediments, and some of these elements can be remobilised and incorporated into food webs. Some metals such as mercury (Hg) can bioaccumulate within food webs (Goodyear and McNeill, 1999), and affect the physiology, growth and reproduction of organisms at multiple trophic levels (Kelly, 1988). In contrast, other metals such as aluminium (Al) and iron (Fe) do not seem to bioaccumulate up food chains, as found by Winterbourn et al. (2000) in one of the few New Zealand investigations of metal accumulation in stream communities.

In this chapter the biota of New Zealand freshwaters is introduced, and the effects of metal toxicity on freshwater organisms discussed. This is followed with a review of toxicological and field studies relevant to New Zealand that provide us with some understanding of how metals affect our freshwater communities, and the chapter concludes with comments on gaps in our understanding of metal and mine effects on the biota.

BIOTA OF NEW ZEALAND FRESHWATERS

Aquatic plants in the form of algae, bryophytes (mosses and liverworts), and macrophytes are commonly found in New Zealand waterways. Algae (or periphyton), are ubiquitous throughout New Zealand rivers and lakes, and detailed reviews of their distribution and taxonomy are given by Biggs (2000) and Biggs and Kilroy (2000). Some algae are highly acid tolerant, and species such as *Ulothrix* sp., *Microspora* sp., and *Tribonema* sp., can dominate mine discharges (Winterbourn et al., 2000) (Fig.1). Bryophytes require highly stable substrates and are frequently found on bedrock and in shaded streams. They can occur in highly acidic systems with high metal concentrations. In contrast, macrophytes commonly occur in slow-flowing lowland streams, springs and standing waters, and are usually absent from acidic streams. Both bryophytes and macrophytes frequently accumulate metals, and several reviews have assessed their effects on plant communities (e.g., Crowder, 1991).

New Zealand's streams, rivers and lakes are home to a diverse and globally unique aquatic fauna that includes approximately 660 described invertebrate species and some 59 freshwater fish species (McDowall, 2000; Harding, 2003). Of the invertebrates, the majority are insects; primarily mayflies (Ephemeroptera), stoneflies (Plecoptera), caddisflies (Trichoptera) and true flies (Diptera), while common non-insects include crustaceans, snails (Mollusca) and worms (Oligochaeta). The early isolation of New Zealand coupled with a history of glaciation, volcanism, folding and faulting created exceptional opportunities for speciation and the evolution of a biogeographically distinct biota (Boothroyd 2000). Consequently, about 90% of our invertebrate species are endemic, and numerous insect families commonly found elsewhere (e.g., Baetidae, and Caenidae mayflies, Perlidae, Perlodidae and Leuctridae stoneflies and Limnephilidae caddisflies) are absent. In contrast, the caddisfly family Hydrobiosidae, stoneflies of the subfamily Antarctoperlinae, and the non-biting chironomid midges are highly speciose (Boothroyd, 2000). Not surprisingly, this

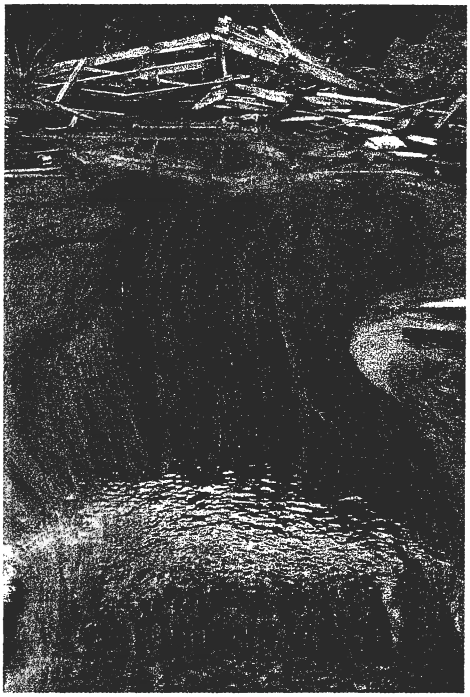

FIGURE 1. Filamentous algal mats associated with the Escarpment mine adit (pH 3, dissolved Fe 33 mg l^{-1}, dissolved Al 12.5 mg l^{-1}) on the Denniston Plateau, West Coast.

diversity within some groups is associated with regions of freshwater endemism, which include Banks Peninsula, the West Coast of the South Island, Nelson-Marlborough, Otago and North Auckland (Craig, 1969; Cowley, 1978; Harding, 2003).

Despite the high level of regional endemism numerous invertebrate species are widely distributed throughout New Zealand. The commonest of these include species of the leptophlebiid mayfly genus *Deleatidium*, a collector-browser, which feeds on diatoms and fine detritus in flood-prone and stable streams and rivers throughout the North, South and Stewart Islands. Mayflies are common in New Zealand streams, and although members of the order (Ephemeroptera) are generally considered to be highly susceptible to pollution, recent surveys indicate that some species of *Deleatidium* may be able to tolerate moderate levels of metal toxicity (Winterbourn et al., 2000). Another common group of insects that is also relatively intolerant of pollution are stoneflies (Plecoptera), however, on the West Coast of the South Island some species of *Spaniocerca*, and *Spaniocercoides*, and possibly other genera are tolerant of low pH and moderate-heavy metal concentrations (Winterbourn, 1998; Winterbourn et al., 2000; J.S. Harding, unpublished data). Caddisflies can also be abundant in New Zealand streams and rivers, particularly the free-living Hydrobiosidae (e.g., *Hydrobiosis* and *Psilochorema*) (Fig 2.) and the cased Conoesucidae (e.g., *Olinga*, *Pycnocentria*, and *Pycnocentrodes*). Internationally, caddis are frequently used as sentinel organisms for metal pollution (see review by Johnson et al., 1993), and although stony-cased caddis are usually absent from heavy metal and mine-impacted streams in New Zealand some free-living species, notably *Psilochorema* spp., are not

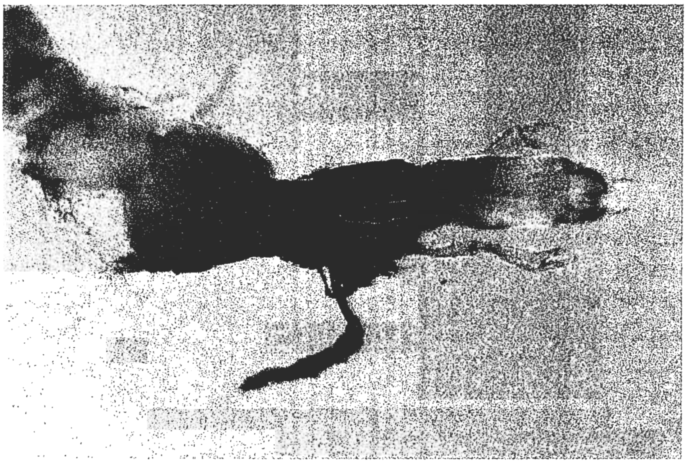

FIGURE 2. Larvae of the caddis *Psilochorema* (Hydrobiosidae) with black spots (lesions) and abnormalities, collected from below an abandoned gold mine in Carton Creek, Reefton.

uncommon in such habitats (J.S. Harding, unpublished data). The hydrobiid mudsnail *Potamopyrgus antipodarum*, a grazer that feeds on algal, bacterial and fungal films and fine detritus is another widely distributed invertebrate in New Zealand, although principally in low-gradient, moderately enriched river systems. It is intolerant of low pH, which can decalcify its shell, but snails seem able to maintain viable populations in metal-polluted urban streams (Blakely et al., 2003). Among the true flies Chironomidae are common and abundant in many in New Zealand waterways, and several species can tolerate organically polluted and metal contaminated environments. More detailed descriptions of the ecology and habitats of New Zealand invertebrates can be found in Collier and Winterbourn (2000), Harding et al. (2004) and references therein.

In contrast to the invertebrates, the New Zealand freshwater fish fauna is relatively depauperate (with 59 species, including introduced ones), although recent collecting and advances in DNA techniques result in biologists increasing the number of described species. Many of our freshwater fish are diadromous (migratory) and require access to the sea to complete some parts of their life cycles (McDowall, 1990). As a result, many species do not migrate far inland (i.e., <50 km). Notable exceptions are the koaro (*Galaxias brevipinnis*), shortfin eel (*Anguilla australis*) and longfin eel (*Anguilla dieffenbachii*), that travel significant distances inland. Koaro have rarely been found in acid or metal-polluted systems, and seem to be restricted to relatively pristine waters. However, eels tend to be highly tolerant of organic pollution, and have been recorded in urban streams where heavy metals have been detected (McMurtrie and Taylor, 2003). They appear to be the fish species most likely to be found in metal or acid-impacted systems. Naturally low pH streams are common on the West Coast of the South Island, and several species, notably the inanga (*Galaxias maculatus*), banded kokopu and giant kokopu (*Galaxias fasciatus* and *G. argenteus*, respectively) seem well adapted to these conditions (Collier et al., 1990). In these naturally low pH waters (pH 4 - 6) potentially toxic Al is bound to dissolved organic carbon greatly ameliorating its toxicity (Collier et al., 1990).

New Zealand has two species of freshwater crayfish, one of which, *Paranephrops planifrons* is frequently found in naturally low pH, brown waters on the West Coast, but has rarely been found in metal or mine-impacted systems. Several frog species are also associated with New Zealand waterways, although they prefer standing water habitats such as temporary pools, ponds and lakes, and are less likely to occur in metal-impacted regions.

METALS AND STREAM BIOTA

Overview

It is well known that trace amounts of certain metals can have both positive and negative effects on biota. These trace metals, which include sodium, potassium, magnesium, calcium, manganese, iron, cobalt, copper, zinc and molybdenum are present in varying concentrations in all living tissues, and are essential if an organism is to grow and metabolise, successfully (Kelly, 1988). The loss or removal of trace metals from an organism results in impaired biochemical functioning, whereas an oversupply will frequently have toxic effects (Fig. 3; see also Chapters 2 and 7).

Metal ions used by biota must be naturally abundant and readily available in a soluble form. Furthermore, they need to be present in an appropriate form as their toxicity is less dependent on the total amount of metal present as on the particular metal species, e.g., Al^{3+} is more toxic to many freshwater organisms than Al^{2+} (Crowder, 1991).

The effects of metal toxicity on invertebrates is complex, and varies markedly from taxon to taxon. Some species are able to develop a degree of tolerance to heavy metals, through physiological acclimation or genetic adaptation (Le Blanc, 1985; Clements, 1999) but other species do not. Numerous experimental studies have also shown that taxa can differ in sensitivity to toxins depending on their life history stage. For example, juveniles of the hydrobiid gastropod *Potamopyrgus antipodarum* were sensitive to 54 µg l-1 (96 h LC50) copper, whereas adults tolerated concentrations of 79 µg l-1 (Watton and Hawkes, 1984). Similarly, early instars of a chironomid midge *Chironomus tentans* tolerated 12-27 times higher concentrations of copper than late instar larvae (Gauss et al., 1985).

Experiments with the zooplankter *Daphnia magna* showed that when given short-term exposure to copper (ranging from 10 to 30 µg l-1) it was able to survive

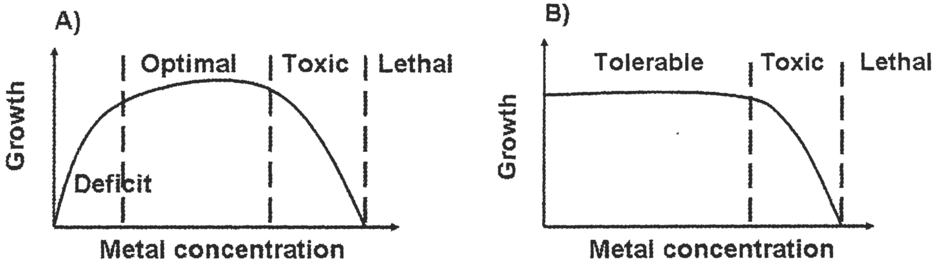

FIGURE 3. Model of deficiency and oversupply of a) essential and b) non-essential metals (after Förstner & Wittmann, 1981).

and out-compete its usually more successful conspecific *D. pulex* (LeBlanc, 1985). Le Blanc suggested that *D. magna* might have evolved the capability to synthesize copper-binding metallothionein. Metallothionein may act to regulate copper metabolism, thus rendering it non-toxic within the organism. In a similar vein, Clements (1999) found that the nymphs of two mayflies species *Baetis tricaudatus* and *Rhithrogena hageni*, which had already been exposed to chronic levels of Cd, Cu and Zn, survived better and were less inclined to drift than nymphs that had not been exposed previously to the pollutants.

Some invertebrate taxa are able to detect potentially toxic heavy metal concentrations and respond to their threats. For example, McMurtry (1984) observed that the oligochaetes *Tubifex tubifex* and *Limnodrilus hoffmeisteri* both attempted to avoid sediments contaminated with zinc and copper and selected uncontaminated sediment over metal-contaminated sediment in choice experiments. Similarly, Clements (1999) exposed the nymphs of *Rhithrogena hageni* from a pristine stream to metal contaminated water, and found that mayfly drift rates increased four fold.

The physiological effect of heavy metals can be highly variable. Exposure to chronic concentrations of nickel (5 µg l-1) and copper (2 µg l-1) caused *Daphnia magna* to decline in fecundity, slowed maturation and reduced the size and number of eggs (LeBlanc, 1985). The shrimp *Macrobrachium carcinus* showed reduced respiration rates and ammonia excretion when exposed to toxic levels of copper and zinc, resulting in reduced ratios of oxygen to nitrogen in the blood (Correa, 1987) and led Correa to suggest that sublethal concentrations of zinc and copper might inhibit gill permeability. Furthermore, Anderson (1978) found that high concentrations of lead denatured mucus normally present on the gills of crayfish reducing protection of the respiratory epithelium. Exposure to sublethal levels of cadmium also resulted in physical damage to a species of hydropsychid caddis, which lost anal papillae and gills (Vuori, 1994), while Petersen and Petersen (1983) found anomalies in the construction of hydropsychid nets after exposure to heavy metals. These territorial caddis larvae also changed their behaviour radically by spending less time being aggressive towards conspecifics when exposed to cadmium, possibly as a result of impaired respiration from gill damage. Finally, in several studies metal toxicity has been shown to alter interactions between species by reducing competition, or making them more susceptible to predation (Petersen and Petersen, 1983; Clements et al., 1989).

Metal toxicity in streams

The documentation of high heavy metal concentrations in water is frequently difficult as levels often fluctuate rapidly making the detection of spikes problematic. Furthermore, a small increase in the concentration of metals in water may lead to a significant increase in uptake by organisms. An additional complication is that analysis of total metals gives an inadequate indication of both the availability of a metal for uptake and its toxicity under conditions occurring in the waterway.

Changes in pH have a direct effect on metal speciation, and on the moderating effects of water hardness and organic substances. Some metals (e.g., iron and aluminium) go into solution or form precipitates when stream water pH reaches specific thresholds, a phenomenon that is well documented (Elangovan et al., 1997) (Table 1).

Table 1. Minimum pH values for precipitation of metal ions as hydroxides (modified from Kelly 1988 and Niyogi et al. 1999)

Metal	Minimum pH	Metal	Minimum pH
Sn	4.2	Zn	8.4
Fe 3+	3.5 - 4.3	Ni	9.3
Al	4.9 - 5.4	Fe 2+	9.5
Pb 2+	6.3	Cd	9.7
Cu 2+	7.2	Mn 2+	10.6

Organisms accumulate toxic metals via three main pathways:

i) through respiration, i.e., either across gill or skin surfaces
ii) by adsorption onto the body surface
iii) through the ingestion of food items, and in which heavy metals have already accumulated.

Levels of metal accumulation can be influenced by the trophic position of the organism (e.g., primary consumer or top carnivore), although not all metals bioaccumulate along food chains. A review by Wren and Stephenson (1991), for example, indicated that among mercury, lead, aluminium and cadmium, only mercury bioaccumulated in aquatic food chains. Metals such as iron and aluminium are common in mine drainages, however, in general neither seem to bioaccumulate (Goodyear and McNeill, 1999; Winterbourn et al., 2000). However, Elangovan et al. (1997) suggested that the freshwater snail *Lymnaea stagnalis* may accumulate Al in its gut, digestive gland and kidney at neutral pH, a process that could facilitate bioaccumulation if the animal is preyed upon.

The feeding mechanism of an organism may also play an important role in its susceptibility to metal uptake. For example, filter-feeders such as bivalves, blackfly larvae (Simuliidae), and net-spinning hydropsychid caddis larvae ingest metals associated with organic and inorganic matter in the water column, whereas grazers (e.g., snails) accumulate metals from periphyton, and associated organic matter. Sediment feeders and collector-browsers (e.g., some mayfly nymphs and oligochaete worms) ingest metals absorbed to organic and inorganic sediment particles, and carnivores (e.g., predatory stoneflies, caddis and fish) obtain metals from their prey.

Physico-chemical conditions within the water column of a stream or river can also have a significant effect on the availability and toxicity of many heavy metals. Both water temperature and dissolved oxygen concentration vary diurnally and seasonally, and both strongly influence metabolic processes in freshwater organisms. Thus, respiration, activity and growth rate generally increase as temperature and dissolved oxygen increase up to a threshold, and decrease as they fall. In parallel with these changes metal toxicity can also change, as in rainbow trout (*Oncorhynchus mykiss*) which were found to survive significantly longer in water contaminated by zinc at low compared to high temperatures (Kelly, 1988). Water hardness has also been shown to affect the toxicity of heavy metals, which may form insoluble complexes with carbonates, or adsorb to calcium carbonate (Förstner and Wittmann, 1981). In general, the concentration of heavy metals required to become toxic is greater in hard than soft water, in part because cations such as calcium and magnesium compete with metal ions for active sites within an organism's tissues thereby reducing the potential toxicity of the metals (Kelly, 1988).

The amount of dissolved organic matter (particularly in eutrophic or anthropogenically polluted systems) can also influence the toxicity of various metals. For example, acid brown water streams, which are relatively common on the West Coast of the South Island also have high concentrations of dissolved organic carbon, predominantly humic and fulvic acids derived from decomposing vegetation that give them their colour. The toxicity of aluminium to benthic invertebrates and fish is greatly reduced in these streams because, although present at high concentrations, it is complexed with dissolved organic matter (Collier et al., 1990).

In coal mine-contaminated rivers with significant acid generation the production of iron hydroxide precipitate ("ochre" or "yellowboy") frequently occurs. The location of numerous abandoned mines in the Reefton area and on the Stockton-Denniston plateau of the West Coast of the South Island can be detected by the present of iron precipitate (see Chapter 12). White aluminium hydroxide precipitates can also form below the confluence of acidic and circum-neutral pH streams, but in New Zealand this situation seems to be rare.

Freshwater algae have been used successfully as indicators of heavy metal pollution in rivers and lakes overseas, but no attempt to use them in this way has been made in New Zealand. Phytoplankton, which is generally limited to lakes and the largest rivers in New Zealand, is less useful as an indicator of metal pollution than periphyton because of the short life cycles of the species, which can only indicate the presence of metals in the environment during their life. In contrast, periphyton (algae on stony substrate), which is generally long-lived has been widely studied in mined systems, internationally. The filamentous alga *Cladophora* has been found to accumulate Pb, Cd, Zn and Cu in European studies (see Förstner and Wittmann, 1981), and both bryophytes (mosses and liverworts) and higher vascular plants accumulate a variety of metals heavy metals (Engleman and McDiffett, 1996). Crowder (1991) provides a comprehensive review of the pathways and effects of Al, Cd, Pb and Hg uptake on bryophyte and macrophytes communities. In New Zealand, Reay (1972) recorded up to 0.5g per kg dry weight (DW) of arsenic in the indigenous charophyte *Nitella hookeri* in the Waikato River, where arsenic occurs naturally in stream water as a result of geothermal inputs, while Fish (1963) reported values of 120 ppm arsenic in the exotic macrophyte *Lagarosiphon major* in Lake Rotorua. Heavy metals accumulate in different parts of vascular plants, with the highest accumulation usually occurring in the leaves, followed by stems and then roots (Table 2).

Table 2. Heavy metal concentrations in parts of vascular plants (mg/kg DW)(modified from Förstner & Wittmann 1981).

	Cd	Zn	Pb	Cu
Roots	0.33	54.9	2.2	16.1
Stems	1.60	222.7	6.4	21.3
Leaves	3.59	500.2	8.6	100.0

In almost all freshwater ecosystems exchanges of water, nutrients and biota occur between the water body and underlying groundwater. Emerging research on the region of interchange, the hyporheic zone, has clarified its importance as a boundary habitat (Stanford and Ward, 1988), which can provide habitat for species also found among surface sediments and specialist subsurface (hyporheic) fauna. It can also play an important role as a refuge for surface-dwelling invertebrates and fish during floods and droughts, and several salmonid species use the hyporheos for spawning (laying and incubating their eggs in sub-surface gravels). Recent work in New Zealand has identified numerous invertebrate species, rarely found in surface waters, that inhabit the hyporheos either temporarily or permanently (Collier and Scarsbrook, 2000). Heavy metal pollution of the hyporheos is an issue that has been largely overlooked in New Zealand. However, it is a potential problem as indicated by a study of the hyporheic zone in Silver Bow Creek, Montana (U.S.A.), which revealed that the mixing of surface and groundwaters differing in pH (7.8 and 4.5, respectively) resulted in the formation of metal precipitates, and as a result groundwater then acted as a source of metal pollution for the surface water (Wielinga et al., 1994). In another Montana study by Nagorski and Moore (1999) circum-neutral pH and low dissolved oxygen conditions in the hyporheic zone enabled sediment-bound arsenic to be released as dissolved As (III). In this more toxic form, As (III) poisoned the invertebrate fauna in surface waters. Heavy metals frequently occur in high concentrations in benthic sediments, and these studies highlight the importance of the hyporheic zone as a potential storage area for accumulated metals. Work by Nelson and Roline (1999) lends support to this view, as they showed that hyporheic communities in Colorado recovered very slowly after remediation of surface water. In New Zealand, a comparative study of surface and hyporheic waters of small streams draining abandoned coal mines in the Reefton, Anthony (1999) found that the chemistry (including total iron, total aluminium, nitrate-nitrogen and reactive phosphate) of hyporheic water was very similar to that of surface water although conductivity, alkalinity and pH differed markedly. She also found a distinctive hyporheic fauna dominated by harpacticoid copepods. Insufficient research has yet been conducted to determine how whether hyporheic organisms in general differ from epigean (surface-dwelling) organisms in tolerance to metal pollution, though Plénet (1999) found that a hypogean amphipod *Niphargus rhenorhodanesus* was more resistant to Zn and Cu than a comparative hypogean (underground) amphipod.

In New Zealand few studies have assessed the effects of metal toxicity independently from other pollutants. However, Hickey and Clements (1998) found that streams dominating historically mined catchments on the Coromandel Peninsula had high concentrations of metals including Cd, Cu, Pb and Zn, were low in invertebrate species richness (< 5 taxa), had reduced abundances of metal-sensitive mayflies, and were dominated by metal-tolerant orthoclad chironomids. Their work also indicated that caddisflies were more tolerant of heavy metals than mayflies and stoneflies, and that the abundance and species richness of mayflies were among the most useful indicators of metal pollution in New Zealand streams. Recent studies in urban streams have also found that the presence of heavy metals (Cu, Zn, Cd, and Pb) in sediment may be related to a decline in invertebrate species richness (Blakley et al., 2003), as in some New Zealand estuaries (Snelder and Trueman, 1995). However, separation of potential metal toxicity from other possible factors is difficult, and studies that combine both field trials and laboratory toxicology tests are needed.

In general, streams impacted by acid mine drainage have low pH (although not always), and frequently high concentrations of Al, Fe, Ni, Zn and sometimes As. In New Zealand, mine-impacted invertebrate communities are usually depauperate close to the source of a mine discharge and as few as 1-3 taxa are likely to be present. These invertebrate communities may be dominated by Chironomidae (e.g., *Chironomus zealandicus* and *Eukiefferiella* sp.), although scirtid beetles and notonemourid stoneflies (e.g., *Spaniocerca* and *Spaniocercoides*) may also be found close to mine adits (Winterbourn, 1998; Harding and Boothroyd, 2004). Further downstream from the source, communities may start to recovery, typically with the addition of free-living hydrobiosid caddisflies (e.g., *Psilochorema*) and further chironomid species (Fig 4). Fish, crayfish and eels are almost always absent from these systems, although they may be common in adjacent streams not receiving mine waters. The ability of some New Zealand invertebrates to persist in mine–impacted streams has been the source of some discussion (see Collier et al., 1990; Winterbourn, 1998), and although many of these species may be well adapted to tolerate low pH, which is a natural condition of brown water streams, their apparently high tolerance of metal contaminated conditions is not easy to explain. The mechanisms enabling some of invertebrate to survive in these harsh environments have not yet been rigorously investigated, and should represent a fertile field of research.

Toxicity tests with heavy metals

Internationally, considerable work has been done on the toxic effects that heavy metals have on freshwater invertebrates and fish (see reviews by Johnson et al., 1993; Goodyear and McNeill, 1999). In New Zealand, however, testing has been limited to relatively few key metals of concern (e.g., Zn, Cd, and Cu) and very few freshwater species, most of which are more characteristic of still than flowing waters (Hickey, 2000).

Copper is one of the most toxic metals to invertebrates, and can be toxic to several taxa at concentrations <0.01 mg L-1 (Kelly, 1988). In general, insects seem more tolerant of copper and zinc than are molluscs and crustaceans, whereas oligochaete worms show a wide range of responses to Zn, but are generally intolerant of copper (Kelly, 1988). It needs to be appreciated, however, that many factors (some of which have been discussed previously) affect the toxicity of metals to invertebrates, and make the interpretation of simple laboratory assays difficult.

Tests on the toxicity of various metals to members of the New Zealand freshwater biota are relatively few, and a useful summary of the acute sensitivity of 12 stream invertebrates to four heavy metals (Cd, CrVI, Cu and Zn) is given by Hickey (2000). The pond and lake-dwelling cladoceran *Ceriodaphnia dubia* and the stream-dwelling amphipod *Paracalliope fluviatilis* were both sensitive to all four metals, and in laboratory bioassays had high mortality at <0.2 mg/L Cd, 0.05 mg/L CrVI, 0.06 mg/L Cu and <0.6 mg/L Zn. Interestingly, the mayfly *Deleatidium* was less sensitive to Cd, CrVI, and Cu, and highly insensitive to Zn, whereas the cased caddisflies *Olinga feredayi* and *Pycnocentria evecta* were particularly insensitive to Cd and Zn, even at concentrations >10 mg/L (Hickey, 2000).

Several tests have been conducted using acid mine waters where both low pH and elevated concentrations of Fe and Al are interrelated issues (Anthony, 1999; Bradley, 2003). Adaptation to low pH was tested by Anthony (1999) who exposed *Deleatidium* mayflies from pH 5.5 and pH 6.9 streams to pH 3. The nymphs from low pH streams survived significantly better than nymphs from circum-neutral waters. Bradley (2003) attempted to tease apart the effects of pH and metals when she conducted 96h toxicity tests on *Deleatidium*. She found 80% mortality at pH 3.5 in waters with high dissolved aluminium, and total iron (10 mg l-1, 40 mg l-1, respectively), however, mortality declined to 60% in pH 3.5 water without heavy metals (Fig 5).

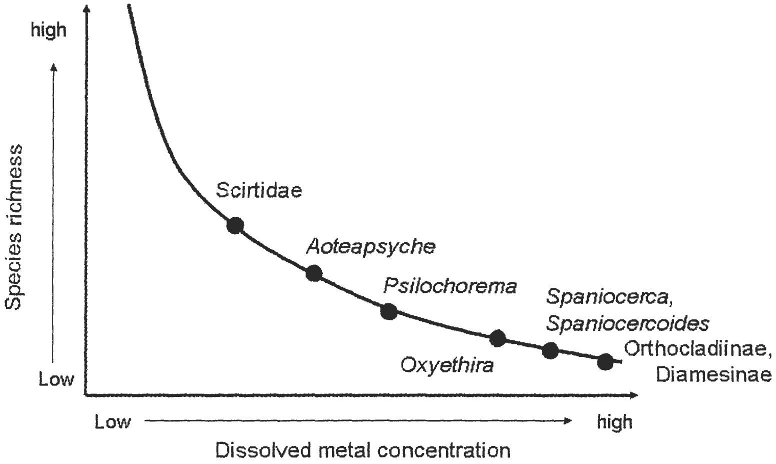

FIGURE 4. Generalised model of change in species richness (and species tolerances) with increasing metals in New Zealand streams (J.S. Harding, unpublished data).

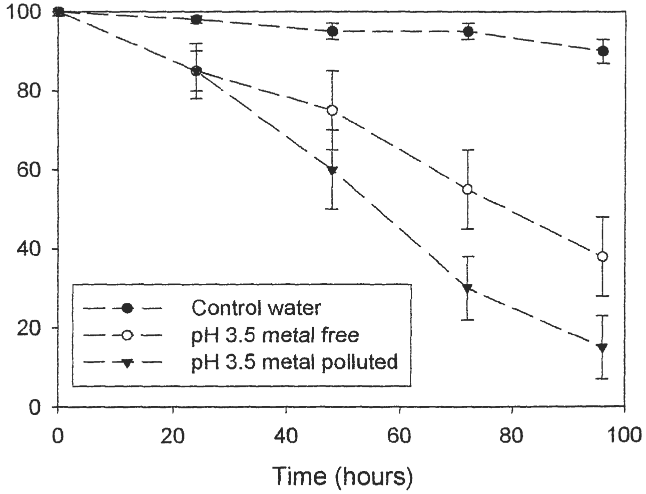

FIGURE 5. Survival of Deleatidium mayfly nymphs after 96h exposure to control water, pH 3.5 water (free of metals), and mine-impacted pH 3.5 waters with aluminium and iron. Mean ±1SE. (Modified from Bradley, 2003).

As for invertebrates, toxicity data on New Zealand fish are relatively sparse, and primarily concern the effect of Cd and Zn on shortfin and longfin eels, common bully, smelt and rainbow trout (Hickey, 2000). Rainbow trout and smelt are both sensitive to these metals, although the mechanisms by which they act have not been fully investigated.

In general, acute toxicity results from laboratory experiments often indicate higher levels of tolerance than are recorded in the field, emphasizing the importance of non-acute toxic effects. Because of their short-term nature, laboratory tests rarely account for the range of subtle impacts that can affect test organisms (e.g., changes in behaviour, impaired physiology, and increased susceptibility to disease).

SUMMARY

Extensive international literature now exists on the specific effects of metal contaminants on freshwater organisms. However, the high levels of endemism of the New Zealand freshwater fauna makes the application of overseas findings to our organisms, challenging. This challenge is highlighted by those studies, which have reported numerous invertebrate species in acid mine-impacted systems where metal concentrations are high. Teasing apart the individual and combined effects of low pH and metals is an essential task for New Zealand researchers, and will be necessary before attempts to remediate and restore metal-impacted waterways can be successful. Historically, few attempts have been made to restore waterways impacted by metals and mining in New Zealand (for an exception see Chapter 18), although, in recent years greater emphasis has begun to be placed on restoration and remediation. As a consequence, freshwater ecologists in this country are being challenged to improve their understanding of the effects of these activities on our diverse aquatic environments.

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Key Points

- Metal contamination in New Zealand freshwaters is commonly associated with coal and gold mining operations.
- New Zealand's freshwater biota is characterized by having many widespread species, and particularly in the case of freshwater invertebrates and fish these species are almost entirely endemic to New Zealand.
- This high endemism requires New Zealand researchers to treat overseas toxicological findings with caution, and emphasizes the need for continuing research on metal effects on New Zealand biota.

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