NIWA

Taihoro Nukurangi

Comparison of the Sensitivity to Heavy Metals and Organic Toxicants of Native New Zealand Invertebrates Compared with Standard International Test Species

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1. SUMMARY

The Resource Management Act, 1991 contains mainly narrative standards for the protection of New Zealand aquatic environments. Two narrative standards covering contaminants require interpretation of "adverse effect" and "significant adverse effect". This legislative requirement has stimulated research which considers ecological effects of toxic and other contaminants. Practical laboratory techniques have been established for toxicity testing of contaminated freshwater systems and sediments using native invertebrates. The major issues arising are: sensitivity of native organisms, detection of effects at low levels of contamination, and interpretation of legislative requirements for environmental protection. This report reviews toxicity tests developed at NIWA for freshwaters and considers management implications and future research needs.

2. INTRODUCTION

Assessment of the environmental impacts of potentially toxic contaminants will continue to be an area of both public and scientific concern in the foreseeable future. While the environmental problems experienced in New Zealand may not be on a level with the gross contamination present at many overseas locations, some areas of contamination have been identified. Additionally, present and future industrial development will be increasingly required to provide levels of effluent treatment which do not cause environmental harm. The presence of relatively low levels of contaminants, often associated with organic and nutrient enrichment, poses considerable challenges to quantify the levels of ecosystem impact. The development and application of appropriate techniques, particularly related to sediment associated contaminants, is a major research challenge.

Public interest and concern regarding toxic contaminants in the environment have grown in recent times. The dredging of sediments from Auckland harbour and the disposal of sludge in the Hauraki Gulf raised considerable public debate on contaminant effects on recreational and commercial fishing areas. Most recently, the widespread use of 1080 poison (monofluoroacetic acid) for the control of the introduced Australian possum has raised public concern for possible adverse effects caused to aquatic systems. The widespread use of herbicides for control of bankside and submerged macrophyte species has also come in for critical appraisal. Much of this public debate has been stimulated by the provisions for public consultation of environmental issues embodied in the Resource Management Act, 1991 (RMA).

The RMA has narrative standards covering contaminant effects on receiving waters. The granting of resource consents requires interpretation of "adverse effect" or "significant adverse

effect". This legislative requirement has further stimulated research considering ecological effects of toxic and other contaminants (e.g., organic enrichment, nutrients and inorganic suspensoids) to provide numeric guidelines for their interpretation. Research and consulting studies have encompassed both freshwater and marine environments with field monitoring around discharges, experimental manipulation using chemically-dosed sites and laboratory based toxicity bioassays with effluents and sediments. For the latter, the general approaches use a suite of "standard" test species representing a range of phylogenic levels (e.g., microorganism, invertebrate, fish) for routine acute (short term) assessments. Site-specific and high risk situations necessitate consideration of impacts at a chronic (long term) level and on specific native species. The availability of toxicity tests for both fresh and marine waters and sediments with native species is, as yet, poorly developed in New Zealand. Smith (1986) in reviewing heavy metal pollution in New Zealand, found that few studies had examined biological effects (e.g. toxicity) or long-term impacts.

Toxicity testing in New Zealand has largely developed since 1986. The ecological impacts of contaminants have also been increasingly studied in both marine and freshwaters. The development of ecotoxicity testing in New Zealand has been reviewed elsewhere (Hickey 1995). The use of whole effluent toxicity testing (WET) offers a number of advantages over chemical specific approaches to contaminant effect assessment. Principal among these is the quantitative integration of the effects of all toxicants present in the effluent (Hickey and Roper 1994). This report covers freshwater studies which were partially funded by the Department of Conservation between 1990 and 1993. These include investigation of the suitability of native freshwater invertebrate species for laboratory toxicity assessment using standard test protocols; comparison of their sensitivity to heavy metals and ammonia with internationally used standard test species; and development of techniques for assessment of both water and sediment toxicity assessment. A validation study has been undertaken comparing laboratory test results with heavy metal impacts on river invertebrate communities. The analysis of the validation study has yet to be completed.

The objectives were:
- To assess the suitability of native invertebrate species for laboratory toxicity testing.
- To establish laboratory methods for acute (short term) toxicity testing with representative native riverine species.
- To compare the relative acute toxicant sensitivities of native species with standard overseas test species.

3. METHODS

A laboratory testing protocol was developed for *Deleatidium*. Specimens were collected from an uncontaminated stream and transported to the laboratory where they were held in an aerated aquarium for 24h at 15°C with a light: dark (16:8) cycle, with measurements at 24, 48 & 96h. Toxicants tested were: 3 metals (chromium, Cr (VI); copper, Cu; & zinc, Zn) and 1 organic (pentachlorophenol, PCP). All were of analytical grade and confirmatory chemical analyses were made on all stock solutions. Detailed methods are provided elsewhere (Hickey and Vickers 1992).

The toxic concentration for un–ionised ammonia (NH_3) was assessed for nine native New Zealand invertebrate species. The 96 h EC_{50} values at 15°C and pH 7.6 and pH 8.2 were assessed using a standard laboratory technique. Detailed methods are provided elsewhere (Hickey and Vickers 1994).

Field trials were undertaken on 3 Coromandel stream systems (Waiomu/Paraquet; Tararu/Ohio; and the Tunakahoia) which each receive heavy metal drainage from mining activities. Quantitative invertebrate samples were taken at all sites, rocks were scraped for attached periphyton and mayflies (*Deleatidium*) collected for metal analysis. Water samples were collected for laboratory toxicity testing. Laboratory toxicity results were compared with quantitative river invertebrate data measured at the reference upstream site, in the highly contaminated stream and below the confluence.

4. RESULTS

A laboratory testing protocol for carrying out toxicity tests with native mayflies (*Deleatidium* spp.) has been developed (Hickey and Vickers 1992). Control survival was good for 96 h exposure period. The sensitivity of mayflies to four heavy metals and the organic compound pentachlorophenol (PCP) has been established, and comparisons were made with the cladoceran *Daphnia magna*, which is commonly used overseas for toxicity testing. Mayflies were found to have similar sensitivity to *D. magna* when exposed to metals, but were less sensitive to pentachlorophenol. Comparisons with data for other overseas river invertebrates and fish showed *Deleatidium* to be among the more sensitive species. Figures 1 and 2 show the relative sensitivity of *Deleatidium* to copper and PCP compared with the species acute sensitivity data used to derive water quality criteria values.

Hickey and Vickers (1994) compared the ammonia sensitivity of nine native invertebrate species. The four most sensitive invertebrate species had greater acute sensitivity to ammonia

than the species used to derive US Environmental Protection Agency tables, including rainbow trout (U.S. Environmental Protection Agency 1985) The 96 h EC_{50} values at 15°C and pH 7.6 and pH 8.2 ranged from 0.18 to >0.8 g/m^3 NH_3. The rank of species sensitivity was: shrimp (*Paratya curvirostris*) (least) $\approx$ mayfly (*Zephlebia dentata*) $\approx$ stonefly (*Zealandobius furcillatus*) < Oligochaeta (*Lumbriculus variegatus*) < fingernail clam (*Sphaerium novaezelandiae*) < mayfly (*Deleatidium* spp.) < a snail (*Potamopyrgus antipodarum*) < caddis (*Pycnocentria evecta*) < crustacean (*Paracalliope fluviatilis*) (most). Surprisingly, the more sensitive species were those which would normally be associated with lowland streams (the snail and crustacean) rather than the normally accepted "sensitive" species (mayflies and stoneflies). Temperature had no significant effect on the acute toxicity of un-ionized ammonia with snails tested at 15, 20 and 25°C.

Figure 3 shows the relative sensitivity of the New Zealand native species to ammonia compared with overseas species. The invertebrates were more sensitive than the native fish species tested (inanga, EC_{50} 1.60 g/m^3 NH_3, (Richardson 1991)). A final acute value (FAV) calculated for these species was 0.15 g/m^3 NH_3. This compares with the FAV value of 0.52 g/m^3 NH_3 derived by the US Environmental Protection Agency (EPA) as the basis for the ammonia criterion for salmonoid containing waters (U.S. Environmental Protection Agency 1985). Thus EPA guidelines may not provide adequate protection for New Zealand species. These data suggest that chronic studies would be particularly desirable on native New Zealand species to better determine their sensitivity to long term ammonia exposure.
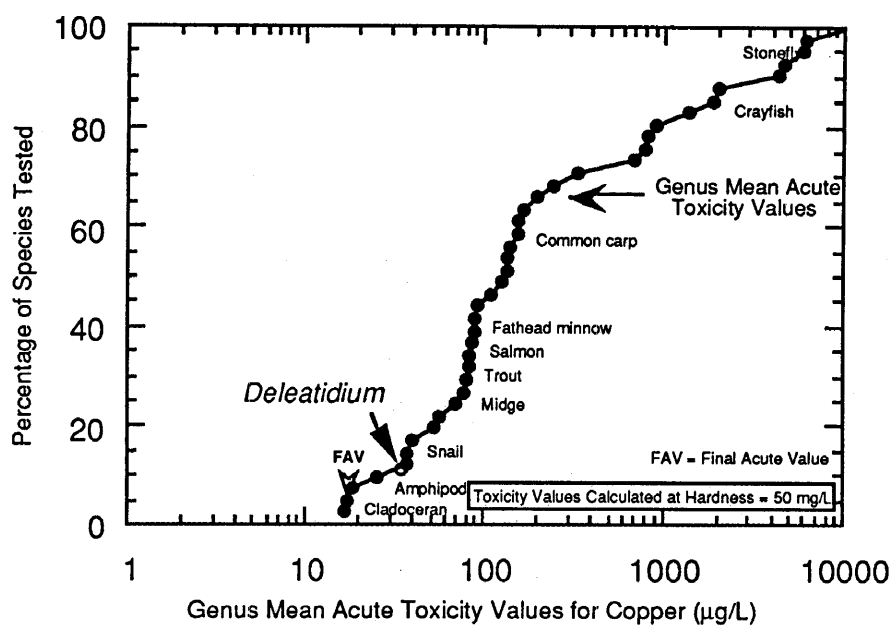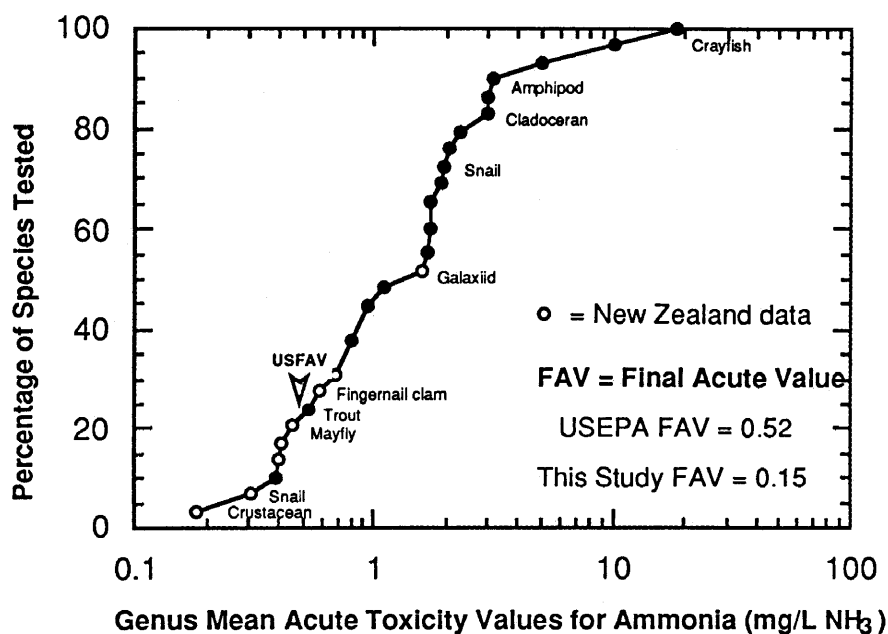
Figure 1. Acute toxicity of copper to various species of aquatic life (from U.S. EPA 1985)
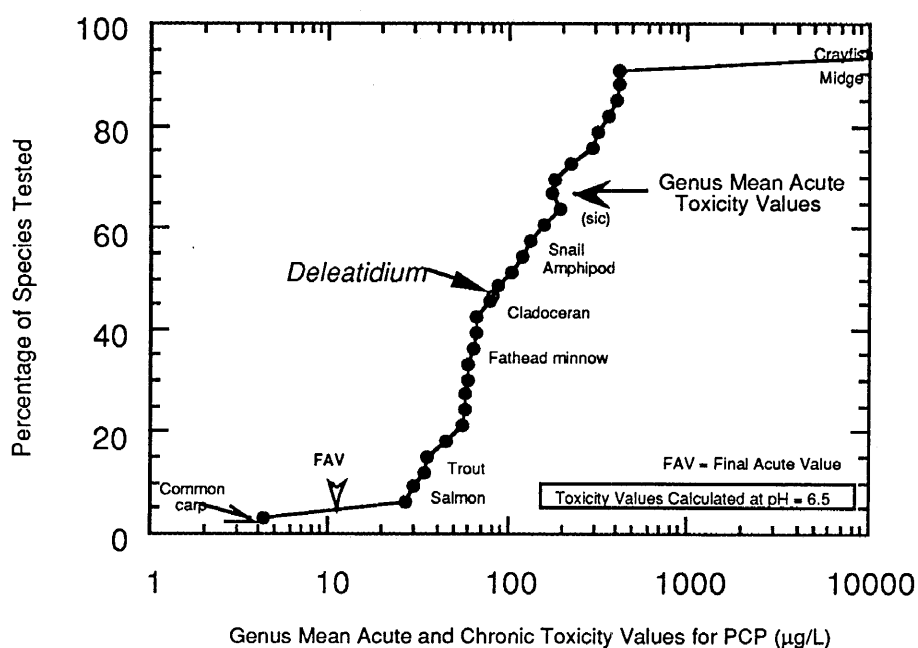
Figure 2. Acute toxicity of pentachlorophenol (PCP) to various species of aquatic life (from U.S. EPA 1986)

Genus Mean Acute Toxicity Values for Ammonia (mg/L NH₃)

Figure 3. Acute toxicity of ammonia (NH3) to New Zealand native and international species (modified from U.S. EPA 1985)

The laboratory protocols have also been used to determine the thermal tolerance of twelve common native invertebrate species (Quinn et al. 1994). They found that the most sensitive species (a plecopteran and two ephemeroptera) may be limited in their riverine distribution by summer temperatures.

The suitability of five sediment dwelling species (amphipod, *Chaetocorophium lucasi*; freshwater clam, *Sphaerium novaezelandiae*; oligochaete, *Lumbriculus variegatus*; freshwater shrimp, *Tanais standfordi*; & the burrowing mayfly, *Ichthybotus hudsoni*) for 10 day sediment toxicity testing has recently been assessed by comparison of sensitivity to reference toxicants (phenol and PCP) and contaminated sediments (Hickey and Martin 1995). The results showed good survival and high sensitivity to reference toxicants for the amphipods and clams. Further development of sub-lethal growth and reproduction tests are required for the amphipods and sphaeriids.

Table 1 summarises the 20 freshwater native invertebrate species which have been successfully held under standardised laboratory test conditions for toxicity or thermal sensitivity assessments. The results have shown that a range of species from lake and riverine environments are suitable for laboratory use.

Table 1. Freshwater native invertebrate species which have been successfully held under standardised laboratory test conditions for toxicity or thermal sensitivity assessments.

Organism		Contaminant/Effect	Reference*
Common name	Scientific name		
amphipod	*Chaetocorophium lucasi*	Phenol, PCP, Cd	5
caddis	*Aoteapsyche colonica*	temp	6
caddis	*Pycnocentria evecta*	NH₃, temp	1, 6
caddis	*Pycnocentrodes aureola*	temp	6
cladoceran	*Ceriodaphnia c.f. pulchella*	Cr (VI), PCP, B, F	2
cladoceran	*Ceriodaphnia dubia*	Cr (VI), PCP, B, F	2
cladoceran	*Daphnia carinata*	Cr (VI), PCP, B, F	2
cladoceran	*Simocephalus vetulus*	Cr (VI), PCP, B, F, temp	2, 3
crustacean	*Paracalliope fluviatilis*	NH₃,	1
crustacean	*Tanais standfordi*	Phenol, PCP	5
elmidae	*Hydora* sp.	temp	6
fingernail clam	*Sphaerium novaezelandiae*	NH₃, Phenol, PCP	1, 5
mayfly	*Deleatidium* spp.	NH₃, Cr (VI), Cd, Cu, Zn, PCP, temp	1, 4, 6
mayfly	*Ichthybotus hudsoni*	Phenol, PCP	5
mayfly	*Zephlebia dentata*	NH₃, temp	1, 6
oligochaeta	*Lumbriculus variegatus*	NH₃, Phenol, PCP, temp	1, 5, 6
shrimp	*Paratya curvirostris*	NH₃,	1
snail	*Physa acuta*	temp	6
snail	*Potamopyrgus antipodarum*	NH₃, temp	1, 6
stonefly	*Zealandobius furcillatus*	NH₃, temp	1, 6

* References: 1. Hickey & Vickers (1994); 2. Hickey (1989); 3. Willis (1994); 4. Hickey & Vickers (1992); 5. Hickey & Martin (1995); 6. Quinn et al. (1994)

A validation study has been undertaken comparing laboratory test results with heavy metal impacts on river invertebrate communities. The results of several freshwater toxicity tests were compared with the impacts on invertebrate communities in streams contaminated by heavy metals. The results showed that generally there was good agreement between measured toxicity and impacts on invertebrates. However, in some cases greater impact on stream communities was recorded than would have been expected based purely on the toxicity assessments. High concentrations of metals in algal periphyton and mayflies suggested that the unexpectedly large impacts observed may have been the result of bioaccumulation of metals in the stream invertebrates. The analysis of the validation study for publication has yet to be completed (Hickey 1995).

5. CONCLUSIONS

- Practical laboratory techniques have been established for toxicity testing of contaminated freshwater systems and sediments using native invertebrates.

- The sensitivity of the native mayfly *Deleatidium* to contaminants is particularly high, suggesting that tests using this species should be incorporated in investigations assessing the potential impact of contaminants on river ecosystems.

- The acute sensitivity to ammonia of native New Zealand freshwater invertebrates is higher than that of species used to derive tables which are widely used to establish water quality guidelines.

- The observed impacts of heavy metals on riverine invertebrate communities suggested that bioaccumulation of heavy metals may be an important mechanism affecting ecological integrity.

6. MANAGEMENT IMPLICATIONS

- A testing protocol is now available for native mayfly species. Tests of potentially toxic effluents discharging to rivers should be undertaken as part of environmental impact assessments and incorporated in resource management permit conditions.

- Native invertebrate species are more acutely sensitive to ammonia than the species used to derive US EPA guideline tables. Thus EPA guidelines may not provide adequate protection for New Zealand species.

- Additional tests of the relative sensitivity to toxicants of a range of native invertebrate species should be undertaken. This would help determine whether the use of the *Deleatidium* test would provide a useful surrogate for the protection of a wide range of native invertebrate species.

- Care must be taken in applying toxicity test results for invertebrate sensitivity to metals to riverine environments, since a major exposure pathway is likely to be bioaccumulation through ingestion of algae growing on rock surfaces.

- Attached algae may potentially provide better monitoring for riverine heavy metals than the overlying waters. Monitoring the algal heavy metal concentrations would be more sensitive because of the bioconcentration of these elements thus providing an improved detection level, and integration of time-varying metal concentrations in the overlying water.

7. FUTURE RESEARCH NEEDS

- Chronic toxicity assessments should be made for ammonia effects on stream invertebrates.

- Chronic toxicity test techniques should be developed for water and sediment toxicity assessment using a range of native invertebrate species.

- Validation of sediment toxicity test should be undertaken by comparison of laboratory test measurements with observed impacts on field communities.

8. ACKNOWLEDGEMENTS

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