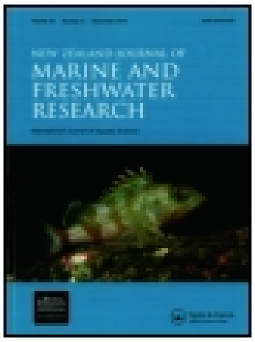

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Talitrid amphipods as biomonitors of trace metals near Dunedin, New Zealand

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Abstract Concentrations of copper, zinc, and cadmium were measured in two widespread New Zealand talitrid amphipod crustaceans, *Talorchestia quoyana* (Milne-Edwards) and *Orchestia tenuis* Dana, collected from ten sites in the region of Dunedin, Otago, New Zealand in February 1990. Body metal concentrations were compared intraspecifically by Analysis of Covariance, differences in these accumulated concentrations reflecting differences in metal bioavailabilities in local coastal waters. We conclude that both amphipods can be used as biomonitors of these metals in New Zealand coastal waters.

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INTRODUCTION

The use of biomonitors to assess the relative bioavailabilities of toxic metals in coastal waters is now routine, particularly in north-west Europe and north America (Bryan et al. 1980; Phillips 1980, 1990). Selected biomonitors need to meet established criteria (Phillips 1980; Phillips & Rainbow 1993), for concluding that differences in accumulated metal concentrations in the bodies (or occasionally tissues) of the biomonitors are direct reflections of differences in local bioavailabilities of the metal. Biomonitors provide relative measures of the quantities of bioavailable metal that is available to the organism in different situations; they do not, however, themselves provide measures of the percentage contributions of bioavailable metal to total metal concentrations present. Accumulated metal concentrations are measures of the metal concentrations available to the chosen organism. As such they are of greater ecotoxicological relevance than any local metal concentrations measured in water or sediment samples. Given that different organisms take up metals via different routes (water, suspended detritus, deposited material, etc.), the employment of a suite of biomonitors is the preferred basis of any biomonitoring programme assessing local metal contamination of ecotoxicological potential (Phillips & Rainbow 1993).

Common biomonitors include mussels such as *Mytilus edulis* (Phillips 1976a, 1976b) and *Perna viridis* (Phillips 1985). The blue mussel *Mytilus edulis* is available as a biomonitor in New Zealand (Brooks & Rumsby 1965; Nielsen & Nathan 1975), as are the green-lipped mussel *Perna canaliculus* (Hoggins & Brooks 1973; Nielsen & Nathan 1975) and the ridged mussel *Aulacomya maoriana* (Nielsen & Nathan 1975). Relatively new additions to the list of available biomonitors are talitrid amphipod crustaceans, particularly the beach-hopper *Orchestia gammarellus* in British waters (Rainbow et al. 1989; Moore et al. 1991), given that there is laboratory evidence that talitrid amphipods are net accumulators of trace metals derived both from dissolved sources (Weeks & Rainbow 1991) and from food (Weeks 1990; Rainbow 1992).

Smith (1985, 1986) reviewed the state of knowledge of heavy metals in the New Zealand aquatic environment, highlighting the need for areas of likely contamination to be identified and for properly designed monitoring programmes to be developed. In 1985, he specifically referred to large-scale sewage discharges into harbours as possible sources of heavy-metal contamination, and such discharges are present in the Dunedin area of Otago. Earlier studies of heavy-metal contamination in the Otago region involved measurements of metals in water (e.g., Dickson & Hunter 1981) and sediment samples, although Johnson et al. (1981) showed a relationship between levels of chromium in the crab *Helice crassa* in Sawyers Bay, Otago Harbour and the distance from the effluent outlet of a nearby tannery (since discontinued).

The opportunity has been taken here to extend the assessment of the suitability of talitrid amphipods as trace metal biomonitors to the Southern Hemisphere. Two talitrid species were collected in the area of Dunedin: *Orchestia tenuis* from the northern shore of Otago Harbour, and *Talorchestia quoyana* from sandy shores along the oceanic southern coast (Fig. 1, Table 1). The two talitrid species together therefore cover a wide range of coastal habitats from sheltered to wave-exposed beaches, and both are common throughout New Zealand (Hurley 1956, 1957).

MATERIALS AND METHODS

Two species of talitrid amphipods, *Talorchestia quoyana* (Milne-Edwards) and *Orchestia tenuis* Dana, were collected from 10 sites in the region of Dunedin, South Island, New Zealand, on 22 February 1990 (Fig. 1, Table 1). The stations at St Kilda and Tomahawk Beach lie to either side of the major sewage outfall at Lawyers Head.

Individual amphipods were rinsed in double-distilled water and dried to constant weight at 60°C in acid-washed glass vials. Amphipods were not allowed to depurate the gut contents nor were they segregated by gender (see Rainbow et al. 1989; Moore et al. 1991). Since all amphipods were collected on the same day, there is no scope for any seasonal effects in the data.

Individual dried amphipods were digested in Aristar grade concentrated nitric acid (BDH Ltd, Dorset, England) at 100°C and made up to volume (2 ml) with double-distilled water. Digests and/or dilutions of digests were analysed for copper (Cu) and zinc (Zn)—and for cadmium (Cd) where sample volume and metal concentration allowed—by atomic absorption spectrophotometry (AAS) on an International Laboratory IL–157 AA spectrophotometer, with background correction as appropriate. All metal concentrations are quoted in microgrammes per gramme dry weight (μg g^{-1}). Analytical quality was checked against blanks and against Tort–1 Lobster Hepatopancreas Marine Reference Material (NRC, Canada) and Copepod Homogenate Reference Material MA-A-(TM) (IAEA, Monaco), and was very satisfactory: Tort–1 measured means (95% confidence limits) ($n = 3$) were 406 (26) μg Cu g^{-1}, 188 (42) μg Zn g^{-1} and 30.0 (3.5) μg Cd g^{-1}, in comparison with certified values (95% CL) of 439 (22) μg Cu g^{-1}, 177 (10) μg Zn g^{-1}, 26.3 (2.1) μg Cd g^{-1}. Copepod homogenate measured means ± 1 standard error ($n = 3$) 8.1 ± 1.0 μg Cu g^{-1}, 170 ± 23.1 μg Zn g^{-1}, 1.9 ± 0.3 μg Cd g^{-1} in comparison with certified values (± 1 standard error) of 7.6 ± 0.2 μg Cu g^{-1}, 158 ± 2 μg Zn g^{-1} and 0.75 ± 0.03 μg Cd g^{-1}.

Table 1 Details of collections of talitrid amphipods from the vicinity of Dunedin and Otago Harbour in February 1990 (see Fig. 1).

Species	Site	Habitat
Talorchestia quoyana		
South Coast	Waldronville	Sand
	St Kilda	Sand
	Tomahawk Beach	Sand
	Smails Beach	Sand
	Sandfly Bay	Sand
North Coast	Pilots Beach	Sand
	Aramoana	Sand
Orchestia tenuis		
Otago Harbour (North)	Sawyers Bay	Under stones
	Deborah Bay	Weed on gravel between stones
	Waipuna Bay	Weed on gravel between stones

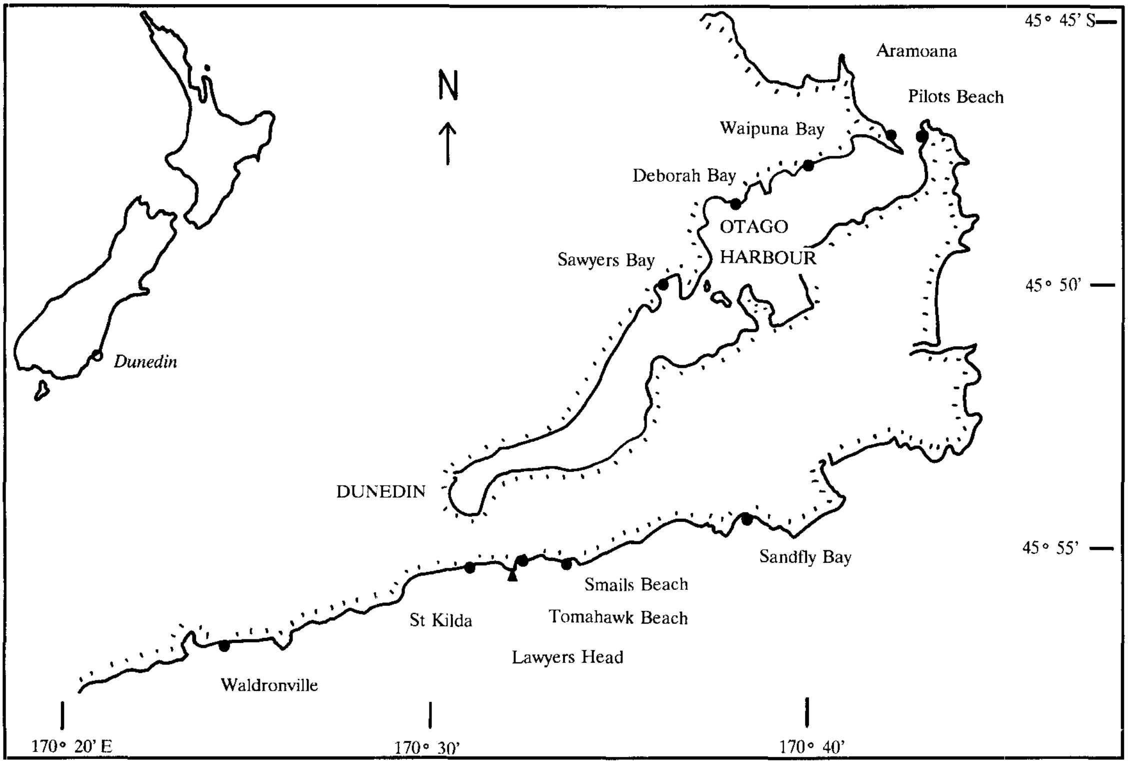

Fig. 1 Sites of collection of talitrid amphipods (details in Table 1) in the Dunedin area, Otago, New Zealand in February 1990.

STATISTICAL ANALYSIS

The procedure of Rainbow et al. (1989) and Moore et al. (1991) was followed to allow for size effects, namely any relationships between body weight and trace metal concentration. Only individuals > 2 mg dry weight were analysed, except in the case of the Sawyers Bay *O. tenuis* sample where amphipods were generally small and scarce. Dry weight and metal concentration data were then transformed logarithmically (see Rainbow & Moore 1986), and fitted by least squares regression to the straight line equation $\log y = \log a + b \log x$, where y is the metal concentration and x the amphipod dry weight. Typically the transformed power relationship is a good model for such data (Rainbow & Moore 1986) and the derived linear regressions can be compared by Analysis of Covariance. ANCOVA tests for significant differences in transformed metal concentrations after allowance for differences in the transformed dry weight. It is a precondition that there is no significant difference between the regression coefficients (slopes) of the regressions compared. All probabilities are considered not significant if $P > 0.05$.

RESULTS

Tables 2, 4, and 6 summarise information on the double-log regressions of concentrations in the talitrid amphipods of Cu, Zn, and Cd, respectively. There was at least one significant regression of metal concentration against dry weight for each metal and species (even after transformation into logarithms), confirming the necessity to use ANCOVA for statistical comparisons. Every ANCOVA comparison made between metal concentrations met the prerequisite of no significant difference between slopes of regressions compared.

Tables 3, 5, and 7 present metal concentration data in terms of the metal concentrations of 10 mg standardised dry weight amphipods with 95% confidence limits as estimated from the double log

Table 2 The number (n) and the dry weight (g: mean and range) of amphipods *Talorchestia quoyana* and *Orchestia tenuis* analysed for Cu concentration with details of the relationship $\log y = \log a + b \log x$, where y is the metal concentration ($\mu g\ g^{-1}$), x is the dry weight (g), and a and b (the regression coefficient) are constants. SIG. REG. is the significance of the regression; ns not significant ($P > 0.05$).

Site	Dry weight (g)			Double-log regression		
	n	Mean	Range	*b*	SIG.REG.	log *a*
Talorchestia quoyana						
Aramoana	17	0.0163	0.0069–0.0321	–0.8407	ns	0.0014
Tomahawk Beach	14	0.0214	0.0107–0.0459	–0.0779	ns	1.6819
St Kilda	15	0.0345	0.0162–0.0650	0.0129	ns	1.5290
Smails Beach	16	0.0237	0.0122–0.0368	0.0436	ns	1.4584
Waldronville	9	0.0173	0.0053–0.0338	–0.2381	ns	0.9697
Pilots Beach	21	0.0072	0.0023–0.0184	–0.5670	$P < 0.05$	0.1487
Sandfly Bay	15	0.0231	0.0098–0.0421	–0.1578	ns	0.8786
Orchestia tenuis						
Deborah Bay	13	0.0131	0.0071–0.0197	–0.3282	$P < 0.05$	1.3016
Sawyers Bay	10	0.0035	0.0013–0.0064	–0.2347	ns	1.1586
Waipuna Bay	15	0.0054	0.0027–0.0076	–0.2859	ns	0.9123

Table 3 Estimates of Cu concentrations ($\mu g\ g^{-1}$) with 95% confidence limits (CL) for amphipods of 10 mg standardised dry weight derived from best-fit double-log regressions. Locations are in descending order of estimated metal concentrations. Samples of one species sharing any common letter in ANCOVA column are not significantly different.

Site	Cu concentrations (CL)		ANCOVA
Talorchestia quoyana			
Aramoana	48.2	(27.2–85.5)	a
Tomahawk Beach	33.6	(19.6–57.6)	a
St Kilda	31.9	(19.6–51.8)	a
Smails Beach	23.5	(14.7–37.6)	a, b
Waldronville	22.2	(17.4–28.2)	b, c
Pilots Beach	19.2	(13.3–27.6)	c
Sandfly Bay	15.6	(12.6–20.3)	c
Orchestia tenuis			
Deborah Bay	48.8	(44.4–53.6)	a
Sawyers Bay	42.5	(26.8–67.2)	a
Waipuna Bay	30.5	(23.3–39.9)	b

regressions. These 95% confidence limits are asymmetrical about the estimate after taking antilogs of the transformed data. Sites are listed in descending intraspecific order of these estimates, and this order is imposed on the regression data in Tables 2, 4, and 6, as appropriate. Tables 3, 5, and 7 also show the results of intraspecific ANCOVA comparisons, the metal concentrations of amphipods sharing a common letter in the ANCOVA column not differing significantly ($P > 0.05$). Not every ANCOVA comparison possible is shown in these tables for the sake of clarity. A consistent feature of many of the ANCOVA comparisons is the significant difference between metal concentrations in amphipods from sites at the top and bottom of the lists, whereas amphipods close together in each list do not differ significantly in metal concentration. This feature is to be expected in such a comparison of graded samples (see also Rainbow et al. 1989; Moore et al. 1991).

Copper

Copper concentrations (Table 3) in *T. quoyana* fell along a graded series with concentrations highest at Aramoana (Fig. 1). Amphipods from Tomahawk Beach and St Kilda, either side of the sewage effluent at Lawyers Head, followed next. *T. quoyana* from the more remote beaches at Sandfly Bay and Pilots Beach had the lowest Cu concentrations.

In the case of *O. tenuis* (Table 3), Cu concentrations were significantly lower at Waipuna Bay, the outermost of the three Otago harbour sites.

Zinc

Zinc concentrations (Table 5) in *T. quoyana* were highest at St Kilda, and as in the case of Cu, also high at Aramoana and Tomahawk Beach (Fig. 1). As for Cu, Pilots Beach *T. quoyana* were low in Zn.

Zinc concentrations in *O. tenuis* (Table 5) followed the same order of sites as did Cu, amphipods from Deborah Bay being most metal-rich, those from Waipuna Bay least so.

Table 4 The number (n) and the dry weight (g: mean and range) of amphipods *Talorchestia quoyana* and *Orchestia tenuis* analysed for Zn concentration with details of the relationship $\log y = a + b \log x$, where y is the metal concentration (μg g^{-1}), x is the dry weight (g), and a and b (the regression coefficient) are constants. SIG. REG. is the significance of regression; ns not significant ($P > 0.05$).

Site	Dry weight (g)			Double-log regression		
	n	Mean	Range	b	SIG.REG.	log a
Talorchestia quoyana						
St Kilda	15	0.0345	0.0162–0.0650	–0.9222	ns	0.8374
Aramoana	17	0.0163	0.0069–0.0321	–0.8586	ns	0.7923
Tomahawk Beach	14	0.0214	0.0107–0.0459	–0.5881	ns	1.1200
Waldronville	9	0.0173	0.0053–0.0338	–0.3415	ns	1.5985
Sandfly Bay	15	0.0231	0.0098–0.0421	–0.0183	ns	2.0878
Smails Beach	16	0.0237	0.0122–0.0368	0.0372	ns	2.1290
Pilots Beach	21	0.0072	0.0023–0.0184	–0.4351	$P < 0.05$	1.1163
Orchestia tenuis						
Deborah Bay	13	0.0131	0.0071–0.0197	–0.6419	ns	1.0379
Sawyers Bay	10	0.0035	0.0013–0.0064	–0.3058	ns	1.4469
Waipuna Bay	15	0.0054	0.0027–0.0076	–0.7271	$P < 0.001$	0.3809

Table 5 Estimates of Zn concentrations (μg g^{-1}) with 95% confidence limits (CL) for amphipods of 10 mg standardised dry weight derived from best-fit double-log regressions. Locations are in descending order of estimated metal concentrations. Samples of one species sharing any common letter in ANCOVA column are not significantly different.

Site	Zn concentrations (CL)		ANCOVA
Talorchestia quoyana			
St Kilda	481	(120–1930)	a
Aramoana	323	(155–672)	a
Tomahawk Beach	198	(92.8–422)	a, b
Waldronville	191	(72.8–503)	a, b
Sandfly Bay	133	(65.6–270)	a, b
Smails Beach	113	(68.6–187)	a, b
Pilots Beach	96.7	(70.5–183)	b
Orchestia tenuis			
Deborah Bay	210	(149–296)	a
Sawyers Bay	114	(63.0–208)	a, b
Waipuna Bay	68.4	(52.2–89.6)	b

Cadmium

Cadmium concentrations (Table 7) in *T. quoyana* fell into the general pattern seen for Cu and Zn. Levels were high at Aramoana and St Kilda (Fig. 1); amphipods from Pilots Beach and Sandfly Bay occupied two of the lowest three positions.

In the case of *O. tenuis* (Table 7), Cd concentrations did not differ significantly between Deborah Bay and Waipuna Bay amphipods, although they fell in the same order as for Cu and Zn. Cd concentrations in *O. tenuis* from Sawyers Bay were beneath detection limits.

Rank correlations

It has already been noted that the rank orders of sites for Cu, Zn, and Cd concentrations in *T. quoyana* appeared to follow a similar pattern—higher metal concentrations in amphipods from Aramoana, Tomahawk Beach, and St Kilda; lower concentrations in amphipods from Smails Beach, Sandfly Bay, and Pilots Beach. These impressions have been tested by calculating Spearman's rank correlation coefficients. Rank orders of sites for Zn and Cd were significantly positively correlated ($r_s = 0.821, 0.01 < P < 0.05$), as were rank orders of Zn and Cu ($r_s = 0.714, P \leq 0.05$). Rank orders for Cu and Cd, however, were not significantly positively correlated (r_s = 0.643, $P > 0.05$).

DISCUSSION

The use of the talitrid amphipods *T. quoyana* and *O. tenuis* has allowed the recognition of differences in the bioavailabilities of Cu, Zn, and Cd between sites in New Zealand. Thus these antipodean talitrid amphipods are suitable for use as biomonitors in the same way as their British counterpart *O. gammarellus* (Rainbow et al. 1989; Moore et al. 1991). This study therefore succeeded in its aim of assessing the suitability of the two talitrids as biomonitors of differences in metal bioavailabilities. The preliminary nature of the data preclude any in-depth discussion of possible local sources of metal contamination, and indeed the study has not been so designed. It is nevertheless possible to draw some initial conclusions.

Table 6 The number (*n*) and the dry weight (g: mean and range) of amphipods *Talorchestia quoyana* and *Orchestia tenuis* analysed for Cd concentration with details of the relationship $\log y = \log a + b \log x$, where y is the metal concentration ($\mu g\ g^{-1}$), x is the dry weight (g), and a and b (the regression coefficient) are constants. SIG. REG. is the significance of regression; ns not significant ($P > 0.05$).

Site	Dry weight (g)			Double-log regression		
	n	Mean	Range	*b*	SIG.REG.	log *a*
Talorchestia quoyana						
Aramoana	17	0.0163	0.0069–0.0321	–0.7469	ns	–0.2193
St Kilda	15	0.0345	0.0162–0.0650	–0.3047	ns	0.6270
Waldronville	9	0.0173	0.0053–0.0338	–0.1266	ns	0.9431
Tomahawk Beach	14	0.0214	0.0107–0.0459	–0.3615	ns	0.4231
Pilots Beach	21	0.0072	0.0023–0.0184	–0.4809	$P < 0.01$	0.0490
Sandfly Bay	15	0.0231	0.0098–0.0421	–0.0333	ns	1.0136
Smails Beach	16	0.0237	0.0122–0.0368	0.1306	ns	1.0660
Orchestia tenuis						
Deborah Bay	9	0.0132	0.0071–0.0168	–1.5366	$P < 0.01$	–2.2948
Waipuna Bay	9	0.0052	0.0027–0.0076	–0.9298	$P < 0.05$	–1.1251

Table 7 Estimates of Cd concentration ($\mu g\ g^{-1}$) with 95% confidence limits (CL) for amphipods of 10 mg standardised dry weight derived from best-fit double-log regressions. Locations are in descending order of estimated metal concentrations. Samples of one species sharing any common letter in ANCOVA column are not significantly different.

Site	Cd concentrations (CL)		ANCOVA
Talorchestia quoyana			
Aramoana	18.8	(10.9–32.5)	a
St Kilda	17.2	(9.4–31.6)	a
Waldronville	15.7	(13.4–18.5)	a
Tomahawk Beach	14.0	(9.4–21.0)	a, b
Pilots Beach	10.2	(8.1–13.0)	a, b
Sandfly Bay	8.9	(6.1–12.8)	b
Smails Beach	6.4	(3.1–12.6)	b
Orchestia tenuis			
Deborah Bay	6.0	(4.4–8.2)	a
Waipuna Bay	5.4	(3.3–8.9)	a

In the case of *T. quoyana*, availabilities of Cu, Zn, and Cd were relatively high at Aramoana in the outer region of Otago Harbour and either side of the sewage outfall at Lawyers Head. The positive correlations of rank orders of sites between Zn and Cd, and between Zn and Cu suggest that the metals are emitted from the same effluent sources, or at least from sources close together. In the case of all three metals and *O. tenuis*, Waipuna Bay (the site furthest from Dunedin) yielded amphipods with the lowest metal concentrations.

It is not possible to make interspecific comparisons of metal concentrations, because different species (even of the same genus) from the same site contain different accumulated concentrations (Rainbow & Moore 1986; Rainbow et al. 1989). It remains possible therefore that metal bioavailabilities within Otago Harbour are higher than at either side of the Lawyers Head outfall, in spite of the lower observed concentrations of Zn and Cd in *O. tenuis* than in *T. quoyana*. The high rank position of Aramoana in the *T. quoyana* data set suggests that metal bioavailabilities are still high in the outer regions of Otago Harbour.

It is concluded that both *T. quoyana* and *O. tenuis* can be used effectively as biomonitors of Cu, Zn, and Cd bioavailabilities in New Zealand coastal waters.

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