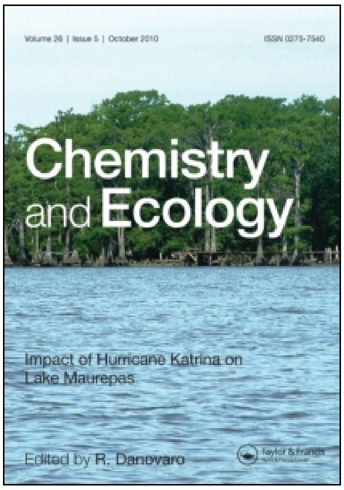

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Environmental Effects on Toxicity of Heavy Metals to Two Species of Tropical Marine Fish from Northern Australia

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The acute toxicities of mercury, copper, cadmium, zinc, nickel, and lead to adult and juvenile glass perch (*Priopidichthys marianus*) and juvenile diamond-scaled mullet (*Liza vaigiensis*) were examined. Tests with adult glass perch were carried out at 20°C and 36‰ salinity whilst those with juveniles were undertaken at all combinations of 30 and 20°C and 36 and 20‰ salinity. Tests with juvenile mullet were conducted at 20°C at both high and low salinity. All tests ran for 96 hours. The general rank order of metal toxicity to juvenile glass perch was Hg > Cu > Cd = Zn > Ni > Pb. Zinc appeared to be more toxic than cadmium to adult glass perch whilst for juvenile mullet the order was reversed. Both adult and juvenile glass perch exhibited similar tolerances towards mercury, copper and lead although juveniles seemed marginally more sensitive to zinc and considerably more sensitive to cadmium and nickel. Juvenile mullet were more susceptible to cadmium than juvenile glass perch tested under similar conditions, and were somewhat less tolerant of mercury and copper when held in low salinity seawater. Changes in the experimental temperature did not affect the toxicity of any metal tested whereas changes in salinity frequently did. Some preliminary observations relating to general and metal specific symptoms of intoxication are described. The toxicity data are discussed with respect to the metal tolerances of other marine fish species reported in the literature, and also with regards to existing water quality criteria.

INTRODUCTION

Tropical marine organisms inhabiting shallow coastal waters often live close to their upper lethal temperatures and are frequently subjected to steep salinity gradients, particularly during the summer months. Therefore, they experience a combination of stresses not normally encountered by similar species from cool, temperate regions of the world. Under such conditions even brief exposure to a potentially toxic material could be particularly damaging. Few studies have considered the interactive effects of environmental variables and pollutants on marine organisms from tropical waters, and in the absence of such data the full impact of environmental perturbations in these areas cannot be accurately assessed.

For these reasons the effects of temperature and salinity on the acute toxicities of six metals (mercury, copper, cadmium, zinc, nickel and lead) to certain tropical species from north Queensland coastal waters of Australia were examined. Tests conducted with juvenile banana prawns (*Penaeus merguiensis*) have previously been reported (Denton and Burdon-Jones, 1982). This paper presents data for juveniles of two, locally common marine teleosts. These are the glass perch, *Priopidichthys marianus* (Gunther), and the diamond-scaled mullet, *Liza vaigiensis* (Quoy and Gaimard). Juveniles of both species are abundant in shallow, nearshore waters during the summer months when ambient water temperatures are relatively high (Kenny, 1974) and cyclonic floods frequently cause coastal water salinities to fluctuate substantially (Archibald and Kenny, 1980). The possibility of them being particularly vulnerable to the added stresses imposed by heavy metal pollutants at this time, and therefore useful indicators of metal pollution in tropical waters, motivated the following investigation. A limited number of tests were also undertaken with adult glass perch and are included here for comparative purposes.

MATERIALS AND METHODS

Collection and preparation of material

Juvenile and adult glass perch (total length 15–20 mm and 50–70 mm respectively) and juvenile diamond-scaled mullet (15–20 mm) were obtained between October and December 1978 from

Townsville Harbour (19°15′18″S; 146°49′16″E). Temperature and salinity readings recorded weekly during this period ranged from 26 to 31°C and 34 to 35.6‰ respectively. The fish were captured in shallow waters using a wide mouthed dip-net. They were carefully transferred to large, plastic bins filled with continuously aerated seawater and transported to the laboratory. Here they remained without further disturbance and minimum temperature change for 48 h after which they were transferred to 200 l, glass, holding tanks (200 per tank). The temperature:salinity regimes adopted for testing juvenile glass perch were 30°C:36‰, 30°C:20‰, 20°C:36‰ and 20°C:20‰. These were considered to be reasonably representative of the range of conditions likely to be encountered locally (Kenny, 1974; Archibald and Kenny, 1980). Adult glass perch were only tested at 20°C:36‰ whilst juvenile mullet were only tested at 20°C:36‰ and 20°C:20‰.

The fish were adjusted to experimental temperatures at the rate of 1°C per day after which salinity adjustments were made at the rate of 2‰ per day. They were acclimatised to the appropriate test conditions for 14 days prior to testing and were fed a daily diet of freeze dried daphnia and tubifex worm up to 48 h before testing. The tanks were continuously aerated and faecal material was removed daily. The water was partially changed (50%) every two days. During the acclimation period the fish were subjected to a photo-period cycle of 12 h light and 12 h darkness. Both species were found to adapt well to laboratory conditions and mortalities were generally less than 5% in all holding tanks during acclimation.

Apparatus

All toxicity tests were conducted in polythene-lined, glass tanks (45 × 22 × 22 cm) covered with clear Perspex tops. The tanks were artificially aerated which maintained oxygen levels above 90% saturation at all times. Salinity adjustments were made with glass distilled water. The toxicant solutions were prepared and monitored as described earlier (see Denton and Burdon-Jones, 1982).

Test procedures

A series of five test tanks plus one control were used for each metal. Mortalities of all fish stocks used to determine metal toxicities were less than 10%. Specimens were carefully transferred, on a random basis, from the holding tanks to the test tanks and were left overnight prior to commencing tests. Each tank contained either 10 adult or 20 juvenile fish. Maximum wet flesh weights for each were approximately 5.0 g/l and <1.0 g/l of seawater respectively.

The test solutions were changed daily. All tanks were emptied simultaneously by siphon action to within 2–3 cm of the bottom, thereby minimising disturbances to the fish inside. Daily variations in temperature, salinity and pH were as previously reported (Denton and Burdon-Jones, 1982). Difficulties were encountered with lead (as $Pb(NO_3)_2$) which formed an immediate dense, white precipitate at all required concentrations. No attempt was made to overcome this problem. The fish were not fed during the tests and were continuously illuminated with white fluorescent light.

The tests were conducted over 96 h and the toxicity response measured was the mortality of the test individuals. The criterion for death was the cessation of opercular movements. Observations for deaths were made at regular intervals during the first 24 h and twice daily thereafter. Dead individuals were removed directly they were observed.

Data analysis

The toxicity data were analysed according to the procedure described by Litchfield and Wilcoxon (1949). This involved plotting the percentage mortalities in 96 h against the respective initial test concentration on log-probability paper. A line was fitted by eye and the median lethal concentration (96-LC50) was read from the graph. The 95% confidence limits, the LC84 and LC16 value, and the slope function (S) and its confidence limits were then calculated nomographically. Test populations whose controls exceeded 10% were rejected. Corrections for control mortalities were made using Abbott's formula (Tattersfield and Morris, 1924).

RESULTS

Table I lists the 96-h LC50 values for each metal to adult and juvenile glass perch and juvenile diamond-scaled mullet under the various conditions of temperature and salinity tested. From the data it is clear that both species of fish were most sensitive to mercury and least affected by lead. In general the toxicity of mercury proved to be:

1. between 5 and 10 times more toxic than copper;
2. between 20 and 50 times more toxic than cadmium and zinc;
3. between 50 and 100 times more toxic than nickel;
4. between 100 and 500 times more toxic than lead.

The general rank order of metal toxicity to juvenile glass perch can be summarized as:

$$Hg > Cu > (Cd, Zn) > Ni > Pb.$$

Zinc was more toxic than cadmium to adult glass perch whilst the reverse was true for juvenile mullet.

In tests conducted at 20°C:36‰ both adult and juvenile glass perch showed similar degrees of tolerance towards mercury, copper and lead, although juveniles appeared marginally more sensitive to zinc and considerably more sensitive to cadmium and nickel.

Juvenile mullet were more susceptible to cadmium than juvenile glass perch tested under similar conditions. Both species showed similar tolerances to the other metals at high salinity, whilst at low salinity mullet appeared more susceptible to mercury and copper.

Behavioural abnormalities

Preliminary observations of behavioural and physiological changes during tests with adult glass perch indicated general and metal specific symptoms of intoxication. General symptoms included increased swimming activity which became progressively more erratic and haphazard with time. Gill ventilation rates generally increased from approximately 40 to 110 per minute. Schooling behaviour was disrupted and fish became generally dispersed throughout the tank, whereas controls remained grouped together and were less active. As intoxication progressed fish became lethargic and often showed complete loss of equilibrium swimming in a head up or head down fashion. There were frequent periods of quiescence interrupted by frenzied, convulsive swimming movements which often terminated in tetanic coma on the tank bottom.

TABLE I

Summary of acute toxicity data derived for adult and juvenile glass perch (*Priopidichthys marianus*) and juvenile diamond-scaled mullet (*Liza vaigiensis*)

Fish species	Temp.: salin.	Decreasing order of metal toxicity	96-h LC84 (mg/l)	96-h LC50 + 95% confid. limits (mg/l)	96-h LC16 (mg/l)	Slope function (S) + 95% confid. limits
P. marianus (adult)	20°C:36‰	Hg	—	0.32–1.00	—	—
		Cu	4.10	2.55 (2.01–3.24)	1.6	1.60 (1.37–1.87)
		Zn	30.0	23.8 (19.4–29.2)	18.8	1.26 (1.01–1.58)
		Cd	59.5	45.0 (38.1–53.1)	35.0	1.30 (1.10–1.53)
		Ni	130	100 (80.0–125)	78.0	1.29 (1.03–1.61)
		Pb	238	183 (146–229)	144	1.29 (1.03–1.61)
P. marianus (juv)	30°C:36‰	Hg	0.58	0.35 (0.26–0.47)	0.22	1.63 (1.25–2.12)
		Cu	4.80	3.00 (2.24–4.02)	1.88	1.60 (1.33–1.92)
		Cd	30.0	18.0 (13.2–24.5)	11.1	1.65 (1.25–2.17)
		Zn	29.6	19.2 (14.6–25.2)	12.3	1.55 (1.27–1.89)
		Ni	62.0	44.5 (36.5–54.3)	32.5	1.38 (1.09–1.75)
		Pb	—	140–180	—	—
	30°C:20‰	Hg	1.12	0.50 (0.33–0.75)	0.23	2.21 (1.43–3.43)
		Cu	11.0	4.40 (2.49–7.79)	1.73	2.50 (0.74–8.5)
		Zn	22.0	17.0 (14.5–20.0)	13.0	1.30 (1.11–1.52)
		Cd	32.0	21.0 (16.9–26.0)	13.8	1.52 (1.25–1.86)
		Ni	64.0	42.0 (33.6–52.5)	27.0	1.54 (1.32–1.80)
		Pb	—	75.0–140	—	—

	20°C:36‰	Hg	1.60	0.42 (0.29–0.60)	0.11	3.90 (1.86–8.19)
		Cu	11.0	2.10 (1.40–3.15)	0.39	5.31 (1.89–14.9)
		Zn	28.0	17.5 (14.8–20.7)	10.8	1.61 (1.29–2.01)
		Cd	32.5	21.0 (10.5–42.0)	13.8	1.54 (0.77–3.08)
		Ni	72.0	47.5 (40.9–55.1)	31.5	1.51 (1.27–1.79)
		Pb	—	140–180	—	—
	20°C:20‰	Hg	1.30	0.65 (0.43–0.99)	0.33	1.99 (1.24–3.18)
		Cu	11.8	6.00 (4.28–8.40)	3.10	1.96 (1.44–2.66)
		Cd	25.0	13.5 (5.63–32.0)	7.0	1.89 (0.65–5.48)
		Zn	22.2	16.0 (11.4–22.4)	11.5	1.39 (1.04–1.86)
		Ni	54.0	30.0 (23.1–39.0)	16.2	1.83 (1.43–2.34)
		Pb	96.0	80.0 (68.1–94.0)	66.0	1.20 (0.96–1.50)
L. vaigiensis (juv)	20°C:36‰	Hg	0.95	0.38 (0.26–0.55)	0.14	2.60 (1.55–4.37)
		Cu	4.80	2.55 (1.70–3.83)	1.33	1.90 (1.31–2.76)
		Cd	10.0	7.80 (6.70–9.10)	6.20	1.27 (1.09–1.47)
		Zn	26.0	18.5 (15.7–21.8)	13.2	1.40 (1.19–1.64)
		Ni	74.0	55.5 (45.9–67.2)	41.0	1.34 (1.09–1.63)
		Pb	210	190 (179–201)	171	1.10 (0.92–1.31)
	20°C:20‰	Hg	0.85	0.33 (0.24–0.46)	0.13	2.56 (1.51–4.35)
		Cu	6.00	2.65 (1.61–4.37)	1.16	2.27 (1.34–3.86)
		Cd	11.0	5.25 (3.98–6.93)	2.53	2.08 (1.14–3.79)
		Zn	21.7	12.5 (9.76–16.0)	7.2	1.74 (1.42–2.13)
		Ni	56.0	40.0 (33.8–47.4)	29.0	1.39 (1.19–1.62)
		Pb	125	98.0 (79.7–121)	78.0	1.27 (1.02–1.57)

Ventilation frequency decreased towards death, but at the same time became deeper and more pronounced. Haemorrhaging from the nostrils, beside the eyes and from the base of the caudal and pectoral fins was occasionally observed.

Metal specific symptoms of intoxication were noted, with lead, mercury, cadmium, zinc and nickel e.g., fish exposed to lead initially spent more time swimming at the surface than did fish exposed to the other metals. Those exposed to mercury and cadmium frequently died with their body arched laterally, the pectoral fins at right angles to the body, and the operculae fully extended from the gills. Fish held in lethal concentrations of zinc suffered severe fin erosion and produced considerable quantities of mucus over their entire body surface, whilst those in cadmium darkened in colour prior to death. Fish exposed to nickel at concentrations of 56 and 75 mg/l showed increased swimming activity quite unlike that observed with the other metals. After 48 h at these concentrations certain individuals displayed short, sharp, forward darting movements in front of other fish, occasionally making deliberate contact with them. This was followed by short bursts of activity involving rapid and exaggerated swimming movements and swimming rapidly in small circles. Such behaviour continued in surviving fish for the duration of the test and was observed on two other occasions when tests with nickel were repeated.

Temperature and salinity effects

Surprisingly, an increase in temperature from 20 to 30°C in both salinity treatments did not significantly influence the toxicity of any metal studied to juvenile glass perch ($P > 0.05$). Salinity, on the other hand, influenced the toxicity of some metals to this species under certain conditions. For example, specimens maintained at 20°C in low salinity seawater were more susceptible to nickel and less sensitive to copper than their high salinity counterparts. At 30°C, however, there was no significant difference between salinity treatments for these metals. In contrast, lead was more toxic to glass perch in low salinity water at both experimental temperatures.

Juvenile mullet were also less resistant to nickel and lead at low salinity, although unlike juvenile glass perch their copper tolerance remained the same in both treatments. At 20°C, both species appeared somewhat more susceptible to zinc and cadmium at low salinity although the difference between data sets were not statistically significant.

DISCUSSION

Lethal concentration comparisons with other fish species

Comparatively few studies have examined the acute toxicity of heavy metals to marine fish. Table II lists some of the more readily available information for the purpose of establishing broad comparisons with the data presented here.

As early as 1881, Richet collectively summarised the 48 h maximum tolerance limits (i.e. 100% survival) of several Mediterranean fish species to mercury, copper, zinc, cadmium and nickel as 0.29, 3.3, 8.4, 17 and 125 mg/l respectively (see Table II). These are in reasonable agreement with the corresponding levels of 1.0, 1.8, 18, 32 and 125 mg/l obtained with adult glass perch during the present study.

The 96-h LC50 mercury values, for adult and juvenile glass perch and juvenile mullet, were similar to those calculated for the mummichog, *Fundulus heteroclitus*, by Dorfman (1977) and Eisler and Hennekey (1977). The 48-h LC50 mercury value for adult glass perch was 3.2 mg/l which is very similar to that given by Portmann and Wilson (1971) for the flounder, *Platichthys flesus*.

The copper tolerance of fish used in the present investigation was similar to other marine species studied (Portmann and Wilson, 1971; Dorfman, 1977; see Table II), although the work of Eisler and Gardner (1973) suggests that mummichogs are more resistant. This species also appears to tolerate relatively high concentrations of zinc (Eisler, 1967; Eisler and Gardner, 1973; Eisler and Hennekey, 1977), nickel (Dorfman, 1977; Eisler and Hennekey, 1977), and lead (Dorfman, 1977).

Juveniles of both species examined here showed similar degrees of tolerance towards zinc as juvenile yellow-eyed mullet, *Aldrichetta forsteri* (Negilski, 1976), and both were notably more susceptible to zinc than pre-adult, small mouthed hardyheads, *Atherinasoma*

TABLE II

Lethal concentrations (LC50's) of heavy metals to some marine fishes. Dashes indicate no data. n/s = not stated; mww = mean wet weight

Species	Developmental stage	Exposure (h)	Temp. (°C)	Sal. (‰)	Metal concentration (mg/l) Hg	Cu	Cd	Zn	Ni	Pb	Reference
Priopidichthys marianus	adult	96	20	36	0.32–1.0	2.55	45.0	23.8	100	183	Present study
Priopidichthys marianus	juvenile	96	30	36	0.35	3.00	18.0	19.2	44.5	140–180	Present study
Priopidichthys marianus	juvenile	96	30	20	0.50	4.40	21.0	17.0	42.0	75.0–140	Present study
Priopidichthys marianus	juvenile	96	20	36	0.42	2.10	21.0	17.5	47.5	140–180	Present study
Priopidichthys marianus	juvenile	96	20	20	0.65	6.00	13.5	16.0	30.0	80.0	Present study
Liza vaigiensis	juvenile	96	20	36	0.38	2.55	7.80	18.5	55.5	190	Present study
Liza vaigiensis	juvenile	96	20	20	0.33	2.65	5.25	12.5	40.0	98.0	Present study
Several species[a]	n/s	48	n/s	n/s	0.29	3.3	17	8.4	125	—	Richet, 1881
Fundulus heteroclitus	n/s; mww = 2.7 g (1.1–6.0)	96	20	5–7	0.3	2.3–3.1	36	17.5–32	55	315	Dorfman, 1977
Fundulus heteroclitus	n/s; mww = 2.7 g (1.1–6.0)	96	20	22–24	0.3	0.4–2.0	23	27.5–31.5	175	315	Dorfman, 1977
Fundulus heteroclitus	adult mww = 4.5 g	96	20	24	—	—	—	66	—	—	Eisler, 1967
Fundulus heteroclitus	n/s; wet wt 0.75–1.0 g	96	20	20	—	8.0[b]	—	60[b]	—	—	Eisler & Gardner 1973
Fundulus heteroclitus	n/s; mww = 1.0 g (0.3–3.2)	96	18	10	—	—	73	—	—	—	Voyer, 1975
Fundulus heteroclitus	n/s; mww = 1.0 g (0.3–3.2)	96	18	20	—	—	78	—	—	—	Voyer, 1975
Fundulus heteroclitus	n/s; mww = 1.0 g (0.3–3.2)	96	20	32	—	—	30	—	—	—	Voyer, 1975
Fundulus heteroclitus	n/s; mww = 0.89 g	96	20	20	—	—	55	—	—	—	Eisler, 1971
Fundulus heteroclitus	n/s; mww = 1.30 g (0.9–2.0)	96	20	20	0.8	—	22	60	350	—	Eisler & Hennekey, 1977
Fundulus majalis	n/s; mww = 0.95 g	96	20	20	—	—	21	—	—	—	Eisler, 1971
Cyprinodon varigatus	n/s; mww = 1.1 g	96	20	20	—	—	50	—	—	—	Eisler, 1971
Agonus cataphractus	n/s	96	15	n/s	—	—	33	—	—	—	Portmann & Wilson, 1971
Agonus cataphractus	n/s	48	15	n/s	—	—	33–100	—	—	—	Portmann & Wilson, 1971
Platichthys flesus	n/s	48	15	n/s	3.3	1–3.3	—	—	—	—	Portmann & Wilson, 1971
Aldrichetta forsteri	juvenile	96	25	35.6	—	—	—	11.5	—	—	Negilski, 1976
Aldrichetta forsteri	juvenile	120	18.6	34.8	—	—	14.3	—	—	—	Negilski, 1976
Atherinasoma microstoma	pre-adult	96	19.5	35.9	—	—	—	40.5	—	—	Negilski, 1976
Atherinasoma microstoma	pre-adult	168	18.0	34.5	—	—	14.7	—	—	—	Negilski, 1976

[a] The work of Richet (1881) collectively summarises the limits of tolerance (i.e., 100% survival after 48-h exposure) for *Serranus cabrilla*, *Crenolabrus mediterraneus*, *Julis vulgaris*, *J. gioffredi*.

[b] Only 30% mortality in 96 hours.

microstoma (Negilski, 1976). Even adult glass perch were less tolerant of zinc than the latter species.

The mechanisms of metal toxicity in fish have not been fully evaluated. Evidence suggests that under conditions of acute toxicity, damage to gill tissues and the subsequent decrease in gaseous exchange is the major cause of death (Lloyd, 1960; Gardner and Yevich, 1970; Skidmore, 1970; Eisler, 1971; Burton *et al.*, 1972a; Skidmore and Tovell, 1972; Hughes, 1973; Matthiesson and Bradfield, 1973; Morgan and Tovell, 1973; Hughes and Adney, 1977). The symptoms of acute poisoning described here also suggest that fish die largely as a result of gradual asphyxia, although additional factors may also be operating, e.g., damage to the alimentary canal and other internal organs may occur as a result of swallowing contaminated seawater during osmoregulation (see Gardner and Yevich, 1970; Cardeilhac *et al.*, 1979).

The absence of a temperature effect on metal toxicity during the present investigation is interesting. Since fish are poikilothermic it seems reasonable to suppose that the toxicity of heavy metals will be influenced by temperature. Indeed, for several species this has proved to be so (Doudoroff and Katz, 1953; Sprague, 1964; Burton *et al.*, 1972b; MacLeod and Pessah, 1973; Hodson, 1975; Negilski, 1976; Smith and Heath, 1979). In fact, just as a 10°C increase in water temperature approximately doubles the rate of metabolism in fish (Cairns *et al.*, 1975), so the susceptibility of certain species to heavy metals is increased by a similar amount (Lloyd, 1960; Pickering and Henderson, 1966; Eisler, 1971; Burton *et al.*, 1972b; Rehwoldt *et al.*, 1972; Hodson and Sprague, 1975; Smith and Heath, 1979). However, for other fish, including those studied here (see Table I), temperature appears to have little or no effect on metal toxicity (Cairns and Scheier, 1957; Pickering and Henderson, 1966; Rehwoldt *et al.*, 1972; Smith and Heath, 1979). There are also certain species for which temperature has been shown to influence the toxicity of some metals but not others (Rehwoldt *et al.*, 1972; Smith and Heath, 1979).

The reasons for the above discrepancies are unclear. Obviously some species will adjust better than others to the stresses imposed by temperature changes and this may be an important consideration. It is also possible that, in some species, increased temperature may accelerate the rates of detoxification and excretion of certain metals, and so cancel out the effect of temperature on their toxicity (Cairns *et al.*, 1975).

The influence of salinity upon metal toxicity to the fish examined here was largely as expected as it is well known that the potency of certain metals to marine fish and fish eggs is increased at decreased salinity (Holliday, 1965; Eisler, 1971; Westernhagen *et al.*, 1974; Dorfman, 1977; Voyer *et al.*, 1977). Such effects are usually attributed to changes in chemical speciation and/or solubility (Pagenkopf *et al.*, 1974; Davies *et al.*, 1976; Sunda *et al.*, 1978) or to competitive interactions with major cations (e.g., Ca^{2+}, Mg^{2+}) for active sites of uptake (Westernhagen *et al.*, 1974; see also fresh-water studies of Zitko and Carson, 1976; Carroll *et al.*, 1979; Judy and Davies, 1979).

The greater toxicity of copper to juvenile glass perch at high rather than low salinity during the low temperature experiments was unusual. As the solubility of copper increases with decreasing salinity and the free copper ion is generally thought to be the most toxic form of the metal (Pagenkopf *et al.*, 1974; Shaw and Brown, 1974) the reverse situation would seem more appropriate. It is possible, therefore, that the data are erroneous, although it is interesting that Dorfman (1977) noted a similar effect of salinity upon the toxicity of copper chloride to mummichogs.

Derivation of upper safety levels from acute toxicity data

"Safe" levels for copper, cadmium, zinc, nickel and lead were derived for juveniles of both fish species using the 96-h LC50 data (Table II) in conjunction with application factors recommended by the National Academies of Science and Engineering (NAS/NAE, 1974) and the American Environmental Protection Agency (EPA, 1976). The lowest overall 96-h LC50 value was selected for each metal from all treatments considered. It can be seen from Table III that the "safe" levels derived for cadmium, zinc and nickel were well above each metal's minimal risk concentration advocated by NAS/NAE (1974) for the protection of the marine environment. Hence, current water quality criteria for these metals appears to provide adequate protection for both species. It is noteworthy, however, that ambient seawater levels of cadmium and zinc in Townsville Harbour (Table III) are very close to their respective

TABLE III
"Safe" levels of heavy metals for juvenile glass perch (*Priopidichthys marianus*) and juvenile diamond-scaled mullet (*Liza vaigiensis*) compared with existing quality criteria for marine waters

Metal	Minimal risk concentrations (μg/l) (NAS/NAE, 1974)	Safe levels (μg/l)		Metal levels in Townsville Harbour[d] (μg/l)
		P. marianus	*L. vaigiensis*	
Mercury	0.1[a]	[c]	[c]	<0.01
Copper	10	21	26	2.15–4.24
Cadmium	0.2	135	53	0.08–0.13
Zinc	20[a]	160	125	10.75–17.87
Nickel	100	300	400	0.29–0.41
Lead	[b]	1600	1960	0.30–0.66

[a] EPA 1976.
[b] Insufficient data for criterion for marine waters.
[c] Application factor not available.
[d] Unpublished data.

minimal risk concentrations. Relatively small concentration increases of both metals in this area could, therefore, threaten the well-being of more sensitive organisms.

In contrast to the above metals, "safe" levels derived for copper† were relatively close to the proposed minimal risk concentration for this metal and less than an order of magnitude above maximum levels recently recorded in Townsville Harbour (Denton, unpublished data). Marginally elevated levels of copper could, therefore, pose a very real potential threat to both fish species in this environment.

No application factor exists for mercury. Instead a maximum acceptable concentration of 0.1 μg/l for the protection of the marine environment has been established (EPA, 1976). This value is approximately 3×10^{-3} times lower than the lowest 96-h LC50 mercury value for both fish species tested and would seem to afford them adequate protection. The value is also well above current mercury concentrations in Townsville Harbour waters.

The "safe" levels derived for lead for each species are considered to be unrealistically high owing to the gross precipitation of lead

† An application factor of 0.01 (NAS/NAE, 1974) rather than 0.1 (EPA, 1976) was used to derive "safe" levels for copper as mortalities were occasionally observed in test concentrations as low as 0.1 mg/l.

salts observed in all test tanks. Undoubtedly it is the soluble lead component which poses the greatest threat to aquatic organisms and for this reason it may be argued that the 96-h LC50 values should be based on this fraction alone. However, the physical impediment of gaseous exchange and/or osmoregulation due to the precipitate adhering to surface membranes could possibly exacerbate the soluble lead toxicity and, therefore, may also need to be taken into account during the final analysis.

Concluding remarks

The results show that the tropical fishes *Priopidichthys marianus* and *Liza vaigiensis* tolerate similar concentrations of mercury, cadmium, lead, copper, zinc and nickel as other marine fish species reported in the literature. They also show that the temperature extremes, normally encountered in local waters, seem to have little effect upon the ability of these species to withstand heavy metal pollution. Although salinity was generally shown to be the more important variable in this regard, its influence was also relatively minor as the 96-h LC50 values rarely differed by more than a factor of 2.0 between treatments. However, it is possible that this resistance to heavy metal pollutants is more severely affected under conditions of rapidly fluctuating salinities, although this has yet to be substantiated.

Both fish species are relatively metal tolerant compared with several other marine organisms, particularly the larval and juvenile crustaceans (Portmann, 1968; Conner, 1972; Rosenberg and Costlow, 1976; Ahsanullah and Arnott, 1978; Denton and Burdon-Jones, 1982). Thus, they are not really suitable for establishing quality criteria for tropical marine waters, at least, not for those metals considered here.

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