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Acute Toxicity of Copper, Cadmium, and Mercury to the Freshwater Fish *Varicorhinus barbatus* and *Zacco barbata*

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ABSTRACT

Acute toxicities of copper, cadmium, and mercury to the freshwater fish *Varicorhinus barbatus* and *Zacco barbata* found in clear upstream waters were studied as a basis for the protection of river water quality and the ease of aquaculture pond management. In all cases, the higher the concentration of metal used, the quicker the animals died. Twenty-four-hour LC_{50} values of copper, cadmium, and mercury to *V. barbatus* were 0.305 mg/l Cu, 1.657 mg/l Cd, and 0.183 mg/l Hg; however 96-h LC_{50} values decreased to 0.246 mg/l Cu, 1.502 mg/l Cd, and 0.168 mg/l Hg,respectively. Similarly, 24-h LC_{50} values of copper, cadmium, and mercury to *Z. barbata* were 0.130 mg/l Cu, 2.598 mg/l Cd, and 0.201 mg/l Hg;96-h LC_{50} values were 0.079 mg/l Cu, 1.510 mg/l Cd,and 0.161 mg/l Hg,respectively. The order of metal toxicity to *V. barbatus* is Hg > Cu > Cd, while to *Z. barbata* it is Cu > Hg > Cd. To protect aquatic organisms, biologically safe concentrations of copper and mercury are suggested to be 7 µg/l and 1.5 µg/l,respectively. However more studies are needed to determine this level for cadmium.

Key words: Acute toxicity, Copper, Cadmium, Mercury, *Varicorhinus barbatus*, *Zacco barbata*.

INTRODUCTION

The importance of experimental exposure of fish to industrial waste for predicting its potential damage to aquatic ecology has been advocated and demonstrated (Sprague, 1969). Information provided by various toxicity tests can be used in the management of water pollution: (a) to estimate the environmental effects of a waste; (b) to compare different toxicants among tested animals; and (c) to regulate the amount of discharge of pollutants (Buikema *et al.*, 1982). Thus an acute toxicity test can easily assess the effects of pollutants at high concentrations and can compare the toxicity of different toxicants in a short time.

Heavy metals have long been considered to be serious pollutants inducing their toxic effects on aquatic fauna (De Mayo *et al.*, 1979; USEPA, 1980; Mance, 1984). Copper, cadmium, and mercury are especially toxic (Arthur and Leonard, 1970; Reeder *et al.*, 1979; Chen *et al.*, 1980; Nriagu, 1980; Ingersoll and Winner, 1982; Nebeker *et al.*, 1984). Copper sulfate has been used to control protozoan diseases in fish and is used extensively in ponds as an algicide. However, copper is quite toxic to fish, including such cultured species as cyprinids and catfish, when concentrations are increased. Cadmium is not a biologically essential trace element for aquatic organisms. It is basically nonexistent in unpolluted water, and if abun-

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dant in water it may induce the following changes in fish: alterations of steroid hormones (Sangalang *et al.*, 1972), extension of skeletal muscle contractions and longitudinal body contractions, and vertebrae collapse due to vertebral overloading (Bengtsson *et al.*, 1975).

Extensive evidence indicates that mercury affects ionic homeostasis. Water-borne mercury inhibits the activity of gill Na^+-K^+ ATPase (Renfro *et al.*, 1974; Borquegneau, 1977), an enzyme responsible for active ion intake by gill epithelium. Lock *et al.* (1981) showed that dissolved mercury altered the permeability characteristics of gills, increasing passive ionic effluxes. Additionally, mercury accumulating via the diet, a more environmentally realistic route of intake (Phillips and Buhler, 1978; Dallinger *et al.*, 1987), also seems to disrupt ion regulation in fish and other organisms (Stagg *et al.*, 1992; Wright and Welbourn, 1993).

There are about 60 species of primary division freshwater fishes in Taiwan. They are widely distributed in streams; the dominant species are *Varicorhinus barbatus* and *Zacco barbata*. The former is found in upper reaches of streams with high dissolved oxygen and water temperatures below 20°C. However, it can still be seen in lower reaches of rivers in eastern Taiwan at low elevations,due to rapid water currents and lower water temperatures (Tzeng, 1986). *Z. barbata*, an endemic freshwater fish,is widely distributed in streams of western Taiwan (Shen *et al.*, 1993). Due to the destruction of habitat by water pollution in rivers and high demand for human consumption in recent years, the cultured area of these two species of fish has increased. Altogether there are many studies on culturing, breeding, and nutrition of *V. barbatus* and *Z. barbata* (Tang *et al.*, 1987; Peng *et al.*, 1988, 1989, 1990; Huang *et al.*, 1998; Shyong *et al.*, 1998), research on the toxicity of heavy metals to freshwater fishes in rivers is very scarce in Taiwan (Chen et al., 1994). Accordingly, the present study investigates and compares the acute toxicities of three heavy metals: copper, cadmium, and mercury to *V. barbatus* and *Z. barbata*. In addition, it can also provide a reference for stipulating water quality criteria to protect aquatic life and for aquaculture pond management.

MATERIALS AND METHODS

Fry of *V. barbatus* were bought from Chienshih Hsiang, Hsinchu Country, Taiwan, and *Z. barbata* were obtained from the hatchery in our laboratory. The fish were acclimatized in a laboratory tank under experimental conditions for at least 1 week before use. Water was changed regularly and maintained at a temperature of 24-26°C, pH 8.1-8.5, dissolved oxygen 6 mg/l, and total hardness 140-160 mg/l as $CaCO_3$. Average total body length of the two species used for this study was in the range of 1.60 to 1.80 cm.

Stock solutions were prepared by dissolving 3.929 g $CuSO{\cdot}5H_2O$ (Merck reagent grade), 2.031 g $CdCl_2{\cdot}21/2H_2O$ (Merck reagent grade), or 1.357 g $HgCl_2$ (Merck reagent grade) in 1 liter of deionized water to make 1000 mg/l solutions of copper, cadmium, and mercury, respectively. Before commencing the experiments, the stock solutions were diluted to the desired concentrations with chlorine-free aerated tap water.

For acute toxicity tests, 20 randomly selected *V. barbatus* or *Z. barbata* were placed in 2-L beakers for each metal concentration, with replications done for each treatment and for untreated controls. Test beakers were kept in rooms with a constant temperature of 25°C. The acute toxicity tests utilized a static method without aeration or feeding (Buikema *et al.*, 1982), test solutions were renewed daily. Concentrations of heavy metals tested by atomic absorption spectrum were checked and maintained between 85%and 100%before the next water renewal. In all test solutions, dissolved oxygen of the water was maintained in a range of 5.2 to 6.7 mg/l, water temperature 25 ± 1°C, pH 7.5-8.3, and total hardness 150-160

Table 1. Mortality rates (%) of *Varicorhinus barbatus* exposed to different concentrations of copper for various time periods.

Time elapsed	Concentration (Cu mg/l)										
(h)	0	0.24	0.26	0.28	0.30	0.32	0.34	0.36	0.38	0.40	0.42
24	0	10	30	45	45	57.5	60	77.5	80	92.5	100
48	0	30	40	55	57.5	65	70	87.5	87.5	97.5	100
72	0	30	50	60	65	70	72.5	92.5	95	100	-
96	0	40	60	75	80	82.5	82.5	92.5	95	100	-

Table 2. Mortality rates (%) of *Varicorhinus barbatus* exposed to different concentrations of cadmium for various time periods.

Time elapsed	Concentration (Cd mg/l)							
(h)	0	1.4	1.5	1.6	1.7	1.8	1.9	2.0
24	0	10	15	45	50	75	90	100
48	0	15	20	45	55	80	95	-
72	0	20	25	60	65	80	95	-
96	0	35	40	70	85	85	100	-

Table 3. Mortality rates (%) of *Varicorhinus barbatus* exposed to different concentrations of mercury for various time periods.

Time elapsed	Concentration (Hg mg/l)							
(h)	0	0.12	0.14	0.16	0.18	0.20	0.22	0.24
24	0	10	10	30	35	70	80	100
48	0	10	15	30	35	70	80	-
72	0	15	20	35	40	75	85	-
96	0	15	25	40	45	80	85	-

mg/l as $CaCO_3$.

The LC_{50} (median lethal concentration) value and 95% confidence limits were calculated using a microcomputer program following the method of Trevors and Lusty (1985).

RESULTS AND DISCUSSION

Percentage mortalities of *V. barbatus* exposed to three heavy metals (copper, cadmium, and mercury) for different times are shown in tables 1-3. It is clear that mercury caused higher mortality than the other metals. From these tables, the LC_{50} values and 95% confidence limits of heavy metals for *V. barbatus* were calculated and are shown in table 4. It can be seen that the LC_{50} values and 95% confidence limits of the three heavy metals decrease with increasing time of exposure in hours. Generally speaking, the higher the concentration of toxicants, the lower the LC_{50} values. However, the LC_{50} values were not remarkedly shortened in prolonged exposure, showing that these three metals are very toxic, even after 24 h. Comparing the toxicity of the three metals

Table 4. LC_{50} values of copper, cadmium, and mercury, and 95% confidence limits for *Varicorhinus barbatus* at different time periods (h).

Heavy metal	Concentration (mg/l) 24-h LC_{50}	48-h LC_{50}	72-h LC_{50}	96-h LC_{50}
Cu	0.305	0.279	0.270	0.246
	(0.295-0.315)	(0.269-0.290)	(0.258-0.282)	(0.229-0.264)
Cd	1.657	1.622	1.587	1.502
	(1.607-1.708)	(1.574-1.671)	(1.536-1.639)	(1.434-1.573)
Hg	0.183	0.181	0.173	0.168
	(0.170-0.196)	(0.169-0.195)	(0.161-0.186)	(0.157-0.180)

Table 5. Mortality rates (%) of *Zacco barbata* exposed to different concentrations of copper for various time periods .

Time elapsed (h)	Concentration (Cu mg/l) 0	0.07	0.09	0.11	0.13	0.15	0.17	0.19	0.21	0.23
24	0	0	10	33.3	56.7	66.7	76.7	90	93.3	100
48	0	26.7	30	70	73.3	93.3	96.7	100	100	-
72	0	30	56.7	80	83.3	100	100	-	-	-
96	0	36.7	60	90	96.7	-	-	-	-	-

Table 6. Mortality rates (%) of *Zacco barbata* exposed to different concentrations of cadmium for various time periods .

Time elapsed (h)	Concentration (Cd mg/l) 0	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0	4.4
24	0	0	0	20	30	42.5	55	67.5	70	80	100
48	0	0	10	32.5	50	67.5	90	100	100	100	-
72	0	0	12.5	40	60	75	95	-	-	-	-
96	0	12.5	22.5	40	65	87.5	97.5	-	-	-	-

Table 7. Mortality rates (%) of *Zacco barbata* exposed to different concentrations of mercury for various time periods.

Time elapsed (h)	Concentrations (Hg mg/l) 0	0.12	0.14	0.16	0.18	0.20	0.22	0.24	0.26
24	0	0	0	5	25	45	80	85	100
48	0	0	15	40	65	97.5	100	100	-
72	0	2.5	20	50	75	100	-	-	-
96	0	2.5	22.5	50	77.5	-	-	-	-

Table 8. LC_{50} values of copper, cadmium, and mercury and 95% confidence limits for *Zacco barbata* at different time periods (h).

Heavy metal	Concentration (mg/l)			
	24-h LC_{50}	48-h LC_{50}	72-h LC_{50}	96-h LC_{50}
Cu	0.130	0.095	0.084	0.079
	(0.121-0.138)	(0.088-0.103)	(0.076-0.094)	(0.073-0.086)
Cd	2.598	1.915	1.774	1.510
	(2.387-2.829)	(1.787-2.052)	(1.660-1.897)	(1.395-1.635)
Hg	0.201	0.163	0.162	0.161
	(0.195-0.207)	(0.158-0.168)	(0.157-0.167)	(0.156-0.166)

to *V. barbatus*, it is obvious that mercury is the most toxic, followed by copper, with cadmium being the least toxic.

It is interesting to note that the order of toxicity of heavy metals to *Z. barbata* has the following sequence: Cu > Hg > Cd. This result indicates that the toxicity of copper to *Z. barbata* is stronger than that of mercury, which is an unusual case; but a similar result was also found in other fish (Yuan, 1994). From tables 4 and 8, it can be seen that toxicities of cadmium and mercury to *V. barbatus* and *Z. barbata* are more or less the same.

In addition, some related literature and important publications dealing with metal toxicity in Taiwan after 1980 are summarized in table 9 for comparison. It is clear that *Acrosscheilus paradoxus* is most sensitive to copper (Chen *et al.*, 1994), followed by *V. barbatus*, *Z. barbata* (present study), *Plecoglossus altivelis* (Lin *et al.*, 1989), common carp (Wai *et al.*, 1982), *Misgurnus anguillicaudatus* (Lin *et al.*, 1989), and grass carp (Wai *et al.*, 1984). The most tolerant fish to copper is *Anguilla japonica* (Tsay *et al.*, 1981).

Similarly, different animals have various degrees of tolerance to cadmium. *A. paradoxus* (Chen *et al.*, 1994)is still the most sensitive species to cadmium poisoning, followed by *V. barbatus*, *Z. barbata* (present study), common carp (Wai *et al.*, 1982) and *Aristichthys nobilis* (Huang, 1987). The most insensitive species to cadmium toxicity is tilapia (Tsay *et al.*, 1981).

As to the toxicity of mercury to freshwater fish, *P. altivelis* was found to be the most sensitive species (Lin *et al.*, 1989), followed by *V. barbatus*, *Z. barbata* (present study), grass carp (Wai *et al.*, 1984) and common carp (Wai *et al.*, 1982); *Acrosscheilus paradoxus* was not tested. The most insensitive species to mercury is *M. anguillicaudatus* (Lin *et al.*, 1989).

Summarizing all the data, the order of toxicity of these three heavy metals to most freshwater fishes in Taiwan is mercury > copper > cadmium; these conclusions were reached from the fact that the LC_{50} values are the lowest and the differences of LC_{50} values among all fish are the least for mercury, then copper, and cadmium. However, the order of toxicity of copper > mercury > cadmium in the case for *Z. barbata* shows that this fish is most sensitive to copper poisoning. Determining the reason requires further studies. It has been mentioned that small fish or younger organisms are more susceptible to metal poisoning than are larger or more mature fish. However, it can also be seen from Table 9 that fish inhabitating clear waters are less tolerant of metal toxicity than those found in eutrophic waters.

Other environmental factors including water temperature, hardness, and pH can also affect the acute toxicity and fish tolerance. Waiwood and Beamish (1978) reported that toxicity increases at lower levels of water hard-

Table 9. Toxicity of copper, cadmium, and mercury to other freshwater fishes in Taiwan.

Chemical	Species	Water quality	LC_{50} (mg/l)		Reference
$CuSO_4$	*Anguilla japonica*	28 ± 1°C	24-h	149.00	Tsay *et al.*
	8.61 cm	pH 7.7-8.4	48-h	34.50	(1981)
	0.65 g		72-h	23.20	
			96-h	23.20	
	Tilapia sp.	28 ± 1°C	24-h	38.575	Tsay *et al.*
	2.13 cm	pH 7.7-8.4	48-h	17.250	(1981)
	0.26 g		72-h	14.686	
			96-h	10.647	
$CuSO_4 \cdot 5H_2O$	*Cyprinus carpio*	23°C	24-h	0.31	Wai *et al.*
	1.5-2.0 cm	210 mg/l $CaCO_3$	48-h	0.29	(1982)
	0.01-0.025 g	pH 6-8			
$CuSO_4 \cdot 5H_2O$	*Ctenopharyngodon idellus*	24-30°C	24-h	0.72	Wai *et al.*
	3.5-4.0 cm	210 mg/l $CaCO_3$	48-h	0.40	(1984)
	1.2-1.5 g	pH 6-8			
$CuSO_4 \cdot 5H_2O$	*Clarias fuscus*	24-30°C	24-h	4.05	Wai *et al.*
	1.0-1.5 cm	210 mg/l $CaCO_3$	48-h	3.30	(1984)
		pH 6-8			
$CuSO_4$	*Aristichthys nobilis*	23-28°C	24-h	1.13	Huang
	5.4-6.3 cm	210 mg/l $CaCO_3$	48-h	0.89	(1987)
	0.16-1.72 g	pH 6-8			
$CuSO_4 \cdot 5H_2O$	*Misgurnus anguillicaudatus*	215 mg/l $CaCO_3$	24-h	0.446	Lin *et al.*
	4.0-5.5 cm	pH 6-8	48-h	0.204	(1989)
	Plecoglossus altivelis	215 mg/l $CaCO_3$	24-h	0.136	Lin *et al.*
	3.9-4.7 cm	pH 6-8	48-h	0.102	(1989)
	Acrosscheilus paradoxus	22°C	24-h	0.044	Chen *et al.*
	1.50-1.80 cm	30-38 mg/l $CaCO_3$	48-h	0.033	(1994)
		pH 7.5-8.3	96-h	0.026	
$CuSO_4 \cdot 5H_2O$	*Varicorhinus barbatus*	24-28°C	24-h	0.305	Present study
	1.50-1.80cm	140-160 mg/l $CaCO_3$	48-h	0.279	(2000)
		pH 8.1-8.5	96-h	0.246	
$CuSO_4 \cdot 5H_2O$	*Zacco barbata*	24-28°C	24-h	0.130	Present study
	1.50-1.80cm	140-160 mg/l $CaCO_3$	48-h	0.095	(2000)
		pH 8.1-8.5	96-h	0.076	

Table 9. Toxicity of copper, cadmium, and mercury to other freshwater fishes in Taiwan. (Cont. 1)

Chemical	Species	Water quality	LC_{50} (mg/l)	Reference	
$CdCl_2 \cdot 21/2H_2O$	*Tilapia* sp.	28 ± 1°C	24-h	140	Tsay *et al.*
	2.13 cm	pH 7.7-8.4	48-h	53.223	(1981)
0.26 g			72-h	38.571	
			96-h	4.053	
	C. carpio	23-27°C	24-h	2.40	Wai *et al.*
	1.0-2.0 cm	210 mg/l $CaCO_3$	48-h	2.15	(1982)
	0.01-0.03 g	pH 6-8			
	Poecilia reticulata	24 ±1°C	96-h	5.98	Lin *et al.*
	1.5 ±0.5 cm				(1983)
	C. idellus	24-30°C	24-h	42.5	Wai *et al.*
	3.5-4.0 cm	210 mg/l $CaCO_3$	48-h		(1984)
	1.2-1.5 g	pH 6-8	41.2		
	C. fuscus	24-30°C	24-h	46.3	Wai *et al.*
	1.0-1.5 cm	210mg/l $CaCO_3$	48-h	43.1	(1984)
		pH 6-8			
	A. nobilis	23-28°C	24-h	8.38	Huang
	4.5-6.3 cm	210 mg/l $CaCO_3$	48-h	7.54	(1987)
	0.61-1.72 g	pH 6-8			
	Micropterus salmoides	23-28°C	24-h	74.64	Huang
	2.5-2.8 cm	210 mg/l $CaCO_3$	48-h	52.40	(1988)
		pH 6-8			
	M. anguillicaudatus	215 mg/l $CaCO_3$	24-h	76.118	Lin *et al.*
	4.0-5.5 cm	pH 6-8	48-h	71.297	(1989)
	P. altivelis	215 mg/l $CaCO_3$	24-h	16.031	Lin *et al.*
	3.9-4.7 cm	pH 6-8	48-h	13.943	(1989)
$CdCl_2 \cdot 21/2H_2O$	*V. barbatus*	24-28°C	24-h	0.305	Present study
	1.50-1.80cm	140-160 mg/l $CaCO_3$	48-h	0.279	(2000)
		pH 8.1-8.5	96-h	0.246	
$CdCl_2 \cdot 21/2H_2O$	*Z. barbata*	24-28°C	24-h	0.130	Present study
	1.50-1.80cm	140-160 mg/l $CaCO_3$	48-h	0.095	(2000)
		pH 8.1-8.5	96-h	0.076	

Table 9. Toxicity of copper, cadmium, and mercury to other freshwater fishes in Taiwan. (Cont. 2)

Chemical	Species	Water quality	LC_{50} (mg/l)		Reference
$HgCl_2$	*A. paradoxus*	22°C	24-h	0.555	Chen *et al.*
	1.50-1.80 cm	30-38 mg/l $CaCO_3$	48-h	0.371	(1994)
		pH 7.5-8.3	96-h	0.292	
$HgCl_2$	*A. japonica*	28 ±1°C	24-h	0.476	Tsay *et al.*
	8.61 cm	pH 7.7-8.4	48-h	0.294	(1981)
	0.65 g		72-h	0.250	
			96-h	0.154	
	C. carpio	23°C	24-h	0.24	Wai *et al.*
	1.5-2.0 cm	210 mg/l $CaCO_3$	48-h	0.21	(1982)
	0.01-0.025 g	pH 6-8			
	C. idellus	24-30°C	24-h	0.25	Wai *et al.*
	3.5-4.0 cm	210 mg/l $CaCO_3$	48-h	0.20	(1984)
	1.2-1.5 g	pH 6-8			
	C. fuscus	24-30°C	24-h	0.34	Wai *et al.*
	1.0-1.5 cm	210 mg/l $CaCO_3$	48-h	0.25	(1984)
		pH 6-8			
	A. nobilis	23-28°C	24-h	0.63	Huang
	4.5-6.3 cm	213.6 mg/l $CaCO_3$	48-h	0.55	(1987)
		DO>6 mg/l			
		pH 6.0-8.9			
	M. salmoides	23-28°C	24-h	0.312	Huang
	2.5-2.8 cm	210 mg/l $CaCO_3$	48-h	0.312	(1988)
		pH 6-8			
	M. anguillicaudatus	215 mg/l $CaCO_3$	24-h	0.997	Lin *et al.*
	4.0-5.5 cm	pH 6-8	48-h	0.813	(1989)
	P. altivelis	215 mg/l $CaCO_3$	24-h	0.185	Lin *et al.*
	3.9-4.7 cm	pH 6-8	48-h	0.148	(1989)
$HgCl_2$	*V. barbatus*	24-28°C	24-h	0.305	Present study
	1.50-1.80cm	140-160 mg/l $CaCO_3$	48-h	0.279	(2000)
		pH 8.1-8.5	96-h	0.246	
$HgCl_2$	*Z. barbata*	24-28°C	24-h	0.130	Present study
	1.50-1.80cm	140-160 mg/l $CaCO_3$	48-h	0.095	(2000)
		pH 8.1-8.5	96-h	0.076	

Table 10. Safe concentrations of three heavy metals for *Varicorhinus barbatus* and *Zacco barbata* and some foreign water quality standards.

Parameter	Water quality standards for aquaculture (Meade, 1989)	Malaysia national water quality standards (Doe·UM, 1986)	Taiwan water quality standards (Taiwan EPA, 1985)	Safe concentration (96-h LC_{50}x 0.1~0.01) (*Varicorhinus barbatus*)	Safe concentration (96-h LC_{50}x 0.1~0.01) (*Zacco barbata*)
Cu (mg/l) Alkalinity					
< 100 mg/l	0.006	0.008	0.003	0.024	0.007
> 100 mg/l	0.03				
Cd (mg/l) Alkalinity					
< 100 mg/l	0.0005	0.0007	0.01	0.0150	0.0151
> 100 mg/l	0.005				
Hg (mg/l)	< 0.02	0.0001	0.002	0.0016	0.0016

ness. Since both high Ca^{+2} and Mg^{+2} concentrations significantly reduce the immediate effects of Cu^{+2} exposure(Bjerselius *et al.*, 1993), Cu^{+2} is less toxic in hard water than in soft water (Andrew *et al.*, 1977; Pagenkopf *et al.*, 1974; Howarth and Sprague, 1978; Chakoumakos *et al.*, 1979; Miller and Mackay, 1980). Similar results have been reported for cadmium (Jones, 1938; Pickering and Henderson, 1966; Eaton, 1974).

Acute toxicity tests can detect the toxic damage of pollutants in a short period; they also make it easy to compare the degree of toxicity among different pollutants and the relative sensitivities of animals to the same pollutant (Buikema *et al.*, 1982). Accordingly, in the evaluation of environmental damage resulting from pollutants or the establishment of water quality criteria to protect aquatic life, we always use 96-h LC_{50} values multipled by a factor of 0.1-0.01 to arrive at a biologically safe concentration (Sprague, 1971). In compliance with such an evaluation, biologically safe concentrations for *V. barbatus* are 0.024 mg/l Cu, 0.015mg/l Cd, and 0.0016 mg/l Hg. Similarly evaluated biologically safe concentrations for *Z. barbata* are 0.007 mg/l Cu, 0.0151 mg/l Cd, and 0.0016 mg/l Hg. Therefore in view of the need to protect most natural resources, a stricter criterion (0.007 mg/l Cu) should be adopted. This is in good agreement with USEPA criteria (1986). A similar result is also obtained for mercury. However, the biologically safe concentration of cadmium obtained in the present study is much higher than those in the USA (USEPA, 1986; Meade, 1989), as well as water quality standards for aquaculture in Malaysia and Taiwan (Taiwan EPA, 1997) (Table 10). Thus, water quality criteria for cadmium have to be further investigated.

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銅、鎘、汞對台灣鏟頜魚和台灣馬口魚的急性毒性

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摘 要

本研究探討銅、鎘、汞對台灣鏟頜魚（*Varicorhinus barbatus*）、台灣馬口魚（*Zacco barbata*）之急性毒性，以做為河川水質、訂定水質基準保護與魚類養殖之參考。由本研究發現銅對台灣鏟頜魚和台灣馬口魚的 24,48,72,96 小時之LC_{50}分別是 0.305 ，0.279 ，0.270 ，0.246 mg/l CuSO4-Cu 和0.130 ，0.095 ，0.084 ，0.079 mg/l CuSO4-Cu 。鎘對台灣鏟頜魚和台灣馬口魚的24,48, 72,96 小時之LC_{50}分別是 1.657 ，1.622 ，1.587 ，1.502 mg/l CdCl2-Cd 和2.598 ，1.915 ，1.774 ，1.510 mg/l CdCl2-Cd 。至於汞對台灣鏟頜魚和台灣馬口魚的24,48,72,96 小時之LC_{50}分別是 0.183, 0.181 ，0.173 ，0.168 mg/l HgCl2-Hg 和0.201, 0.163 ，0.162 ，0.161 mg/l HgCl2-Hg 。三種重金屬對台灣鏟頜魚和台灣馬口魚的毒性大小分別是汞＞銅＞鎘和銅＞汞＞鎘。比較各種淡水魚對重金屬毒性之能力，則發現愈在清淨上游棲身的魚類較不耐重金屬之毒害。由本研究銅與汞對魚類的生物安全濃度建議為0.007 mg/l 及 0.0015 mg/l ，至於鎘，仍待更多研究及參考數據。

關鍵詞：台灣鏟頜魚、台灣馬口魚、銅、鎘、汞、急性毒性。