Bull. Environm. Contam. Toxicol. 22,113-119 (1979)

Acute Toxicity of Copper, Chromate, Zinc, and Cyanide to Freshwater Fish: Effect of Different Temperatures

Micke J. Smith and Alan G. Heath

Department of Biology, Virginia Polytechnic Institute and State University, Blacksburg, Va. 24061

Since fish are ectothermic (poikilothermic), nearly all chemical processes in the animal are affected by the water temperature. Generally, the metabolism of fish increases approximately two-fold for each rise of 10°C, although there are exceptions (PROSSER 1973). It would, therefore, seem that the toxic effect of chemical pollutants on fish would be influenced by temperature. In a survey of the literature, CAIRNS et al. (1975) concluded that an elevated temperature does indeed increase toxicity of most pollutants but the extent of this effect is slight in longer term (>48h) tests, whereas short-term acute exposure situations seem to be more prone to temperature modulation. These conclusions were based on data from a variety of studies utilizing a variety of methodology, and in many cases, the temperature range studied was small. Consequently, comparisons of different pollutants and fish species were limited. This paper reports results from a study where acute toxicities of a variety of pollutants to five species of fish were tested using a uniform methodology and comparable temperature ranges so general patterns of response might be seen.

MATERIALS AND METHODS

Twenty-four h bioassay tests following the general procedures of SPRAGUE (1969) were used to determine the lethal concentrations to freshwater fish of potassium cyanide, copper sulfate, zinc sulfate, and potassium dichromate at three temperatures. Fish species used were: Rainbow trout (Salmo gairdneri), Golden shiner (Notemigonus crysoleucus), Bluegill (Lepomis macrochirus), Goldfish (Carassius auratus), and Channel catfish (Ictalurus punctatus). Young of less than 10 cm total length were used (Table 1). All species except trout were acclimated to 5, 15, and 30°C for 3 wk before exposure to the test toxicant at the acclimation temperature. Trout were acclimated and tested in water at 5, 12, and 18°C.

Supported by a grant from the U.S. Office of Water Research and Technology.

0007-4861/79/0022-0113 $01.40

TABLE 1

Fish Sizes and Chemical Characteristics of Water in Test Tanks

	Fish weight (g)			
	$\bar{X}$	SD	Range	N
Goldfish	1.93	1.05	0.6-5.8	800
Golden shiner	2.56	1.02	0.6-4.9	700
Bluegill	0.64	0.67	0.1-3.0	650
Channel catfish	8.81	3.86	2.0-20.3	350
Rainbow trout	4.42	1.95	1.1-11.8	750

	Fish length (cm)			
	$\bar{X}$	SD	Range	N
Goldfish	4.59	0.73	3.1-6.6	800
Golden shiner	6.42	0.78	3.2-7.6	700
Bluegill	3.43	0.72	2.2-5.8	650
Channel catfish	9.72	1.42	6.3-13.4	350
Rainbow trout	7.25	3.19	4.0-10.6	750

Hardness (mg/L as $CaCO_3$) 36

Oxygen (mg/L)	$\bar{X}$	SD	N	Range	$\bar{X}$ decrease 24/h (SD)
5 C	11.0	0.75	125	9.0-12.5	0.53 (0.35)
15 C	8.5	0.56	100	6.2-9.9	0.65 (0.49)
30 C	6.0	0.91	100	4.2-7.9	0.41 (0.30)

pH (by toxicant)	$\bar{X}$	SD	N	Range
control	7.4	0.4	60	6.5-8.1
CN^-	7.6	0.3	46	6.7-8.1
Zn^{++}	7.1	0.4	40	5.8-7.8
Cr^{+6}	5.8	0.8	50	4.6-7.5
Cu^{++}	7.2	0.4	60	6.3-7.8

The bioassays were performed in 40 L Nalgene containers submerged in a large water bath for temperature control ($\pm$ 1°C). Four groups of 10 fish each were exposed to toxicant concentrations bracketing a preliminary estimate of the 24-h LC50, and the fifth group served as a control. The percent survival at 1, 2, 4, 8, 12 and 24-h in each concentration was recorded. All dead and surviving fish were measured for length and weight (Table 1). The 24-h LC50 for each temperature,

toxicant, and species was then calculated by the method of LITCHFIELD and WILCOXON (1949).

At the beginning and end of each run, dissolved oxygen, pH, and test toxicant concentrations were measured (Table 1). Dissolved oxygen was measured by a YSI oxygen probe and pH was measured with a pH meter. Cyanide, chromate, and copper were measured colorimetrically using the methods outlined in Standard Methods (APHA 1971). Zinc was measured by atomic absorption spectrometry. The concentration of the test toxicants declined over the 24-h period (Table 2) so the mean was used as the effective concentration. In all cases, except cyanide, concentrations reported are for the cation only. For the cyanide tests, the anion concentration is reported.

TABLE 2

Percent Decline in Toxicant Concentration during a 24-h period. Mean with Sample Size in Which a Decline was Observed (N)/Total Number of Concentrations Tested (T).

Temp. (C)	5		15		30	
	$\bar{X}$	(N/T)	$\bar{X}$	(N/T)	$\bar{X}$	(N/T)
% Δ $[CN^-]$/24 h*	32.9	(3/18)	27.4	(9/16)	32.0	(12/12)
% Δ $[Zn^{++}]$/24 h	9.6	(10/16)	2.7	(4/12)	2.0	(3/12)
% Δ $[Cr^{+6}]$/24 h	8.8	(8/20)	19.1	(8/10)	7.1	(3/20)
% Δ $[Cu^{++}]$/24 h	11.0	(13/26)	18.5	(16/16)	17.0	(20/20)

*Analytical method for cyanide at the low concentrations effective upon trout was near its limit of sensitivity thus giving poor precision.

RESULTS

Cyanide: Temperature had a considerable effect on CN toxicity to goldfish, less effect in golden shiners, and none with the other species tested (Fig. 1A). The thermal effect, where found, was not linear in that the only differences were between 5 and 15°C and no significant differences between 15° and 30°. Several workers (CAIRNS et al. 1975) have reported that fish die faster in highly lethal concentrations of CN when the temperature is elevated, however, there seems to have been little examination of temperature effect on the actual concentration that is lethal. Our results suggest this is slight in most species except goldfish where lowering the temperature to 5°C raised the LC50 by a factor of

five, compared to that at 15°C.

Cyanide is a well known aerobic metabolism inhibitor which, if present in sufficient concentration, would force a fish to metabolize anaerobically. Crucian carp (Carassius carassius) are able to metabolize anaerobically for long periods (up to several months) at low temperatures (BLAZKA 1958), an ability not widely developed among fishes. Goldfish are closely related to carp and have been shown to survive anaerobically for several days at 4°C but only a few hours at 20°C (WALKER and JOHANSEN 1977). This might help explain their ability to tolerate relatively high concentrations of CN in water of low temperature.

Chromate: As with CN, the greatest temperature effect on toxicity of Cr (Fig. 1B) was seen with goldfish (ca. three-fold differences between 5° and 30°C). Golden shiner showed a slight, but significant decrease in sensitivity at 5°C compared to 30°C. The other species were unaffected by temperature in their response to Cr. Except for goldfish, this slight thermal effect is in agreement with REHWOLDT et al. (1972) who determined 24h LC50's for chromate using six other species of warm water fish.

Zinc: From the literature reviewed and our study, it is evident there is considerable species variation in the response to Zn (Fig. 2B). There was a definite tendency for it to be more toxic at the higher temperatures to goldfish and bluegill, but not shiners or trout. REHWOLDT et al. (1972) noted no effect of temperature on Zn 24h LC50 levels for a different group of freshwater fish species tested at 15° and 28°C. HODSON and SPRAGUE (1975) in a study on Atlantic salmon found a slightly higher threshold LC50 for Zn at 19° than at either 3° or 11°C, which is the reverse of our findings. However, these authors reported shorter survival times at elevated temperatures in acutely lethal concentrations of Zn. Since our tests were acute 24h ones, rather than threshold determinations, we may not actually be in disagreement, for the response to temperature is apparently concentration dependent. HODSON and SPRAGUE'S data show that at 24 hours Atlantic salmon are more sensitive at 19°C than at 3°C. Such apparent contradictions may be due to the way concentration influences which temperature permits the longest survival. CAIRNS, et al. (1978) indicated "temperature crossovers" occur causing tests using low concentrations (as for threshold LC50's) to show longer survival at higher temperatures while tests using high concentrations (as for acute 24h LC50's) show

longer survival at lower temperatures. Thus, discussions about any toxicant being more or less effective at one temperature over another may depend on what concentration range was being used.

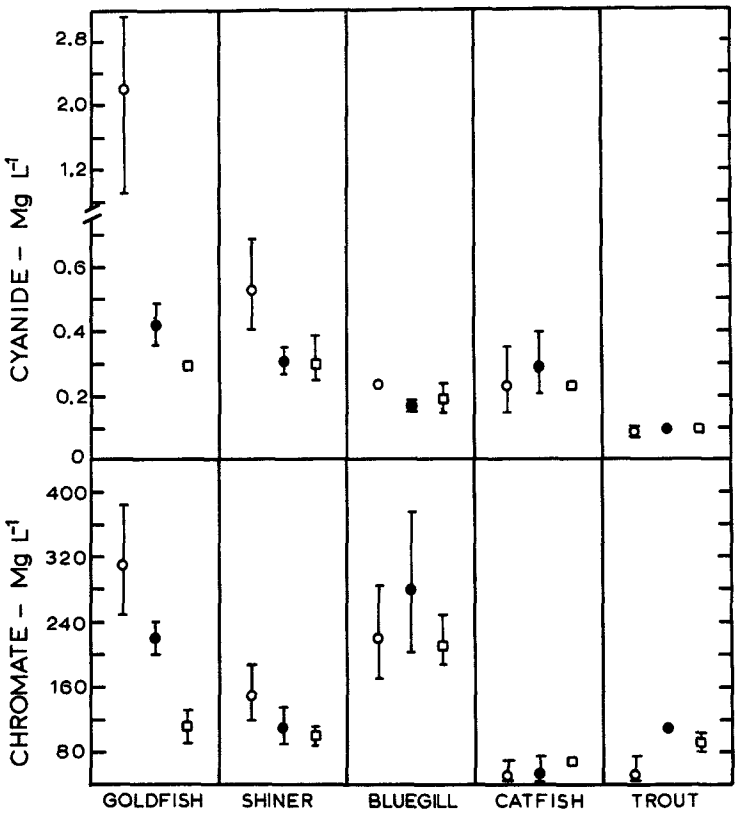

FIGURE 1 - Twenty-four hour median lethal concentrations of cyanide (A) and chromate (B) for the fish species indicated. Vertical lines are 95% confidence intervals. Open circles = 5°C; closed circles = 15°C; squares = 30°C. Trout temperatures 5°, 12°C, and 18°C respectively.

Copper: The Cu bioassays indicate considerable variation between species (Fig. 2A). There was a tendency for a higher sensitivity at the higher temperatures in goldfish, channel catfish, and trout but the converse was seen with bluegill. Also, in catfish, the greatest sensitivity was at 15°C rather than 30°C. In all cases, the differences caused by temperature

were by a factor of two or less, whereas the differences in sensitivity between the various species at a given temperature were as much as six-fold. Again REHWOLDT et al. (1972) noted no significant effect of temperature on Cu toxicity for their group of fish species.

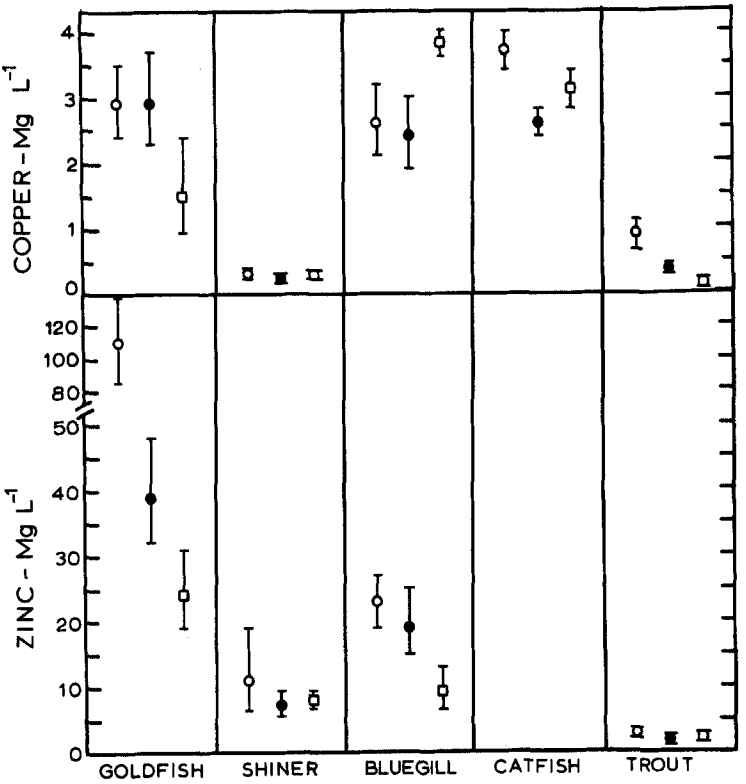

FIGURE 2 - Twenty-four hour median lethal concentrations of copper (A) and zinc (B) for the fish species indicated. Vertical lines are 95% confidence intervals. Open circles = 5°C; closed circles = 15°C; squares = 30°C. Trout temperatures 5°, 12°, and 18°C respectively.

DISCUSSION

The scattered literature reviewed by CAIRNS et al. (1975) suggests there would be a relatively large impact of temperature on toxicity when acute concentrations are studied in a uniform manner as we did. Our results show

that acutely lethal concentrations of some pollutants can be altered by the ambient temperature with some fish species. However, with the exception of goldfish, these differences are not likely to have a large practical importance. Over a temperature span of 25°C the LC50's did not differ by more than a factor of three. On the other hand, LC50 differences between species at a given temperature were as great as ten-fold suggesting the species may be a more critical factor.

The goldfish are interesting because they exhibited the greatest temperature effect on lethal concentrations with each of the pollutants. Goldfish are the specified test organism in the ORSANCO 24h bioassay (ORSANCO 1974). Since our bioassays were also 24h the results are directly relevant and should be considered when using the ORSANCO bioassay for testing industrial effluents.

REFERENCES

APHA: Standard Methods for the Examination of Water and Wastewater. 13 ed. Wash. D.C. 1971.

BLAZKA, P.: Physiological Zoology 31, 119 (1958).

CAIRNS, J., Jr., A. G. HEATH, and B. C. PARKER. Hydrobiologia 47, 135 (1975).

CAIRNS, J., Jr., A. L. BUIKEMA, A. G. HEATH, and B. C. PARKER: Virginia Water Resources Research Center, Bull. 106, 88P (1978).

HODSON, P. V. and J. B. SPRAGUE: J. Fish. Res. Bd. Can. 32, 1 (1975).

ORSANCO Biological Water Quality Committee: ORSANCO 24-Hour Bioassay. Cincinnati, Ohio River Valley Sanitation Commission (1974).

PROSSER, C. L. (ed): Comparative Animal Physiology, 3rd ed. Philadelphia: W. B. Saunders Co. 1973.

REHWOLDT, R., W. MENAPACE, B. NERRIE, AND D. ALLESSARDRELLO: Bull. Environ. Contam. Toxicol. 8, 91 (1972).

SPRAGUE, J. B.: Water Research 3, 793 (1969).

WALKER, R. M. and P. H. JOHANSEN: Canadian J. Zool. 55, 1304 (1977).