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Synergism Between Dissolved Oxygen and Cadmium Toxicity in Five Species of Aquatic Insects

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Continuous-flow bioassays were employed to determine the relationship between dissolved oxygen and cadmium upon five species of aquatic insects, as measured by survival and the amount of cadmium found within the insect. Results indicate the toxicity of cadmium increases as the dissolved oxygen concentration increases. This may be explained by an observed increase in the amount of cadmium found in the insect as the dissolved oxygen concentration increases. Oxygen consumption has been reported to increase as the dissolved oxygen concentration increases (Petty, 1967; Ericksen, 1963; Fox *et al.*, 1937). In this study, using a fixed cadmium concentration, the amount of cadmium found in the insect also increased with an increase in the dissolved oxygen. Therefore, cadmium absorption may be coupled to metabolism.

INTRODUCTION

Literature on the oxygen requirements of aquatic organisms is substantial (Doudoroff, 1957; Ellis, 1937; Doudoroff and Shumway, 1967). These data indicate individual species sensitivity as well as concentrations in which survival is impossible. Gaufin (1973) has reported these data for several species of aquatic insects (Table 1). However, information concerning the effects of dissolved oxygen in combination with exposure to a toxicant are limited. Lloyd (1961) found in rainbow trout, the toxicity of phenol, ammonia chloride, zinc, lead and copper

TABLE 1
THE EFFECTS OF DISSOLVED OXYGEN ON SOME AQUATIC INSECTS AS MEASURED BY SURVIVAL[a,b]

Species	Dissolved oxygen concentration (mg/liter)	Percent survival for 21 or more days
Acroneuria pacifica	4.2	100
Brachycentrus americanus	4.8	100
Ephemerella grandis grandis	4.6	60
Holorusia sp.	4.6	100
Pteronarcella badia	3.6	50

[a] From Gaufin, 1973.
[b] Data verified by senior author with excellent corroboration.

were increased as the dissolved oxygen concentration decreased. Downing (1954), Westfall (1945), and others have corroborated Lloyd's findings.

Specific studies on the effect of dissolved oxygen on the toxicity of cadmium to aquatic insects are unknown to the authors. However, Hynes (1963), Jones (1964), and Mackenthun (1969) state that in fish and aquatic invertebrates, the toxicity of most toxicants are increased as the dissolved oxygen concentration decreases.

The purpose of this study was to determine the relationship between dissolved oxygen and cadmium upon five species of aquatic insects, as measured by survival time and the amount of cadmium found within the insect. If laboratory conditions characterize occurrences in the environment, these data may then be used to establish cadmium concentration limits for aquatic environments with low dissolved oxygen concentrations.

METHODS

Continuous-flow bioassays were conducted in accordance with the methods described by the American Public Health Association (1971). Tap water, thermostatically controlled, was deoxygenated by a degasser (Mount, 1964), then cycled through a serial diluter (Mount and Warner, 1965) to introduce cadmium. The deoxygenated cadmium-containing water was then channeled to the top of a glass ladder (Gaufin, 1973). Since oxygen was absorbed from the air, there was an increasing oxygen gradient from the top of the ladder with a constant cadmium concentration.

Survival rate comparisons were made at a fixed cadmium concentration, while varying the dissolved oxygen concentration. Cadmium uptake was determined using the surviving insects at the completion of a bioassay. Experimental procedures, preparation and collection of insects, and cadmium analysis recapitulated methods described by Clubb, Gaufin, and Lords (1974).

The test organisms in this study were: the crane fly (Diptera), *Holorusia* sp.; the mayfly (Ephemeroptera), *Ephemerella grandis grandis* Eaton; the stoneflies (Plecoptera), *Acroneuria pacifica* Banks and *Pteronarcella badia* (Hagen); the caddisfly (Tricoptera), *Brachycentrus americanus* (Banks).

The dilution water had the following characteristics: temperature 12° ± 2° C; pH 7.8; alkalinity 240.0 mg/liter. The average flow rate was 30.0 liter/hour. The cadmium concentrations tested ranged from 1.0 to 5.0 mg/l as Cd^{2+}. Bioassays were discarded if the cadmium concentration varied more the 0.1 mg/liter from the designated concentration or if the dissolved oxygen concentration varied more than 0.25 mg/liter from the designated concentration.

RESULTS

A summary of the effect of dissolved oxygen on the toxicity of cadmium to aquatic insects tested is given in Table 2. All data, except that for *Brachycentrus*, show an increase in cadmium toxicity with increasing dissolved oxygen. The effect of dissolved oxygen on the toxicity of cadmium in *Pteronarcella* after seven days of 5.0 mg Cd/liter at various dissolved oxygen concentrations is illustrated in Fig. 1. No mortality was observed with *Pteronarcella* at dis-

TABLE 2
THE EFFECT OF DISSOLVED OXYGEN ON CADMIUM TOXICITY AS MEASURED BY SURVIVAL

Species	Cadmium concentration (mg Cd/liter)	Percent survival @ 2 weeks D.O. 4.6–4.9 mg/liter	Percent survival @ 2 weeks D.O. 6.2–7.6 mg/liter
Acroneuria pacifica	1.0	80	50
Ephemerella grandis grandis	2.5	70	20
	5.0	40	10
Holorusia sp.	5.0	100	80
Brachycentrus americanus	5.0	100	100

solved concentrations of 2.1–3.0 mg/liter. Beginning with 3.0 mg/liter dissolved oxygen, the mortality increased as the dissolved oxygen concentration increased: these data best fit the equation $Y = 2.38e^{-0.3X}$, with a correlation coefficient[1] of 0.99.

Table 3 shows the amount of cadmium found in the supernatant and 3000 g sediment of *Brachycentrus, Ephemerella* and *Pteronarcella* when exposed to 5.0 mg Cd/liter for 4 days at different dissolved oxygen concentrations. All data indicate an increase in the amount of cadmium found in the supernatant and sediment, when the dissolved oxygen concentration is increased.

CONCLUSIONS

Petty (1967), Ericksen (1963) and Fox *et al.* (1937) report oxygen consumption increases as the dissolved oxygen concentration is increased, in studies with stoneflies and mayflies. These data indicate oxygen consumption may be interpreted by an exponential function, since at high dissolved oxygen concentrations, the rate of oxygen consumption becomes asymptotic with respect to the dissolved oxygen concentration. Petty (1967) has explained the attenuation in the rate of oxygen consumption with increased dissolved oxygen by a "Pasteur Effect," i.e., oxygen inhibition of metabolism.

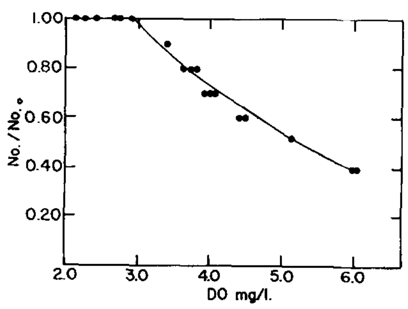

FIG. 1. The effect of dissolved oxygen upon cadmium toxicity to *Pteronarcella badia*, when exposed to 5.0 mg Cd/liter for 7 days.

[1] Correlation coefficient (r) determined by Least Square Fit.

$$r = n\Sigma_{XY} - \Sigma_x\Sigma_y/([n\Sigma_X{}^2 - (\Sigma_X)^2][n\Sigma_Y{}^2 - (\Sigma_Y)^2])^{-1/2}.$$

TABLE 3
CADMIUM UPTAKE IN THE SUPERNATANT AND 3000 GRAMS SEDIMENT AT DIFFERENT DISSOLVED OXYGEN CONCENTRATIONS AFTER FOUR DAYS OF 5.0 mg Cd/l

Species	Dissolved oxygen concentration (mg/liter)	μg Cd/g insect in the supernatant	μg Cd/g insect in the sediment
Brachycentrus americanus	3.5	2.04	25.0
	4.5	4.05	27.6
	5.8	4.20	32.2
Ephemerella grandis grandis	3.0	22.0	41.0
	3.5	32.0	123.0
	4.0	39.0	233.0
Pteronarcella badia	3.8	7.8	114.0
	5.4	17.8	136.0
	6.1	27.6	254.0

Two facts support the possibility that cadmium absorption may be coupled to metabolism. First the rate of oxygen consumption has been used as a measurement of metabolic activity, i.e., increased oxygen consumption equals increased metabolic activity. Therefore, the observed decrease in the amount of cadmium absorbed with decreased dissolved oxygen, may be explained if cadmium absorption were coupled to the metabolism of the insect. Second the survival of *Pteronarcella* at a fixed cadmium concentration is best explained by an exponential curve. This curve would appear to approximate a mirror image of the curve for the rate of oxygen consumption found with other insects. Again, metabolic coupling appears to be involved.

In comparing mortality rate with cadmium absorption at different oxygen concentrations, the abatement in the toxicity of cadmium, with the attenuation of the dissolved oxygen, may be explained by the decrease in the amount of cadmium found in the insect. Although no mortality was observed with *Brachycentrus*, at any dissolved oxygen concentration tested, an increase in the amount of cadmium found in the supernatant and sediment was still observed, when the dissolved oxygen concentration increased.

Since this study employed relatively low cadmium concentrations, at higher cadmium levels *Brachycentrus* could also show increased mortality with increased dissolved oxygen concentrations. These data would therefore suggest that cadmium may have less of an effect in an oxygen deprived environment, than in one with normal oxygen concentrations.

SUMMARY

Three conclusions may be drawn from these data: (1) The toxicity of cadmium in the aquatic insects tested decreased with decreased dissolved oxygen concentrations. (2) The abatement in cadmium toxicity with decreased dissolved oxygen may be explained by the reduction in the amount of cadmium found in the insect. (3) Cadmium absorption may be coupled to the metabolism of the insect.

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