*Variations in algal sensitivity to metals

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Abstract

A radiotracer study of the accumulation and toxicity of Cd, Zn, Ag, and Hg in four marine phytoplankters showed that varying algal sensitivities to these metals was in part attributable to the varying metal reactivities of the different cell surfaces but primarily attributable to the extent of safe accommodation or storage of metal within the cells.

Résumé

Une étude avec radiotraceurs de l'accumulation et de la toxicité du Cd, Zn, Ag, et Hg pour quatre espèces phytoplanctoniques a montré que les différentes sensibilités algales à ces métaux étaient en partie attribuables aux variations des réactivités métalliques pour les différentes surfaces cellulaires, mais qu'elles étaient dues avant tout à une séquestration, par securité, de ces métaux dans les cellules.

There are numerous reports which document the very wide range of sensitivity of phytoplankton - both marine and freshwater - to metals. There is both considerable variation in toxicity of different metals to a given algal cell and in sensitivity of different algal species to a given metal. Previous studies have identified two possible mechanisms for the latter observation: differential metal accumulation between sensitive and resistant cells (see, for example, Foster, 1977) and sequestration of cellular metal in harmless sites within the cell (see, for example, Daniel and Chamberlain, 1981). However, to date there have been no systematic studies to compare the varying sensitivities of different algal species to different metals and at the same time to monitor metal accumulation in these cells. We have therefore conducted a series of laboratory culture experiments, using gamma-emitting radiotracers, to examine the accumulation and toxicity of Cd, Ag, Zn, and Hg in four marine phytoplankters, including a diatom, a green alga, a coccolithophore, and a filamentous blue-green alga (cyanobacterium) (Fisher *et al.*, in press).

The results indicated that accumulation of all metals always proceeded by passive adsorption, in general accordance with Freundlich adsorption

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isotherms. Volume/volume concentration factors (VCFs) computed at equilibrium ranged from 3×10^2 for the diatom to 9.5×10^4 for the coccolithophore (Table 1). Toxicity, determined by depression of log-linear cell division rate (μ), was examined as a function of external and cellular metal concentration. In both cases, and for all metals and species, toxicity was best described as an exponential function of metal concentration:

$$y = 100 - ae^{bx}$$

where y = (μ treated ÷ μ control cells)(100) and x = metal concentration (log M for dissolved ambient, log mol $cell^{-1}$ for cellular). When expressed as a function of ambient metal, the order of accumulation and toxicity was $Hg > Ag > Zn \geq Cd$. On a cellular basis, Hg was the most toxic to all species while no clear trend appeared for the other metals. EC_{50} values, or those metal concentrations in the cells which depressed μ by 50%, ranged from 7.9×10^{-5} M for Hg in the blue-green to 0.2 M for Zn in the green alga. In comparing the algal response to cellular metal (on a weight basis) with metal levels in natural phytoplankton in the Mediterranean and the Pacific, it was found that natural cellular levels of Cd are 7×10^{-4} the lowest EC_{50} observed. Ag is 5×10^{-3} the lowest EC_{50}, Hg is $\sim 10^{-2}$ the lowest EC_{50}, and Zn is $\sim 5 \times 10^{-2}$ to 10^{-1} the lowest EC_{50}. Thus, only in very contaminated coastal waters would cellular concentrations of these metals be expected to approach levels toxic to marine phytoplankton.

Table 1. Concentration factors (VCFs)($\times 10^3$) and sublethal toxicity (EC_{50}) of four metals in four marine phytoplankters. Cellular EC_{50} values are normalized on a cellular volume basis (-log mol metal μm^{-3} cell).

	Cd		Zn		Ag		Hg	
	VCF	EC_{50}	VCF	EC_{50}	VCF	EC_{50}	VCF	EC_{50}
<u>Thalassiosira pseudonana</u> (diatom)	0.3	16.7	12	16.8	34	16.6	93	18.6
<u>Dunaliella tertiolecta</u> (green)	1.0	16.8	10	15.7	13	16.2	32	16.9
<u>Emiliania huxleyi</u> (coccolithophore)	0.4	16.7	4.6	16.7	24	17.8	95	18.8
<u>Oscillatoria woronichinii</u> (blue-green)	1.0	nd	5.2	16.6	66	18.0	76	19.1

<u>Dunaliella tertiolecta</u>, the green alga, was the most resistant species to Zn, Ag, and Hg. In part, its greater resistance was attributable to metal exclusion, as it had 2 to 5 fold lower VCFs for Ag and Hg than did the other

species (Table 1). However, D. tertiolecta was capable of tolerating cellular metal concentrations of up to 10 (Zn) or 100 (Ag and Hg) times those in the other species (Table 1), indicating safe accomodation of cellular-bound metal. This hypothesis of safe accommodation of cellular metal is consistent with the "threshold" response of the cells to cellular metal concentrations, as reflected in the exponential equation which described μ vs. metal concentration. Thus, it appears that differential metal sensitivity among algal species is primarily a function of the degree to which the different cells can safely sequester - chemically or physically - the metal within the cell.

Mechanisms of detoxification of cellular metal may include precipitation of metal sulfide, binding of metal by metallothionein-type proteins, and metal inclusion in intracellular vesicles.

REFERENCES

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Discussion

A. BOLOGA: Have you used contaminated phytoplankton for food chain experiments?

N. FISHER: Yes, we frequently conduct experiments in which we feed radio-labelled phtyoplankton to marine herbivores, including mussels, crustacean and gelatinous zooplankton. I would refer you to another contribution in this volume - involving mussels - as an example of this sort of work.

F. CARVALHO: Did the metals tested behave similarly to transuranium elements, in particular with respect to adsorption by cells and localization in the cell?

N. FISHER: I did not attempt to localize the sites of deposition in the cells of these metals. However, I can say that the accumulation process appeared to be strictly passive in all cases. You'll recall that all metal-treated cells were washed with 10^{-4} M EDTA, so the metal we detected was either within the cells or very firmly bound to the cells' surfaces.

T. VUCETIC: Have you done some experiments with algal resting stages?

N. FISHER: No, all experiments were conducted with algal cells in the vegetative state.

S. FOWLER: What was the range of concentrations you used and those at the threshhold of toxicity?

N. FISHER: The external (i.e. dissolved) range of Cd was 4.4×10^{-8} M to 4.4×10^{-3} M; of Zn from 1.5×10^{-6}M to 1.5×10^{-3}M; of Ag from 9.3×10^{-10} M to 9.3×10^{-5} M. and of Hg from 5×10^{-10} M. Given the different concentration factors of different metals in different species, it is most appropriate to relate toxicity to cellular metal concentrations, and compare these with metal concentrations in natural phytoplankton populations. In so doing, it was found that natural cellular levels of Cd are 7×10^{-4} the lowest EC_{50} observed; Ag is $\sim 5 \times 10^{-3}$ the lowest EC_{50}; Hg is $\sim 10^{-2}$ the lowest EC_{50}, and Zn $\sim 5 \times 10^{-1}$ the lowest EC_{50}. Thus, in contaminated waters, one can expect Zn and perhaps Hg to reach levels toxic to sensitive algal species.