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Cadmium—A Priority Pollutant

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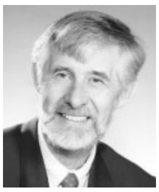
This issue of *Environmental Chemistry* features a series of papers that focus on cadmium as an environmental contaminant. This emphasis on cadmium is welcome and perhaps overdue. Unlike mercury and lead, two metals that are widely recognized as environmental contaminants, cadmium historically has had a much lower profile.

Attempts for both pre- and post-industrial times to quantify the relative importance of anthropogenic and natural contributions to cadmium cycling in the environment have consistently shown that the contribution from anthropogenic sources (e.g. non-ferrous metal industry) has increased greatly over the past century and that it currently dominates the cadmium biogeochemical cycle.[1,2] In addition, acid rain and the resulting acidification of soils and surface waters have increased the geochemical mobility of cadmium, and as a result its surface-water concentrations tend to increase as lakewater pH decreases (for review see ref. [3]).

Since the 1970s there has been sustained interest in possible exposure of humans to cadmium through their diet, e.g. through consumption of certain species of shellfish or vegetables. Concern regarding this latter route (agricultural crops) led to research on the possible consequences of applying sewage sludge (cadmium-rich 'biosolids') to soils used for crops destined for human consumption, or of using cadmium-enriched phosphate fertilizer. Indeed, one of the papers in the current Research Front[4] updates this particular research area, and identifies criteria that may be used to identify high-risk soils to which such amendments should not be added. However, the driving force in this research area has been concern for the health of the final (human) consumer, not for the state of the plant itself.

This lack of concern for the effects of cadmium on comestible plants carried over to the other environmental compartments, and historically the possible effects of cadmium on the aquatic or terrestrial ecosystem have simply been ignored. However, there is now mounting evidence that cadmium is present in aquatic and terrestrial environments at levels that are sufficient to provoke a biological response in the indigenous biota.[5–7] For example, Larison et al.[5] measured trace metals in the tissues of the white-tailed ptarmigan or grouse (*Lagopus leucurus*) in Colorado, USA, and in the food web leading to this herbivorous species. Their results showed that cadmium concentrations in the buds and recently grown shoots of various willow species (*Salix* spp.) were several orders of magnitude higher than normal background concentrations for this species, and indeed were also higher than those in other ptarmigan foods. The foraging behaviour and over-wintering distribution of individual birds appeared to affect their exposure and internal dose of cadmium; levels sufficient to be toxic were observed in 44% of adult birds from the ore-belt area. Indeed, histopathological examination revealed renal damage in 57% of the high-cadmium populations.

Similarly, but in the aquatic environment, Campbell et al.[6] (and references cited therein) collected yellow perch (*Perca flavescens*) from a series of lakes up- and down-wind from a major copper–zinc smelter located in Rouyn-Noranda, in north-western Quebec, Canada. In lakes at the high end of the exposure gradient, cadmium accumulated in the indigenous yellow perch to concentrations well above background tissue values. Cadmium accumulation was accompanied by metallothionein induction, but metal detoxification by metallothionein was incomplete[8] (see also ref. [9]). Consistent with this diagnosis of incomplete cadmium detoxification, multiple deleterious responses (biochemical, physiological, morphological, demographic) were detected in fish from the metal-contaminated lakes. Using a different approach, focused on the same geographical region but involving the freshwater amphipod *Hyalella azteca* as a test species, Borgmann et al.[7] confirmed that in the single lake where



Peter Campbell, a professor at the Institut National de la Recherche Scientifique (Université du Québec, INRS-ETE) since 1970, is interested in the biogeochemistry of metals in freshwater environments. His current research includes elements of analytical chemistry (development and refinement of methods to determine metal speciation), geochemistry (identification of factors controlling metal speciation in natural waters) and ecotoxicology (development of predictive models relating the biological response elicited by a metal to its speciation, both in the external medium and in the intracellular environment). He directed the Metals in the Environment Research Network (MITE-RN) from 1998 to 2004 and presently holds a Canada Research Chair in Metal Ecotoxicology.

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the sediments exhibited chronic toxicity, only cadmium was accumulated to levels in the test organism that approached the recognized critical body burden.

Note too that there is some recent evidence for the biomagnification of cadmium in certain aquatic food chains.[10] Croteau and co-workers[10] studied the food-chain transfer of cadmium in a littoral food web in the delta of San Francisco Bay, using nitrogen and carbon stable isotopes to identify trophic position and food web structure. They demonstrated that cadmium was progressively enriched among trophic levels in two discrete epiphyte-based food webs composed of macrophyte-dwelling invertebrates (the first link being epiphytic algae) or fishes (the first link being gobies). Cadmium concentrations were biomagnified 15 times within the scope of two trophic links in both food webs. Metal biomagnification, defined as the progressive accumulation of a metal with increasing trophic levels, was previously thought to occur only for mercury.

Turning now to the papers composing the Research Front, readers will find a diverse but balanced group of contributions. On the terrestrial side, as mentioned earlier, McLaughlin et al.[4] consider effects of biosolid amendments on the transfer of cadmium from soils to wheat, over a wide range of field conditions. In a complementary laboratory investigation, Degryse et al.[11] examine possible rate-limiting steps in the uptake of cadmium by two higher plants (spinach and wheat), and demonstrate that metal uptake can be limited by the transport of the metal to the root surface, particularly in unbuffered systems. The authors conclude that diffusional limitations for uptake by higher plants may be more important than previously believed, and they sound a note of caution about the use of equilibrium models (such as the biotic ligand model, or BLM) to predict metal uptake. In the final paper with a terrestrial focus, Dedieu et al.[12] report on a laboratory study of cadmium uptake by the rhizobacterium *Sinorhizobium meliloti*, a bacterium commonly found in soils and in the rhizosphere (the key zone surrounding the roots of terrestrial plants). The authors speculate that exudates produced by *S. meliloti* may affect cadmium speciation and bioavailability in the rhizosphere.

The Research Front includes three papers with an aquatic emphasis. Néron et al.[13] consider the possible release of cadmium from dissolved organic matter (DOM) under the influence of UV_B irradiation (see also ref. [14]). The authors observed release of free cadmium from artificial media containing a well-characterized standard fulvic acid, but not in experiments with natural lake waters. They speculate that any free cadmium released by irradiation of the natural waters would bind to the newly produced iron oxyhydroxides, and thus remain undetectable. Wood et al.[15] discuss the protective role played by calcium in reducing cadmium uptake and toxicity in freshwater fish. Of particular interest in this paper is the new evidence showing that dietborne calcium can protect freshwater fish against both waterborne and dietary cadmium exposure. The authors emphasize the importance of considering not only water chemistry but also dietary chemistry in devising environmental regulations for cadmium. In the third aquatic paper, Wang and Rainbow[9] examine the subcellular partitioning of cadmium within aquatic organisms, both freshwater and marine, and consider how the knowledge of how organisms handle their accumulated cadmium may allow more accurate predictions of cadmium-induced toxicity, and better predictions of the eventual transfer of cadmium to higher trophic levels.

Finally, Lodeiro et al.[16] approach the environmental chemistry of cadmium from the standpoint of pollution control, with an emphasis on waterborne waste streams. Starting from a physicochemical, thermodynamic and kinetic perspective, they review the biosorption of cadmium onto biomaterials, focusing on removal and recovery methods that may apply to waste streams containing low metal concentrations.

In summary, cadmium clearly merits its classification as a ‘priority pollutant’, not only from the human health perspective, but also from a broader ecosystem viewpoint. The present Research Front devoted to cadmium is particularly timely.

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