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# CADMIUM DYNAMICS IN TERRESTRIAL FOOD WEBS OF A COAL ASH BASIN

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## ABSTRACT

Trophic relationships of cadmium were investigated in a terrestrial ecosystem occupying an island composed entirely of coal ash. The coal ash substrate contained 0.05 ± 0.01 (SE) μg/g of water extractable and 0.12 ± 0.002 μg/g dry weight of total cadmium. Increasing across trophic levels, the cadmium concentrations were 0.35 ± 0.03 for producers, 0.97 ± 0.11 for herbivores (grasshoppers, crickets, and leafhoppers), and 2.82 ± 0.34 for carnivores (spiders). The detritivore (snails) level contained the highest concentrations (16.87 ± 4.44), indicating the importance of litter as a cadmium sink in terrestrial systems.

Increased release of heavy metals to the environment by anthropogenic sources poses a threat of undetermined magnitude to human health and the environment. Cadmium is considered among the most toxic of the heavy metals (Buhler, 1972). The occurrence of "itai—itai" disease in a segment of the Japanese population has been correlated with high cadmium concentrations in rice irrigated by waters receiving cadmium-contaminated mine effluent (Yamagata and Shigematsu, 1970). Such incidents have aroused concern over the potential chronic toxicity of cadmium and have emphasized the need for a better understanding of cadmium cycling through biological systems, including trophic transfers and biomagnification. Rapid mobilization of cadmium into the biosphere from anthropogenic sources can have chronic adverse effects on organisms with enzyme systems that have evolved with very low concentrations of this relatively rare element.

Cadmium is released into the environment by a variety of industrial processes, including coal combustion. Cadmium is more highly concentrated in coal than the general lithosphere, indicating a high potential for environmental contamination through combustion. Gluskoter and Lindhahl (1973) surveyed cadmium contents of 23 Illinois coals and observed a range of 0.3 to 28 ppm, and Hiatt and Huffs (1975) cited a range of 0.02 to 10 ppm for U. S. coals. The cadmium content of coal fly ash is somewhat higher, in the range of 12 to 35 ppm, owing to vaporization during combustion and subsequent condensation on small ash particles (Davison et al., 1974). Because of the widespread distribution and probability of increased coal combustion to meet future energy needs, the potential for cadmium contamination due to fly and bottom ash dispersion is great. Cadmium is highly enriched in fly ash, which is often not collected by stack precipitators (Davison et al., 1974; Kaakinen et al., 1975; Klein, Andren, and Bolton, 1975). Klein, Andren, and Bolton (1975) projected that $1.1 \times 10^1$ tons/year (6.7%) of the cadmium in coals burned in the United States would be in the bottom ash, whereas $1.48 \times 10^2$ tons/year (90.3%) would be in the fly ash fraction collected by stack precipitators, with 4.6 tons/year (2.8%) released to the atmosphere. The resulting projected atmospheric discharge is estimated to produce an eightfold atmospheric enrichment. Cadmium input into the environment due to coal combustion is estimated to be equal to or greater than natural weathering processes (Bertine and Goldberg, 1971).

Surveys of cadmium concentrations in soils and vegetation proximate to industrial areas have been made (Little and Martin, 1972; Goodman and Roberts, 1971; Lagerwerff and Specht, 1970). Klein and Russell (1973) and Lindberg et al. (1975) investigated cadmium inputs into areas adjacent to coal-fired power plants and found soils and plants containing elevated cadmium concentrations.

Fly ash is presently being used in landfill operations (Carnes, 1975), and the possibilities of employing the nutrient-rich ash as a soil amendment to micronutrient-deficient plants are being explored (Martens, 1971). Caution must be exercised to ensure that alternative disposal methods do not merely provide additional pathways for the entrance and dispersion of trace contaminants into the environment.

Although numerous studies carried out in the laboratory under controlled conditions have investigated factors influencing plant cadmium uptake (Francis and Rush, 1973), there have been few studies concerned with in situ cadmium cycling in terrestrial ecosystems. Banus, Valiela, and Teal (1975) have analyzed lead, zinc, and cadmium flow in four compartments of an experimentally

(heavy-metal) enriched salt-marsh ecosystem, and Huckabee and Blaylock (1974), using microcosms, analyzed the cadmium distribution in various terrestrial ecosystem compartments following cadmium enrichment. Van Hook (1974) traced the transfer of cadmium from soils to earthworms, and Van Hook and Yates (1975) compared uptake and elimination rates for two forms of cadmium in crickets and analyzed cadmium bioaccumulation in a producer—omnivore—carnivore food chain in laboratory experiments.

The purpose of this study was threefold: (1) analyze cadmium concentrations in various trophic levels of an ecosystem on a coal ash substrate composed of bottom and fly ash from coal combustion, (2) compare these concentrations to control and literature cadmium levels, and (3) determine terrestrial trophic relationships of cadmium. This work provides base-line information on cadmium cycling and biomagnification and evaluates contamination potential in terrestrial systems receiving coal ash.

## STUDY AREA

Samples were collected from a 104- by 380-m island, located in an ash basin, approximately 600 m southwest of a coal-fired power plant. The island substrate is composed of coal ash that has accumulated since 1952. The power plant presently consumes $3.6 \times 10^8$ kg of coal annually and has released an estimated $3.6 \times 10^8$ kg of fly ash since startup (Horton, 1976). Between 1952 and 1975 the plant operated with mechanical stack collectors that were 75% efficient. Cadmium inputs to the island are from coal ash via sluice water from boiler grating, stack precipitators, and aerial deposition.

The island supports a dense and diverse ecosystem. The year of the initial colonization is unknown. However, photographs taken in 1956 show a small ash island, and 1966 photographs reveal vegetation on a larger ash island. Cores taken from three pines on the island date the trees at 13, 9, and 7 years. The herbaceous vegetation is dominated by broomsedge (*Andropogon virginicus* var. *abbreviatus*) and goldenrod (*Solidago* sp.) with camphor weed (*Heterotheca subaxillaris*) and other minor forbs and grasses. Scattered over the island is a series of shrubs and small trees composed of wax myrtle (*Myrica cerifera*), black willow (*Salix nigra*), cottonwood (*Populus deltoides*), consumption weed (*Baccharis halimifolia*), and small pines (*Pinus* sp.).

This particular species of *Andropogon* is found at other sites at the Savannah River Plant but only in moist habitats such as bogs and

wet ditches. Gonsoulin (1975) lists *A. virginicus* (variety not given) and *Solidago* sp., respectively, as dominants on 3- and 8-year ash pits in middle Tennessee. Also listed as dominants were *P. deltoides* and *S. nigra*. Certain abiotic parameters, such as substrate particle size, pH, and moisture, can be similar across fly ash substrates; this results in colonization by many of the same species of plants.

## MATERIALS AND METHODS

The island was sectioned by grid coordinates, and 10 randomly selected sampling locations were marked. Each location consisted of a central subsampling station, with three other similar stations located at random angles along 1-, 2-, and 3-m radii from the central station. Each subsampling station covered an area of 0.25 $m^2$ within each 28.26-$m^2$ sampling location. An 11*th* location was selected in an *Andropogon*-dominated old field as a control.

Collections were made between Oct. 20 and Nov. 25, 1975. Plants collected included leaves and stems of *A. virginicus*, *Solidago* sp., *B. halimifolia*, *S. nigra*, *P. deltoides*, and seeds of *A. virginicus* and *Solidago* sp. Plant samples and soil cores were taken from 0.25-$m^2$ plots. Plant samples were collected by clipping stem and leaf with stainless-steel scissors and pulling seeds from stems and sheaves with Teflon forceps. Invertebrate samples included grasshoppers (Acrididae), leafhoppers (Cicadellidae), crickets (Gryllidae), spiders (Arachnidae), and the snail (*Triodopsis vannostrandi*). Soil cores were obtained using a plexiglass tube fitted with a rubber plunger and frozen intact in plastic bags. Invertebrates were netted within each sampling location (grasshoppers and leafhoppers) or captured beneath 30-$cm^2$ boards (crickets, spiders, and snails) set out near each subsampling station. Plant and invertebrate samples were transferred to numbered and washed plastic vials and frozen immediately upon return to the laboratory. No attempt was made to remove atmospheric fly ash deposition from samples before digestion.

Plant and invertebrate samples were lyophilized for 1 week, weighed, placed in Erlenmeyer flasks, and wet-ashed using concentrated redistilled $HNO_3$ and 30% $H_2O_2$. Acid was added in a ratio of 1 ml of acid to 1 g dry weight of sample. Samples were covered with watch glasses and refluxed at 85°C on a hot plate until solutions were clear. The flasks were cooled, a volume of 30% $H_2O_2$ equivalent to that of the initial acid was added, and samples were refluxed for an additional 5 min. Samples were cooled and diluted with double distilled $H_2O$ to a known volume containing 10 to 20% acid and stored in polyethylene bottles.

Soluble cadmium in soil was determined by water extractions. Soil core length was recorded, and cores were divided into two fractions by separating the upper 10 cm from the remainder of the core. Each fraction was homogenized, and 10-g aliquots were removed for extraction. Each aliquot was extracted for 1 hr with 100 ml of double distilled $H_2O$ in 250-ml Erlenmeyer flasks on a rotary shaker at 200 rpm and 23°C. The mixtures were filtered through washed No. 4 Whatman filters, and the supernatant leachates were stored in polyethylene bottles. Total cadmium concentrations in ash from the basins were determined by flameless atomization of an ash suspension. Aliquots of 0.75 g of ash were suspended in 10% glycerol in distilled $H_2O$ and injected directly into the furnace.

Sample contamination was minimized by soaking all glassware and polyethylene bottles for 12 hr in 2% Contrad (American Hospital Supply Co., McGaw Park, Ill.) and by rinsing them in tap $H_2O$ followed by double-deionized $H_2O$. The glassware was then soaked 5 min in 1% HCl, rinsed three times with double-deionized $H_2O$, and allowed to drip dry.

Cadmium determinations were made by atomic absorption spectrophotometry. The instruments were equipped with deuterium continuum background correction systems and graphite flameless atomizers. Flameless determinations were made in normal mode with argon as a purge gas. Flame determinations were made with an air—acetylene fuel-rich flame. The sensitivity for cadmium determination by flame AA was 0.025 $\mu$g/ml, where sensitivity is defined as the concentration that gives an absorbance reading of 0.004 (1% A). Detection limit in the flame mode was 0.005 $\mu$g/ml where detection limit is defined as the concentration that gives a signal greater than $2S_x^-$ above background. If continuous-flow argon is used, 2.0 pg of cadmium produces an absorbance of 0.004 units. The amount of sample injected into the graphite rod atomizer varied but was usually 10 $\mu$l. If a 10-$\mu$l sample and the continuous purge mode are used, the sensitivity is $2 \times 10^{-4}$ $\mu$g/liter in solution. Detection limits varied with matrix so that it is impossible to give a general value.

All determinations were corrected for reagent blanks that were carried through digestion and dilution or extraction procedures and compared with commercially prepared certified standards. Matrix interferences were evaluated in each material analyzed for cadmium by using internal standards. Background matrix interferences were also checked by determining absorbances at a nonabsorbing analytical wavelength adjacent to the primary analytical line of 228.8 nm. Absorbances determined at the nonabsorbing wavelength of

226.2 nm resulted in absorbances of between 0.000 and 0.002. The selected charring and atomization time and temperature regimes removed all background interferences for flameless cadmium analysis in all matrices. Internal standard curves had the same slope as curves constructed from standards in distilled water. When matrix interferences were absent, an analytical program of 10 sec at 250°C charring and 4 sec at 1000°C atomization was used. When matrix interferences were encountered, they were eliminated by adding 25% $(NH_4)_2SO_4$ equal to the sample volume and increasing charring and atomization temperatures to 400°C for 15 sec and 1400°C for 4 sec, respectively.

Sample preparation and analytical procedures were tested by determining cadmium in bovine liver (BL), standard orchard leaves (SOL), and fly ash (FA) supplied by the National Bureau of Standards (NBS). These matrices are analogous to other animal matrices and allow the evaluation of preparatory and analytical techniques. The cadmium levels in BL and SOL were below the detection limits of our flame AA techniques. Using flameless methods, however, we measured mean cadmium concentrations of 0.31 μg/g dry weight in BL (NBS certified value is 0.27 ± 0.03 μg/g), 0.13 μg/g dry weight in SOL (NBS certified value is 0.11 ± 0.02 μg/g), and 1.32 μg/g dry weight in FA (NBS certified value is 1.45 ± 0.06 μg/g).

Data analyses were performed with an IBM-360, Model 195 Computer, equipped with Statistical Analysis System (SAS) (Service, 1972). Treatment effects were tested for significance by one way ANOVA. Means were rank ordered from lowest to highest cadmium levels (Table 2) and separated with a Student–Newman–Keuls (SNK) multiple range test (Sokal and Rohlf, 1969). Although the assumption of homogeneity of variance is violated in the ANOVA, we feel that the robustness of the test minimizes this bias.

## RESULTS

Water extractable cadmium from the substrate was significantly greater in the upper 10 cm at both the ash basin and control sites (Table 1). Commonly, concentrations of cadmium are greater in surface than in subsurface soils owing to plant cycling. Organic matter accumulation in the surface layers also may tend to bind cadmium and hold it near the surface. Approximately 42% of the total cadmium associated with the fly ash was extracted into distilled $H_2O$ after 1 hr.

TABLE 1

MEAN CADMIUM CONCENTRATIONS IN SUBSTRATUM, PLANT, AND INVERTEBRATE SAMPLES FROM A COAL ASH BASIN AND CONTROL AREA (OLD FIELD)

| Sample | Coal ash basin | | Old field (control) | |
|---|---|---|---|---|
| | No. of samples | Mean* ± SE | No. of samples | Mean* ± SE |
| Substratum† | | | | |
| Top 10 cm (total) | 20 | 0.12 ± 0.002 | | |
| Top 10 cm (extractable) | 39 | 0.05 ± 0.01 | 3 | 0.19 ± 0.05 |
| Remainder to water table (extractable) | 40 | 0.03 ± 0.01 | 3 | 0.08 ± 0.04 |
| Plants | | | | |
| *A. virginicus*‡ | 39 | 0.20 ± 0.02 | 4 | 0.28 ± 0.07 |
| *A. virginicus* (seeds) | 39 | 0.24 ± 0.02 | 4 | 0.10 ± 0.03 |
| *Solidago* sp. | 31 | 0.25 ± 0.04 | 4 | 0.11 ± 0.05 |
| *Solidago* sp. | 35 | 0.14 ± 0.02 | | |
| *B. halimifolia* | 39 | 0.60 ± 0.07 | 2 | 0.30 ± 0.004 |
| *P. deltoides* | 34 | 2.19 ± 0.22 | | |
| *S. nigra* | 40 | 4.02 ± 0.26 | | |
| Invertebrates | | | | |
| Acrididae | 39 | 0.88 ± 0.09 | 4 | 0.35 ± 0.14 |
| Cicadellidae | 6 | 0.89 ± 0.38 | | |
| Gryllidae | 37 | 1.32 ± 0.25 | | |
| Arachnidae | 34 | 2.86 ± 0.34 | 4 | 1.56 ± 0.60 |
| *T. vannostrandi* (shell) | 8 | 1.22 ± 4.46 | 1 | 0.35 ± |
| *T. vannostrandi* (body) | 10 | 16.94 ± 4.46 | 1 | 5.55 ± |

*Micrograms per gram of dry weight.
†Collected in 5.5-cm cores.
‡Var *abbreviatus*.

Mean cadmium concentrations varied widely within and between sampling categories (Table 1). The coefficient of variability (CV) ranged from 42% for *Salix* to 129% for soil. An ANOVA test excluded sample locational differences between sampling stations within the ash basin as a significant contributing factor to variability in cadmium concentrations within each sample category. Mean values ranging from those for *Solidago* sp. seeds (0.14 ± 0.02 μg/g) to Gryllidae (1.32 ± 0.25) were not significantly different ($P > 0.05$) (Table 2). Mean values for *P. deltoides* (2.19 ± 0.22 μg/g) and Arachnidae (2.82 ± 0.34 μg/g) were significantly different from the

TABLE 2

A MEAN SEPARATIONS ANALYSIS (STUDENT–NEWMAN–KEULS MULTIPLE RANGE TEST) OF MEAN CADMIUM LEVELS IN THE PLANT AND ANIMAL SAMPLES*

| Sample | No. of samples | Mean, μg/g |
|---|---|---|
| *Solidago* sp. (seeds) | 35 | 0.14 |
| *A. virginicus* (seeds) | 43 | 0.22 |
| *A. virginicus* | 43 | 0.23 |
| *Solidago* sp. | 35 | 0.23 |
| *B. halimifolia* | 41 | 0.56 |
| Acrididae | 43 | 0.84 |
| Cicadellidae | 6 | 0.89 |
| *T. vannostrandi* (shell) | 9 | 1.19 |
| Gryllidae | 37 | 1.32† |
| *P. deltoides* | 34 | 2.19 |
| Arachnidae | 38 | 2.82† |
| *S. nigra* | 40 | 4.02 |
| *T. vannostrandi* | 11 | 16.87 |

*Means covered by the same line are not significantly different ($P > 0.05$).

†Mean concentrations for Gryllidae and Arachnidae were significantly different ($P < 0.05$) even though they are covered by the same line.

lower mean values for *Solidago* sp. ($0.23 \pm 0.04$ μg/g) and *A. virginicus* ($0.23 \pm 0.02$ μg/g). Cadmium concentrations for *S. nigra* ($4.02 \pm 0.26$ μg/g) were significantly greater than all other plant samples. *Triodopsis vannostrandi* (body) ($16.87 \pm 4.44$ μg/g) had significantly greater mean cadmium concentrations than all other animal samples. The variability about the mean values for *T. vannostrandi* was quite high owing to the smaller sample size. Cadmium concentrations in the control samples were significantly lower than those in the ash area samples (Table 1) except for *A. virginicus* foliage. However, the comparison is somewhat weakened by the reduced sample size of the controls.

A more general view of cadmium in the ecosystem is obtained by grouping the samples into trophic levels as illustrated in Fig. 1. *Andropogon virginicus*, *Solidago* sp., and *B. halimifolia* were combined into the producer level. Seeds were excluded since they did not differ in cadmium concentrations from the other plants in that group and, in addition, were not likely a significant component of the

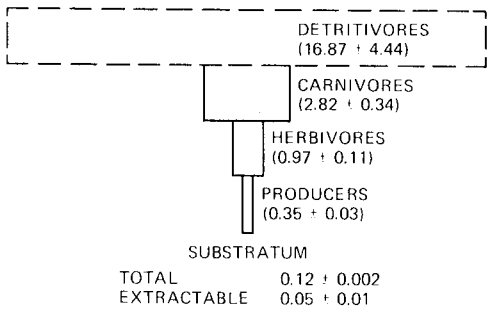


**Fig. 1 Mean (±SE) trophic level concentrations (micrograms per gram of dry weight) of cadmium in a terrestrial invertebrate food web.**

producer—herbivore food web. The two trees (*P. deltoides* and *S. nigra*) were not included among the producers because they were quite sparse, unequally distributed, and, being much taller than the grasses and forbs, were probably less utilized by the herbivores. The herbivore level consisted of the Acrididae, Cicadellidae, and Gryllidae; the predator, or carnivore, level was composed of the Arachnidae; and the detritivore level consisted of body tissue of the snail (*T. vannostrandi*). For the sake of convenience, the detritivore level was placed atop the pyramid, although it is more closely coupled to the producer level than the carnivore level. *Triodopsis vannostrandi* is a detritus feeder, and the greatest source of detritus is plant litter.

Cadmium concentrations increased at each successively higher trophic level; this results in an inverted pyramid (Fig. 1). Concentration ratios (CR), defined as the ratios of dry weight cadmium concentrations in trophic level n to trophic level $n-1$, were calculated. The resulting CR's were 2.77 for herbivore/producer and 2.91 for predator/herbivore. It would be misleading to calculate a CR for detritivore/predator because, as mentioned, the detritivore level is more closely linked to the producer level.

## DISCUSSION

Although NBS-certified reference materials can be used effectively to evaluate sample preparation and analytical techniques derived for these materials, they may not be appropriate for all analogous biological and geological materials. Matrix effects on

cadmium analyses not only varied between plant and animal samples but between species and tissue types. The results of this study demonstrate the importance of optimizing analytical conditions for each matrix of interest. Matrix effects of each soil, plant, or animal sample must be addressed individually. Although internal standards are tedious and on occasion can be misleading, they provide the best means of evaluating matrix interferences and correctives.

Cadmium dynamics of a natural system on a coal ash substrate have received little investigation. However, high trace metal concentrations, especially in the plants, might be expected owing to the relatively high cadmium concentrations associated with coal and coal ash. In this study cadmium levels in grasses and forbs (Table 1) were close to those reported by Huckabee and Blaylock (1974) for *A. virginicus* ($0.21 \pm 0.02$ μg/g) and *Fescue* sp. ($0.28 \pm 0.21$ μg/g) growing on soils far removed from industrial contamination. Klein and Russell (1973) reported cadmium concentrations in plants growing on background and cadmium-enriched soils of 0.12 and 0.35 ppm, respectively, whereas Furr et al. (1975) found cadmium levels of 2.1 ppm in clover grown on control soils and 3.2 ppm on fly ash. These levels approach those of the trees, *P. deltoides* and *S. niger*, in the present study. According to Huckabee and Blaylock (1974), trees readily translocate cadmium into the foliage and tend to release it slowly, which results in high concentrations. Van Hook and Yates (1975) reported a soil—plant ratio of 1.0 for cadmium in a grassland food chain, which indicates that plants accumulated but did not concentrate cadmium. Concentration ratios for soil—plant relationships can be misleading because of relative solubilities of cadmium in soil solution and translocation to the plant but can be used as an indication of cadmium input into food webs.

The distribution of an element or contaminant in a biological system depends upon the manner in which it moves through successive food webs. Interactions of assimilation and turnover rates determine whether concentrations of radionuclides increase or decrease over successive trophic levels (Reichle, Dunaway, and Nelson, 1970). When plant and invertebrate groups collected from the coal ash basin are combined and arranged in appropriate trophic levels (Fig. 1), relationships between cadmium uptake and ecosystem function are more readily apparent. Cadmium levels increase uniformly from producers to carnivores with respective CR of 2.77 for herbivore/producer and 2.91 for carnivore/herbivore. The CR's are high compared with those in other investigations of terrestrial food webs. For example, Reichle and Crossley (1969), Crossley (1969), and Anderson, Gentry, and Smith (1973) reported ratios of radiocesium

concentrations ranging from 0.29 to 0.51 (primary producer/primary consumer) and 0.50 to 0.96 (primary consumer/secondary consumer) for forest and old-field communities. However, cesium differs from cadmium, a divalent transition metal. Van Hook and Yates (1975) in a study involving experimentally applied cadmium observed a CR of 0.60 for plant/omnivore (cricket) and of 0.71 for omnivore/predator (spider). This biodiminution at higher trophic levels indicates that animals at each successive trophic level were able to discriminate against cadmium; this resulted in low assimilation or selective elimination of cadmium. In the present study there were successive trophic level increases in cadmium concentration resulting in biomagnification at each successive level. Such a contrast to other studies indicates the possibility of different mechanisms operating in the present study.

It is well recognized that insects constitute an important biotic component of terrestrial ecosystems (Price, Rathcke, and Gentry, 1974). Their high densities and large biomass make them significant contributors to the energy flow from primary producers to carnivores. Insects accounted for 81% of the total energy flow through the herbivores in an old-field (Wiegert and Evans, 1967). Energy production by grasshoppers and tree crickets in an old-field community was 33 times greater than by mice and 100 times greater than by sparrows (Odum, Connell, and Davenport, 1962). Since insects are an abundant energy source in any community, they are important in the food chain of many beneficial insects and vertebrates, allowing for the flow of contaminants to the higher trophic levels.

As more knowledge of cadmium behavior in ecosystems is accrued, it is becoming apparent that detritivore organisms are important in elemental cycling within food webs. Detritivores (*Triodopsis* sp.) collected from the ash island contained extremely high concentrations of cadmium compared with those of other trophic levels. This phenomenon has been recorded in other investigations. For example, Van Hook (1974) reported mean cadmium levels in earthworms of 5.7 ppm compared with 0.35 ppm for soils, an accumulation of over 20-fold. In studies of cadmium behavior in a grassland arthropod food chain, Van Hook and Yates (1975) observed greater cadmium levels in an omnivore (cricket) than in a predator (spider). In the present study, cadmium concentration in the cricket (Gryllidae) was the highest among the arthropods. Huckabee and Blaylock (1974) found that cadmium in terrestrial systems accumulates in the litter and concluded that cadmium would, therefore, be more available to organisms whose

food base is litter. The same phenomenon has been observed in aquatic systems where mercury has been shown to accumulate in detritus-feeding marine fishes (Cocoros, Cahn, and Siler, 1973). Similarly, Van Hook and Yates (1975) observed the highest cadmium concentrations in the detritus component of their grassland ecosystem. Thus, the snails that make up the detritivore level of the ash island food web are accumulating cadmium through the litter. Much of the cadmium associated with litter is likely the result of aerial input, via both direct dry deposition and wet deposition of rain (Wedding et al., 1975). Lindberg et al. (1975) reported cadmium to be more concentrated in the ash discharged through the stack than in that collected by the precipitator. The ash island has received more than 3 $kg/m^2$ fly ash deposition between 1952 and 1975 (Horton, unpublished data). Since gut contents were not removed prior to analysis, a portion of the cadmium found in the snail body may be due to the direct ingestion of cadmium-bearing fly ash particles. Although approximately 42% of the total cadmium in the ash was extractable by $H_2O$, larger quantities may be available due to chemical—physical conditions in the gut.

Cadmium levels increased with successive trophic levels in the plant—arthropod community occupying the coal ash island, with the lowest cadmium concentrations in the primary producers. This is in contrast to aquatic systems in which heavy metal concentrations decline along successive trophic levels. Knauer and Martin (1973), Fujita and Hashizume (1972) and Cocoros, Cahn, and Siler (1973) found that cadmium, as well as mercury, accumulates in phytoplankton at greater levels than in zooplankton. Phytoplankton sorb metals directly from the aqueous environment in which they are suspended, whereas plants sorb metals that are translocated through the soil interstitial water and plant vascular system. The relatively high concentration ratios into phytoplankton are probably due to the large surface-to-volume ratio and continuous renewal of metal-containing water near the cell surface. In subtidal invertebrates Schwimer (1973) reported cadmium biodiminution from herbivores to predators. Rolfe and Haney (1975), studying lead in stream sediments, found no bioaccumulation through the aquatic trophic structure, and Mathis and Kevern (1975) reported lower cadmium concentrations in fish than in zooplankton and aquatic macrophytes.

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