

Sorption of Pollutants by Plant Detritus: A Review

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Detritus particles derived from the decomposition of vascular plants appear to have a high sorptive capability for a wide range of pollutants. Evidence is presented and reviewed which shows detrital concentration of heavy metals, radionuclides, and organochlorine insecticides. A study of a roadside marsh indicates that lead originating from automobile exhausts may reach concentrations as high as 1415 ppm on marshgrass detritus. We suggest that these elevated concentrations may, in turn, be passed on to detritivores which ingest the contaminated particles and experience desorption and assimilation of the pollutant within the digestive tract. Finally, potential mechanisms are listed which might explain detrital sorption; these include: microbial uptake (adsorption and metabolic absorption), association with detrital and microbial lipids, electrostatic adsorption in response to charges on the detritus particles, and formation of complexes and chelates at active sites on the organic molecules of the decomposing detritus.

Introduction

A thorough understanding of processes capable of concentrating environmental contaminants to potentially harmful levels is of obvious importance. If these same processes also transfer contaminants into foodwebs at elevated concentrations, then it becomes even more critical to have a thorough knowledge of how they operate, what mechanisms are involved, and the nature of controlling factors.

One process of concentration and transfer which is not widely recognized nor well understood is the association of pollutants such as certain heavy metals, radionuclides, and pesticides with particles of decaying plant detritus. Although preliminary evidence exists indicating that the process of detrital concentration may be widespread, detailed knowledge is almost totally lacking. Which pollutants become associated with detritus and to what extent are they concentrated? What are the mechanisms responsible for the process? What factors control the degree of concentration?

In this short paper, the limited literature dealing with this subject is briefly reviewed. Additional evidence derived from a study of automobile lead in coastal marshes is also presented. Finally, limited speculations are presented dealing with mechanisms and controlling factors.

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Basic Hypothesis

The working hypothesis is that certain contaminants, when exposed to the proper physical and chemical conditions, may be sorbed (adsorbed and absorbed) onto particles of plant detritus at concentrations elevated above ambient levels. Furthermore, when contaminated particles are ingested by animals which consume detritus particles, the contaminant is desorbed within the gastrointestinal tract and absorbed by the animal, thus introducing the contaminant at potentially harmful levels in ecosystem foodwebs.

Plant Detritus

For those unfamiliar with research concerned with plant detritus, a brief summary is in order. During the decomposition of plant tissues a variety of organic and inorganic compounds are released, leaving behind a residue of resistant particulate matter variously termed "litter," "particulate plant detritus" or simply "detritus." These particles, which may range in size from an entire leaf or branch to a few microns, typically consist of a substrate composed of resistant carbohydrates such as lignin, cellulose and hemicellulose; varying amounts of relatively insoluble amino acids and carbohydrates; and an attached microbial community of bacteria, fungi, yeasts, Protozoa, and algae. Because of the retained low-solubility amino acids

and carbohydrates and the attached microbial community, detritus particles often have a relatively high nitrogen content and considerable food value for consumers. In all ecosystems, there is a functional group of animal species termed detritivores which obtain at least a portion of their energy requirements from ingested plant detritus particles. An extensive literature exists concerning the role of plant detritus in a variety of environments including soil communities (1), old field communities (2), forests (3), temperate lakes (4), tropical lakes (5), rivers and streams (6), and estuaries (7).

Evidence of Detrital Sorption

Heavy Metals

Reports of detrital sorption of contaminants in general and heavy metals in particular are widely scattered through the literature and often buried within papers dealing with other subjects. Williams and Murdoch (8) measured levels of zinc, manganese and iron in living marshgrass, *Spartina alterniflora*, and in large pieces of marshgrass detritus. They found concentrations in the marshgrass detritus to range from three to ten times higher than in the mature, living plant, but did not examine finely divided detritus particles. Iron displayed the greatest increase in concentration. Similar results were published by Drifmeyer and Odum (9) for lead and manganese from the same plant materials collected in dredge-spoil pond ecosystems.

Lindberg and Harriss (10) examined mercury levels in mangrove leaves and mangrove detritus from the Shark River, a relatively unpolluted estuary within the Everglades National Park, Florida. They found 0.21 ± 0.01 ppm of mercury in actively photosynthesizing leaves, 0.79 ± 0.02 in leaf litter beneath the trees, 1.02 ± 0.03 in detritus particles from the estuarine waters, and 1.05 ± 0.03 in benthic deposits of detritus.

Examples from terrestrial sites include reports from Tyler (11) and Ruhling and Tyler (12), who recorded elevated concentrations of Cu, Zn, Cd, and Ni in conifer needle detritus from the forest floor, concentrations which were significantly higher than those from live needles from the overlying forest canopy. Wixson and Jennett (13) found lead in the upper layers of leaf litter from the forest floor near a lead smelter to contain 150–2000 ppm lead. These concentrations greatly exceeded concentrations from green leaves in the forest canopy.

Radionuclides

Sorption of radionuclides onto litter and detritus

is well documented (14–19). Fritz (personal communication) has found 10–100-fold increases in concentration when *Spartina* leaf detritus is suspended in solutions of ^{60}Co and ^{137}Cs at concentrations of 2 ppm. Luoma and Jenne (20) also have reported extremely rapid uptake and significant concentration when detritus particles are suspended in weak nuclide solutions.

Pomeroy et al. (15) monitored releases of ^{32}P and ^{65}Zn into a coastal salt marsh ecosystem and found detritus particles on the sediment surface to be one of the major sinks for the nuclides. Within 24 hr of the release, almost all detectable radiation was associated with either detritus particles, other sediment particles or the biota. In a laboratory study, Gutknecht (21) found that detrital *Ulva* (sea lettuce) took-up significantly more ^{65}Zn than the living algae when both were placed in dilute solutions of the nuclide.

Reichle and Crossley (22) found that concentrations of ^{137}Cs in the litter of an experimental forest floor increased along a gradient from the least decayed to the most decayed litter on the surface of the soil. Rickard (23) found the same nuclide to be 3–24 times more concentrated in the litter layer than in the foliage from a douglas fir forest. He also discovered that litter from high rainfall areas contained higher concentrations of ^{137}Cs than litter from lower rainfall sites.

Pesticides

In a study of a Long Island, N. Y., marsh, Odum et al. (24) found DDT, DDE, and DDD sorbed onto detritus particles from the surface of the marsh. The pesticide residues, which originated from mosquito control spraying, reached the greatest concentrations on particles between 0.25 and 1.0 mm. Detrital concentrations of from 30–50 ppm were much greater than those in the live marshgrass (1–2 ppm).

Recent measurements of *Spartina* detritus suspended in nylon mesh bags in the James River, near Hopewell, Virginia, show rapid sorption of the pesticide, Kepone, from the water (Drifmeyer and Heywood, unpublished data). After several weeks, concentrations of Kepone associated with the detritus were considerably higher (0.5–4.5 ppm) than concentrations in the river water (< 0.1 ppm).

Transfer to Foodwebs

Duke (25) was one of the first to suggest that loosely bound radionuclides can be removed from sediment particles and assimilated by bottom-feeding organisms. Direct evidence of desorption and assimilation from detritus was provided by

Odum (17), who showed that the striped mullet, *Mugil cephalus*, could concentrate ^{32}P from a diet of marshgrass detritus particles. Chipman (16) similarly showed that the polychaete, *Hermione lystrix*, could accumulate ^{54}Mn from labelled detritus added to sediment and Tenor et al. (18) reported the transfer of ^{65}Zn from detritus to the detritivore, *Rangia cuneata* (bivalve).

Reichle and Crossley (22) documented the transfer of ^{137}Cs from contaminated forest floor leaf litter to arthropod detritus consumers, although the concentration of cesium in the detritivores was only two thirds as great as in the detritus. Whitten and Goodnight (26) found that tubificid worms could accumulate ^{32}P from diets of either contaminated bacteria or detritus. However, uptake occurred more rapidly from an exclusive bacteria diet. Finally, Odum et al. (24) demonstrated that fiddler crabs (*Uca sp.*) concentrate DDT rapidly from a diet of contaminated marshgrass detritus.

Not all of the available evidence supports the theory of detrital transfer of pollutants. Luoma and Jenne (20) found no uptake from ^{109}Cd -labeled marshgrass detritus by the clam, *Macoma balthica*, and Fritz (personal communication) could not demonstrate significant uptake of ^{137}Cs by the amphipod, *Gammarus fasciatus*, from labeled detritus.

Evidence from an Ecosystem Heavily Contaminated with Lead

Most of the literature which we have reviewed thus far is derived from studies of relatively uncontaminated ecosystems. As a result they do not give an indication of the upper limits of detritus as a sink for pollutants. To test the capacity of detritus to concentrate pollutants, we chose roadside right-of-ways, an environment which receives a number of pollutants, including lead, from automobile exhaust and tire wear. Since Banus et al. (27) found high levels of lead (912 ppm) in the soils of coastal marshes lying near highways, it seemed likely that high concentrations would also occur in marshgrass detritus lying on the surface of roadside marshes.

We chose two sites with contrasting traffic volumes at locations where highways cross coastal marshes. The first was adjacent to Md. 611 immediately after it reaches Assateague Island National Seashore; this highway averages less than 2000 vehicles/day annually. The second site was next to the Atlantic City Expressway, New Jersey, a highway which averages over 20,000 vehicles/day annually.

Samples of live leaves of the marshgrasses, *Spartina alterniflora*, (Assateague Island) and *Phragmites communis* (Atlantic City) were collected along with samples of one- to two-year-old marshgrass detritus from the surface of the two marshes. These samples were rinsed repeatedly in deionized water and, after drying to a constant weight at 105°C for 48 hr, were ground in a Wiley Mill to pass through a 1 mm screen. The ground samples were digested by using nitric and perchloric acids (28, 29) and analyzed for lead with atomic absorption spectrophotometry. As a check on the analytical procedure replicate samples of standard orchard leaves from the Bureau of Standards were carried through the entire digestion-analysis procedure.

The results of the investigation are shown in Table 1. At the comparatively unpolluted Assateague Island site, marshgrass detritus shows a 4-5-fold increase in lead content compared to the living plant, while at the heavily polluted Atlantic City site the concentration factor ranges from 20 to 25. Although this increase is due to particulate lead which has settled-out of the atmosphere onto leaf and detritus surfaces, the fact that thorough rinsing did not remove the associated lead indicates that attachment to the detritus particles is relatively permanent.

Conclusions

The evidence reviewed in this paper, while not conclusive, tends to support the hypothesis of detrital sorption of certain pollutants. Increased sorbed concentrations on detritus obviously result from situations in which the pollutant input exceeds

Table 1. Lead content of marshgrass leaves and detritus.^a

Location	Distance from highway, m	Lead content, μg lead/g sample ^a		
		Live	Standing dead	Litter
Assateague Island	10	4.0 ± 0.5	12.1 ± 0.7	56.5 ± 12.0
	30	3.0 ± 0.6	9.0 ± 1.6	22.4 ± 9.8
	100	3.0 ± 0.5	9.6 ± 1.2	12.6 ± 5.0
Atlantic City Expressway	10	58.4 ± 17.6	355.4 ± 47.6	1414.7 ± 347.7
	30	32.0 ± 9.8	272.0 ± 41.6	882.3 ± 240.0
	100	22.9 ± 10.4	119.8 ± 36.7	544.4 ± 194.6

^a As weight lead/dry weight sample (ppm) ± one standard error; each value represents the mean of six samples.

loss from the particle. For sorption to exceed desorption there must be a more or less continuous supply of pollutant as, for example, the low levels of nuclides released in the cooling waters of nuclear power plants or the fall-out of particles of lead near highways. If the supply of the pollutant is sporadic or occurs in a single burst, leaching and desorption may reverse the process.

There are a number of potential mechanisms which might explain the processes of detrital sorption and concentration. First, if the detrital fraction which does not contain any contaminant is lost more rapidly during decomposition than the contaminant-containing fraction, then the relative amount of the contaminant will increase. This may explain small increases, but does not account for the order of magnitude increases reported in this paper. Potential mechanisms which might be responsible for detritus sorption are: association with lipids both in attached microorganisms and in the particle substrate (possible explanation for chlorinated hydrocarbon pesticide sorption); microbial uptake (both metabolic and surface adsorption) by microbes on the detritus particle; electrostatic adsorption in response to charges on the detritus particle; and formation of complexes and chelates (heavy metals) at active sites on the organic molecules of the decomposing detritus.

The principal mechanism or combination of mechanisms probably depend upon the chemical properties of the specific contaminant, chemical and physical properties of the environment containing the detritus particle, and the nature of the detrital substrate (i.e., stage of decomposition, composition of remaining material, extent of microbial colonization, etc.). The importance of external, environmental factors such as temperature, Eh, pH, and salinity cannot be overemphasized. Fritz (personal communication), for example, has shown that the uptake of metals and nuclides is extremely pH-dependent.

Examples discussed in this paper were restricted to sorption of nuclides, heavy metals, and organochlorine pesticides. Although examples of sorption of other pollutants were not discovered in this literature search, there is no reason that compounds such as chlorine, petrochemicals, and phenols might not behave in a similar manner.

As a final point, we would like to emphasize the importance of including detritus as a standard component in pollution surveys and studies. The usual procedure in surveying a pollutant release, such as a pesticide spill or nuclide leak, is to collect and analyze sediments or soils, plants, water, airborne particles, and living plants and animals. Detritus, whether forest litter or particles from a stream bot-

tom, is an important component which should be included. It is an important functional part of most ecosystems, is usually identifiable to source and approximate age, and is easy to collect. In many cases it will prove to be the single best component to collect, especially when other materials such as airborne particles and animals may be relatively expensive to obtain.

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REFERENCES

1. MacFadyen, A. Metabolism of soil invertebrates in relation to soil fertility. *Ann. App. Biol.* 45: 215 (1961).
2. Odum, E. P., and de la Cruz, A. A. Detritus as a major component of ecosystems. *AIBS Bull.* 13: 39 (1963).
3. Bray, J. R., and Gorham, E. Litter production in forests of the world. *Ad. Ecol. Res.* 2: 101 (1964).
4. McConnell, W. J. Limnological effects of organic extracts of litter in a southwestern impoundment. *J. Limnol. Ocean.* 13: 343 (1968).
5. Hickling, C. F. *Tropical Inland Fisheries*, Wiley, New York, 1961.
6. Hynes, H. B. N. Imported organic matter and secondary productivity in streams. *Proc. Int. Cong. Zool. 16th Congr. Wash., D. C.* 4: 324 (1963).
7. Odum, W. E., Zieman, J. C., and Heald, E. J. The importance of vascular plant detritus to estuaries. *Proc. 2nd Marsh and Estuary Management Symp. L. S. U. Press, New Orleans, 1972*, p. 91.
8. Williams, R. B., and Murdoch, M. B. The potential importance of *Spartina alterniflora* in conveying zinc, manganese, and iron into estuarine food chains. *Proc. 2nd Nat. Symp. Radioecology, U. S. Dept. Comm. (Conf. 670503)*; 1969, p. 431.
9. Drifmeyer, J. E., and Odum, W. E. Lead, zinc, and manganese in dredge-spoil pond ecosystems. *Environ. Conserv.* 2: 39 (1975).
10. Lindberg, E., and Harriss, C. Mercury enrichment in estuarine plant detritus. *Mar. Pollution Bull.* 5: 93 (1974).
11. Tyler, G. Heavy metals pollute nature, may reduce productivity. *Ambio* 1: 52 (1972).
12. Ruhling, A., and Tyler, G. Heavy metal pollution and decomposition of spruce needle litter. *Oikos* 24: 402 (1973).
13. Wixson, B. G., and Jennett, J. C. Environmental impact of emissions from lead mining, milling, and smelting. Paper presented at AAAS meeting, New York, N. Y., 1975.
14. Chesselet, R., and LaLou, C. Role du "detritus" dans la fixation de radio elements dans le milieu marine. *C. R. Acad. Sci. (Paris)* 260: 1225 (1965).
15. Pomeroy, L. R., et al. Flux of ^{32}P and ^{65}Zn through a salt-marsh ecosystem. *Proc. Symp. Disposal Radioactive Wastes into Seas, Oceans and Surface Waters. IAEA, Vienna, 1966*, p. 177.
16. Chipman, W., Schommers, E., and Bayer, M. Uptake accumulation and retention of radioactive manganese by the marine annelid worm, *Hermione hystrix*. In: *Radioactivity in the Sea. (IAEA Publ. 25)*, Vienna, 1968, p. 16.
17. Odum, W. E. The ecological significance of fine particle selection by the striped mullet, *Mugil cephalus*. *J. Limnol. Oceanog.* 13: 92 (1968).
18. Tenore, K. R., Horton, D. B., and Duke, T. W. Effects of bottom substrate on the brackish water bivalve, *Rangia cuneata*. *Chesapeake Sci.* 9: 238 (1968).

19. Fukai, R., and Murray, C. N. Environmental behavior of radiocobalt and radiosilver released from nuclear power stations into aquatic systems. IAEA, Proc. Series STI (IAEA Publ. 345) Vienna, 1973, p. 422.
20. Luoma, S. N., and Jenne, E. A. Factors affecting the availability of sediment-bound cadmium to the estuarine, deposit-feeding clam, *Macoma balthica*. In: Radioecology and Energy Resources, C. E. Cushing, Ed. (Ecol. Soc. Am. Spec. Pub. 1) 1977, Dowden, Hutchinson, and Ross, Stroudsburg, Penn., p. 283.
21. Gutknecht, J. Mechanism of radioactive zinc uptake by *Ulva latuca*. J. Limnol. Oceanog. 6: 426 (1961).
22. Reichle, D. E., and Crossley, D. A. Trophic level concentrations of cesium-137, sodium and potassium in forest arthropods, Proc. 2nd Nat. Symp. Radioecology, U. S. Dept. Comm. (Conf. 670503), 1969, p. 678.
23. Rickard, W. H. Cesium-137 in Cascade Mountain vegetation. Proc. 2nd Nat. Symp. Radioecology, U. S. Dept. Comm. (Conf. 670503), 1969, p. 556.
24. Odum, W. E., Woodwell, G. M., and Wurster, C. F. DDT residues absorbed from organic detritus by fiddler crabs. Science 164: 576 (1969).
25. Duke, T. W. Biogeochemical cycling of radionuclides in the estuarine environment. Proc. S. E. Assoc. Game Fish. Comm. 17: 315 (1963).
26. Whitten, B. K., and Goodnight, C. J. The role of tubificid worms in the transfer of radioactive phosphorus in an aquatic ecosystem. Proc. 2nd Nat. Symp. Radioecology, U. S. Dept. of Comm. (Conf. 670503), 1969, p. 270.
27. Banus, M., Valiela, I., and Teal, J. M. Export of lead from salt marshes. Mar. Pollution Bull. 5: 6 (1974).
28. Anderson, J. Wet digestion versus dry ashing for the analysis of fish tissue for trace metals. Atom. Ab. Newsletter 11: 88 (1972).
29. Baumhardt, G. R., and Welch, L. F. Lead uptake and corn growth with soil-applied Pb. J. Environ. Quality 1: 92 (1972).