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Decomposition and Nutrient–Metal Dynamics of Litter in Freshwater Tidal Wetlands

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Abstract: Freshwater tidal wetlands are characterized as highly productive with a high diversity of species that annually contribute litter to the wetland surface. This paper describes the dynamics of litter decomposition for several common species in freshwater tidal wetlands. Decomposition is a two-step process with significantly higher rates occurring during the first 30 days. There were no significant differences in decomposition rate between habitats, but there were significant species differences. Most species lost 80% or more of the original weight within 1 year. Weight loss patterns were positively related to initial nitrogen concentrations. During the period of rapid loss, litter also lost both nitrogen and phosphorus. After initial loss of N and P, concentrations of these elements increased. For longer periods of time, however, almost all species lost N and P, suggesting that the litter layer is only a short-term sink for those nutrients. In contrast, metals (Pb, Ni, Cu, Cd) gradually increased on all litter types suggesting that the litter layer is important to retention of metals.

INTRODUCTION

Most net annual aboveground production of wetlands is not consumed by herbivores but decomposes on the wetland surface (Gallagher, 1978; Polunin, 1982). Rates of decomposition vary in wetlands (Holding et al., 1974; Odum and Heywood, 1978; Odum, 1978; Davis and van der Valk, 1978, 1983; Chamie

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and Richardson, 1978; Neely and Davis, 1985), and the fate of materials released or adsorbed during decomposition depends on the physical and chemical composition of material (Gosselink and Kirby, 1974; Davis and van der Valk, 1978; Day, 1982; DeBusk and Dieberg, 1984; Brock et al., 1985b), as well as environmental conditions at the site of decomposition (Howarth and Fisher, 1976; Gallagher, 1978; Day, 1982; Sharma and Gopal, 1982; Sain, 1984; Brock et al., 1985b).

The decomposition of litter and resultant release of nutrients involves at least two processes (Godshalk and Wetzel, 1978a; Carpenter, 1982; Wieder and Lang, 1982; Melillo et al., 1984; Brock et al., 1985b). An initial loss of soluble materials is usually attributed to abiotic leaching (Boyd, 1970; Gosselink and Kirby, 1974; Godshalk and Wetzel, 1978a, 1978b, 1978c, 1978d; Brock et al., 1985b). Released nutrients may be incorporated into the protoplasm of decomposer organisms (Gosselink and Kirby, 1974) where activities such as respiration and denitrification account for additional nutrient losses (Gosz et al., 1973; Mason and Bryant, 1975). On the other hand, accumulation of materials by components of the microfloral and microfaunal detritus community can cause increased nutrient content in decomposing litter (Davis and van der Valk, 1978; Howard-Williams and Davis, 1979; Hobbie and Lee, 1980; Puriveth, 1980; Brock, 1984). Abiotic factors can also cause increases in the amounts of some nutrients (Davis and van der Valk, 1978). The net effect of abiotic and biotic interactions during decomposition is that some materials are released and presumably used in plant growth at or near the point of release, while other nutrients are immobilized or stored temporarily or permanently at the point of release (Sain, 1984; Bowden, 1986). Additional nutrients may be exported to another, usually downstream, ecosystem.

Details of the decomposition process in freshwater tidal wetlands are poorly understood beyond the fact that litter turnover rates can be extremely high (Odum et al., 1984) and that patterns of nutrient release from decomposing macrophytes are apparently different when comparisons are made between species, either in fresh or brackish wetlands (Odum and Heywood, 1978; Odum, 1978; Simpson et al., 1983a; Odum et al., 1984).

In this paper we report results of four litter decomposition experiments conducted between 1974 and 1980 in two Delaware River freshwater tidal wetlands, the Hamilton Marsh immediately south of Trenton, New Jersey, and Woodbury Creek Marsh at National Park, New Jersey. Both wetlands are highly productive (Whigham et al., 1978; Simpson et al., 1983a) and have been the sites of numerous other studies (Simpson et al., 1983a; Dubinski et al., 1986). Our objectives are to describe the decomposition process, compare rates of decomposition for several species in different habitats, and characterize changes in nutrients (nitrogen, phosphorus) and metals (lead, nickel, cadmium, and copper) during decomposition.

METHODS

Decomposition experiments used 1-mm mesh nylon litter bags that contained approximately 10 (Hamilton Marsh) or 15 (Woodbury Creek) g of freshly harvested material that had been dried to constant weight at 80°C. Fresh rather than senescent plant material was chosen because the major litter input to the wetland surface is green material that is deposited after the first killing frosts. Litter bags were placed on the marsh surface during the last 2 weeks in October or the first week in November (see Table 1). Approximately equal amounts of leaf and stem (blade and petiole material in the case of *Peltandra virginica* and *Sagittaria latifolia* and leaf material only for *Acorus calamus*) were used in the 1975, 1976, and/or 1980 experiments. In 1976, only leaf material was used. In addition, we also used four common annual species (*Bidens laevis, Polygonum arifolium, Impatiens capensis, Zizania aquatica* var. *aquatica*) that represented a variety of life forms and tissue types.

The 1974 study was conducted in four locations described elsewhere (Whigham and Simpson, 1975). One set of bags was positioned at the upper edge of a stream bank terrace within 10 m of the stream channel. The site, normally subjected to 3 h of tidal inundation, was selected because of its proximity to the tidal creek and because large amounts of sediment seemed to be deposited there. Substrate organic matter content averaged 20.3 ± 2.9% for the surface 10 cm and declined sharply to 7.8 ± 1.3% at the 10 to 20 cm depth interval. A second set of litter bags was placed in a pond-like habitat characterized by having standing water at all times, even though there was approximately a 0.5-m tidal amplitude. Substrate organic matter content averaged 26.0 ± 6.3% with little difference from the surface down to 50 cm soil depth (Whigham and Simpson, 1975). The other two sites were both on the high marsh and were similar except that one site normally flooded for 2 h during each tide cycle and the other site normally flooded for 3 h. Substrate organic matter at those two sites averaged 15.6 ± 1.6% and 20.7 ± 2.5%, respectively, with little change with depth. The 1975 and 1976 studies were conducted at the high marsh site that was normally flooded for 2 h. The 1980 Woodbury Creek study was also conducted at a high marsh site (Simpson et al., 1983b) where sets of litter bags were placed at three distances (5, 20, and 50 m) from a storm drain that entered the wetland.

Because our objective was to consider the litter and not litter-sediment interactions, litter bags collected from the field were gently washed to remove as much sediment as possible without losing fragmented plant material. Bags were then dried at 80°C. Samples from the 1975, 1976, and 1980 studies were ground in a Wiley Mill to pass through a 40-mesh screen. They were stored in plastic bags until analyzed for nitrogen (N), phosphorus (P), cadmium (Cd), copper (Cu), lead (Pb), and nickel (Ni). Nitrogen was determined using Kjeldahl procedures (Black, 1965), P using the method of Sommers and Nelson (1972), and metals following U. S. Environmental Protection Agency procedures (EPA, 1979) using the protocol described by Simpson et al. (1981, 1983c). Metal concentrations were calculated on an ash-free dry weight basis by drying 1-g subsamples at 105°C and then ashing at 550°C for 1 h. Nitrogen and P concentrations were not determined on an ash-free dry weight basis.

RESULTS

Weight Loss

Weight loss data expressed as percent of the original remaining were log transformed and fitted to linear, exponential, and nonlinear double exponen-

TABLE 1

Information About Four Litter Decomposition Studies Conducted in the Hamilton (H) and Woodbury Creek (W) Wetlands

Yr	Site	Habitat*	Species†	Sampling interval‡	Reps.§	Analyses¶
74	H	H, P	B, Z, P	Every 30 days for 1 year	2	W
75	H	H	B, P	7, 14, then 30 for 270	2	W, N, P
76	H	H	B, P, S, A, PA	3, 7, 14, 30, 90, and 120	2	W, N, P
80	W	H	B, P, Z, I	3, 7, 14, 28, 56, 94, 119, 147, 175, 210, 239	3	W, M

*Habitat refers to locations within the wetlands where the studies were conducted. Characteristics of both habitat types (H = high marsh and P = pond-like) are described in the text and in Simpson et al., 1983a and b.

†Species studied were: B = *Bidens laevis*, Z = *Zizania aquatica* var. *aquatica*, P = *Peltandra virginica*, S = *Sagittaria latifolia*, A = *Acorus calamus*, PA = *Polygonum arifolium*, and I = *Impatiens capensis*.

‡Sampling interval refers to the number of days that litter bags were in the field prior to collection.

§Reps. is the number of replicates collected at each time interval.

¶Abbreviations for the types of analyses performed on the samples are: W = weight loss, N = nitrogen, P = phosphorus, M = metals.

TABLE 2

Comparison of Decay Coefficients in Percent Per Day for 1975, 1976, and 1980 Experiments

Species	0 to 30 days	More than 30 days
	1975	
Peltandra virginica	2.40	1.75
Bidens laevis	1.24	0.71
	1976	
Peltandra virginica	2.50	0.92
Bidens laevis	5.33	0.22
Acorus calamus	1.37	0.19
Sagittaria latifolia	2.84	0.24
Polygonum arifolium	2.95	0.23
	1980	
Zizania aquatica var. *aquatica*	0.34	0.04
Peltandra virginica	1.05	0.15
Bidens laevis	0.51	0.18
Impatiens capensis	0.52	0.26

tial models (Wieder and Lang, 1982) using SAS procedures (Ray, 1982). The most realistic representation of weight loss for the 1975, 1976, and 1980 studies was obtained by dividing the data into two time periods (0 to 30 days and more than 30 days) and fitting the two sets to the exponential model (Figs. 1a through 1e). The best fit for the 1974 data was obtained by not including time 0 in the analysis and fitting the remaining data, which started with day 30, to the exponential model. Table 2 shows the rates of weight loss during the two time periods for the 1975, 1976, and 1980 studies. The decay coefficients varied widely between species during the first 30 days and were much lower and less variable thereafter.

Analysis of the 1974 data using ANOVA (Ray, 1982) found significant species ($F = 8.59$, $df = 2$, $P \leqslant .003$) differences in weight loss of leaf material but no significant habitat differences ($F = 0.81$, $df = 3$, $P \leqslant .48$). Weight loss for *Zizania* was significantly less than for *Bidens* and *Peltandra* (Fig. 2). All three species lost 75% or more of their original weight over the 270-day study. The species and habitat interaction effect was significant ($F = 2.74$, $df = 11$, $P \leqslant .01$) and was caused by a slower rate of decay of *Peltandra* at the site near the stream as compared to the pond-like site and the high marsh site that normally flooded for 3 h per tide cycle.

Similar to 1974, decay rates for *Bidens* and *Peltandra* were not different when both species were compared at the one high marsh site in 1975 (Fig. 3). Neither did the two species differ in 1976 when they were compared to several other species and only leaf material was used (Fig. 4). Significant species differences in 1976 ($F = 2.64$, $df = 4$, $P \leqslant .04$) were caused by a slower rate of weight loss for *Acorus*. Decomposition rates for *Sagittaria* and *Polygonum* were greater than for *Acorus* but were not different between the two species (*Peltandra* and *Bidens*) that decomposed fastest (Fig. 4).

Within habitat comparisons were made in 1980 when litter of four species was placed at three locations within one high marsh site in the Woodbury Creek wetland. There were significant species differences ($F = 317.92$, $df = 3$, $P \leqslant .0001$) with *Peltandra* decomposing fast and *Zizania* the slowest (Fig. 5). In contrast to the 1974 and 1975 studies, *Peltandra* decomposed faster than *Bidens*. Significant location differences were due to slower decomposition rates of all species at the site located 20 m from the tidal creek.

Changes in N and P

Although there are differences among species in %N, %P, Total N, and Total P (Figs. 6 through 11), a general pattern for nitrogen changes appeared only when leaf litter was used (Figs. 8 and 10). Percent N increased during the first 120 days with the greatest changes occurring during the first month (Fig. 8), and there were significant ($F = 12.87$, $df = 4$, $P \leqslant .0001$) species differences. *Acorus* had significantly lower concentrations of N than the other species. Total N decreased during the first 30 days in all species except *Acorus* (Fig. 10) which showed an overall increase in Total N during the 120-day study. There were also significant species differences in Total N ($F = 4.21$, $df = 4$, $P \leqslant .004$) with *Acorus* and *Bidens* significantly lower in Total N than *Polygonum*.

The pattern is somewhat different when both leaf and stem materials were used in the litter bags (Figs. 6 and 7) and the study conducted for a longer period of time. The initial drop in %N was not as pronounced, but there was still an overall increase in %N during the first 120 days. Total N declined during the first 2 weeks but, in contrast to the 1976 experiment

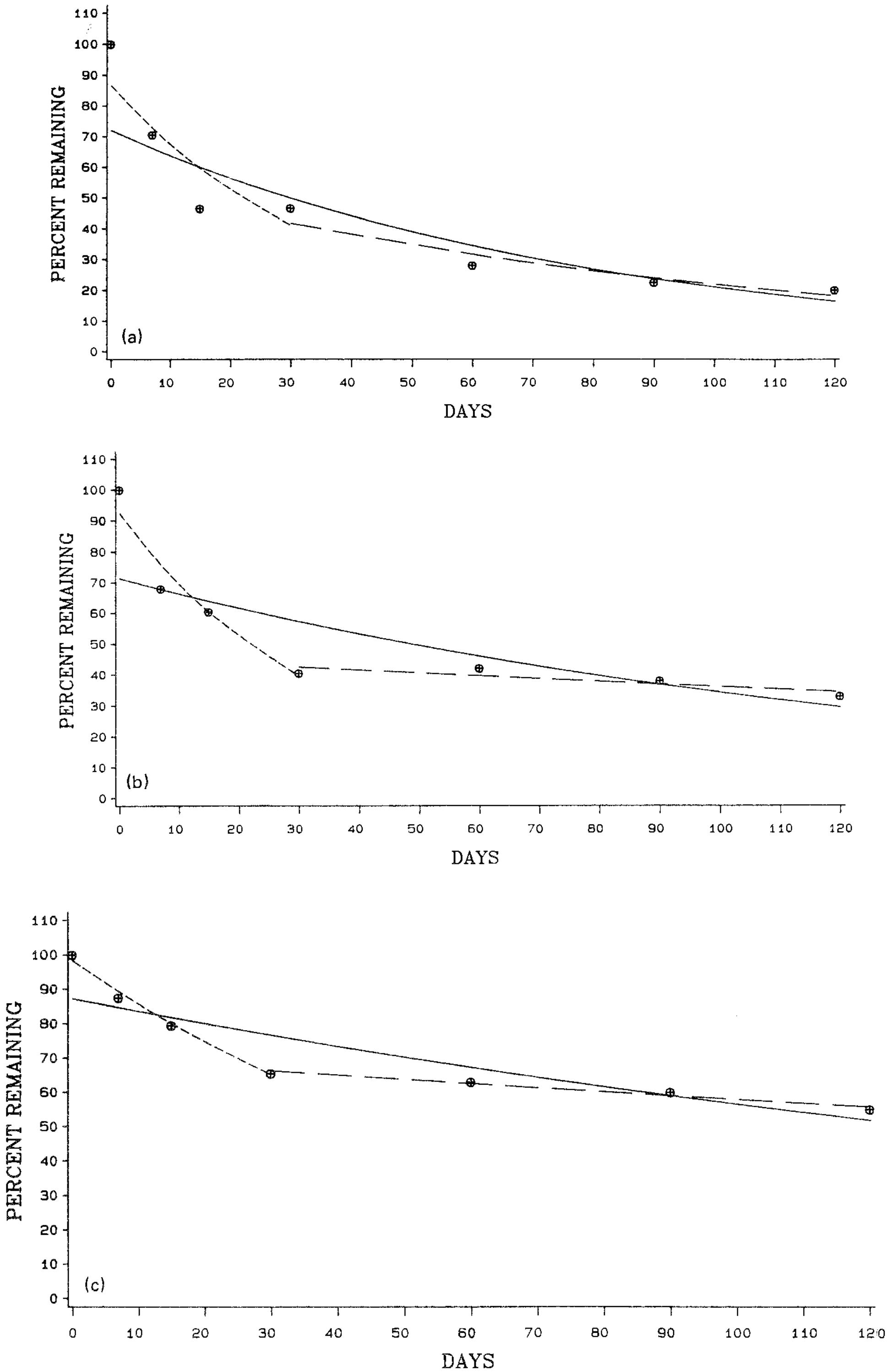


Fig. 1 (See facing page for legend.)

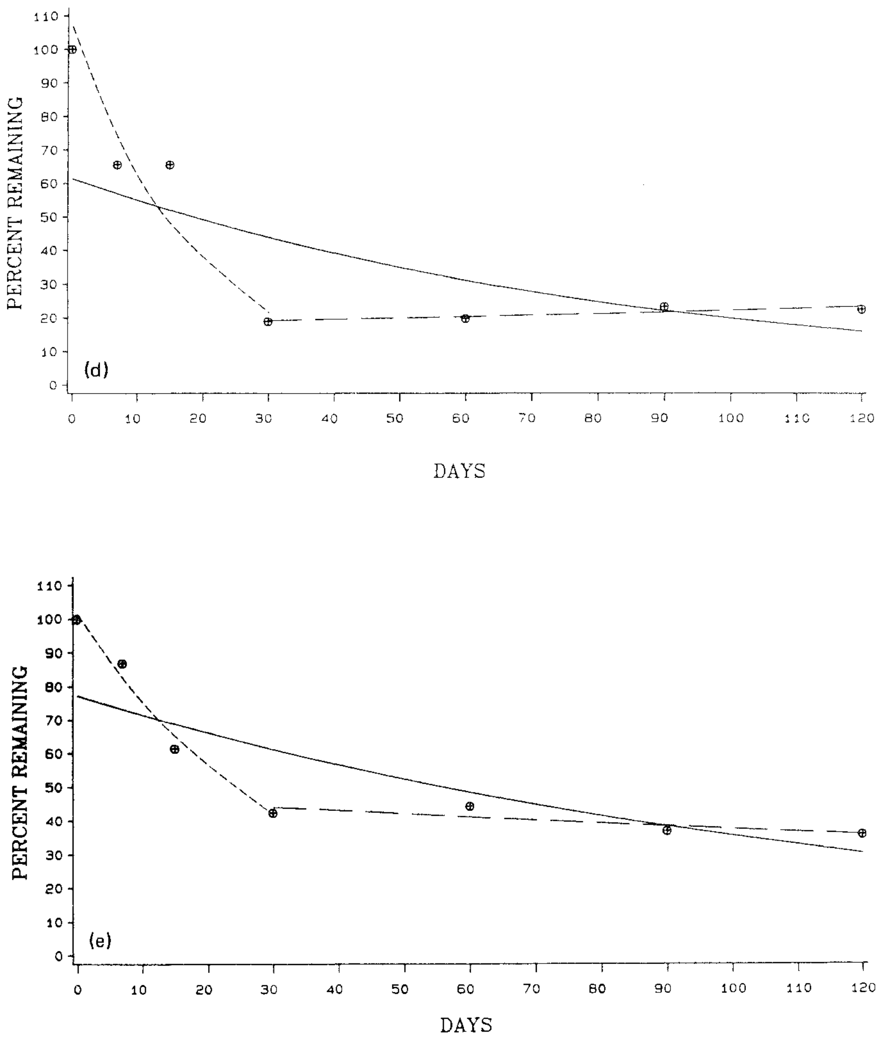


Fig. 1a-e. Decomposition of tissues from five freshwater tidal wetland plant species. (a) *Peltandra virginica.* (b) *Sagittaria latifolia.* (c) *Acorus calamus.* (d) *Bidens laevis.* (e) *Polygonum arifolium.* The solid line is the predicted weight loss pattern when all data were fitted to the negative exponential model. The two dashed lines represent predicted patterns for 0 to 30 days and >30 days. The solid circles are means of two values for each time period. Details of the analysis are given in the text.

(Fig. 11), then increased until about day 150 after which N declined. The decline in Total N from day 150 onward was especially pronounced for *Peltandra* (Fig. 6) which had significantly higher %N ($F = 36.66$, $df = 1$, $P \leq .0001$) and Total N ($F = 8.08$, $df = 1$, $P \leq .007$) than *Bidens* for the first 120 days.

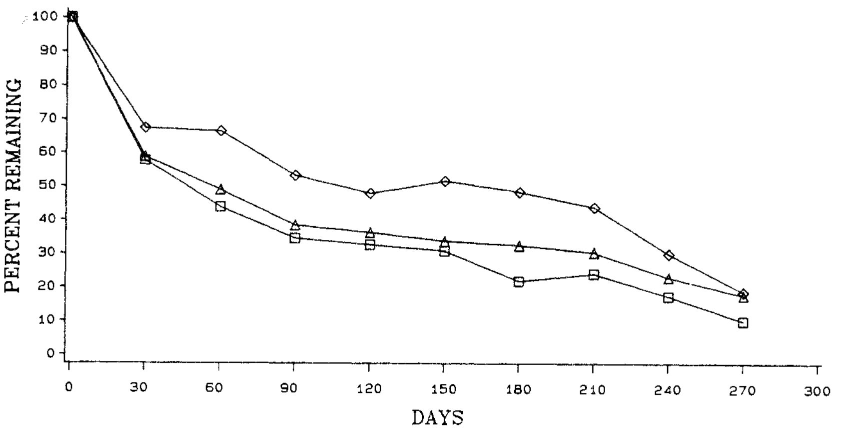


Fig. 2 Decomposition of leaves and stems of *Zizania aquatica* var. *aquatica* (◇), *Peltandra virginica* (□), and *Bidens laevis* (△) from the 1974 experiment.

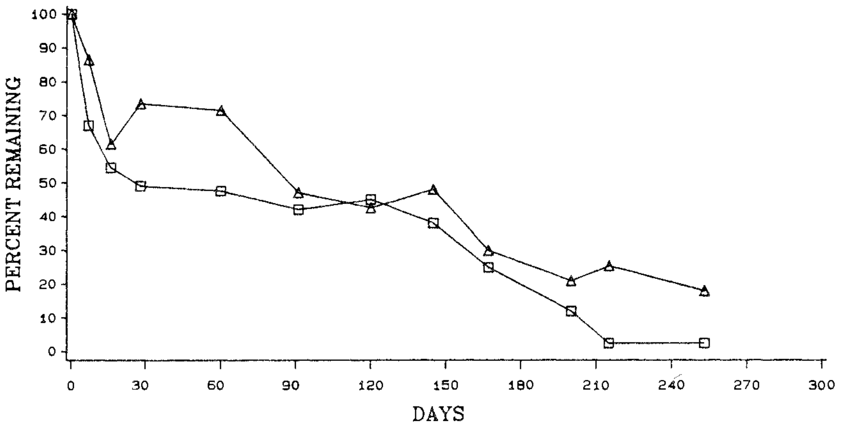


Fig. 3 Decomposition of leaves and stems of *Peltandra virginica* (□) and *Bidens laevis* (△) from the 1975 experiment.

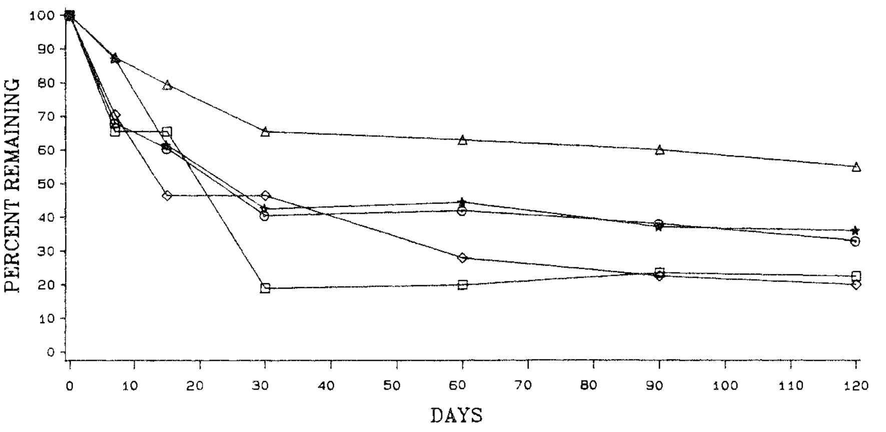


Fig. 4 Decomposition of leaves of *Peltandra virginica* (◇), *Bidens laevis* (□), *Sagittaria latifolia* (○), *Polygonum arifolium* (*), and *Acorus calamus* (△) from the 1976 experiment.

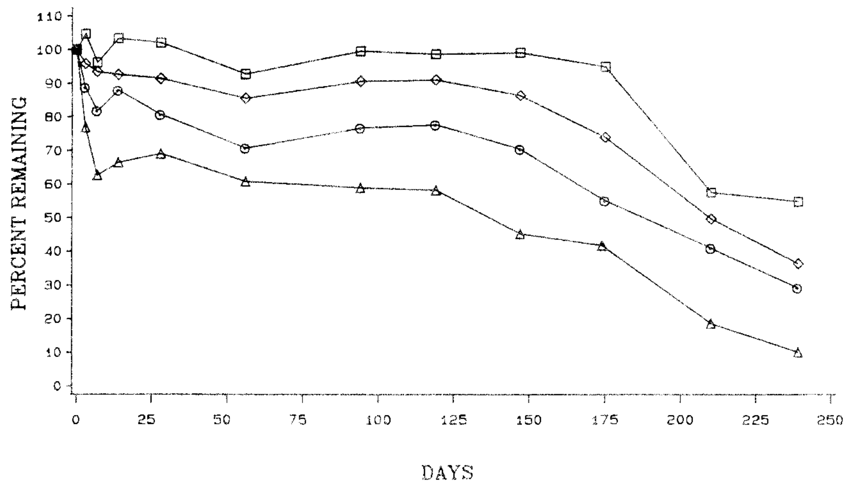


Fig. 5 Decomposition of leaf and stem material of *Impatiens capensis* (○), *Zizania aquatica* var. *aquatica* (□), and *Bidens laevis* (◇) and leaf and petiole material of *Peltandra virginica* (△) from the 1980 experiment.

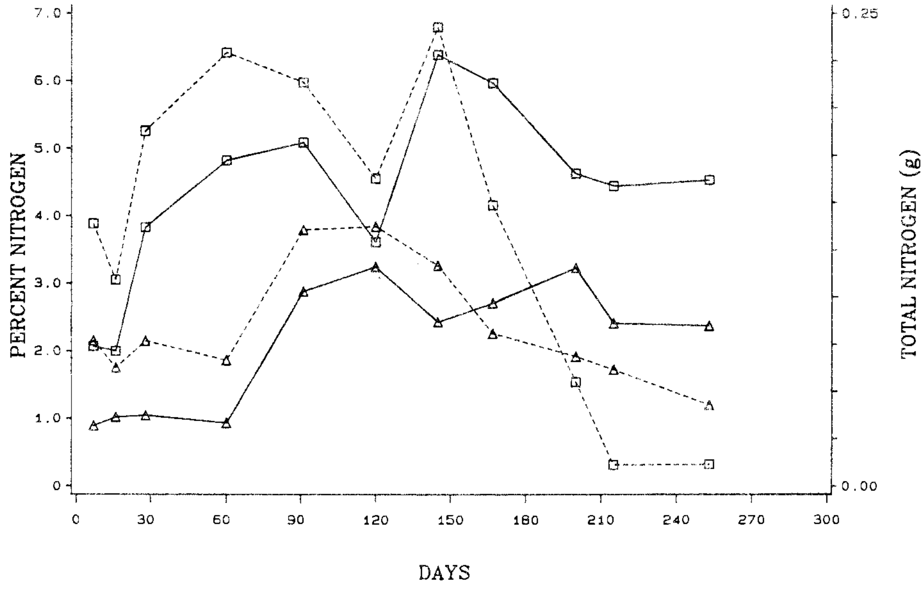


Fig. 6 Percent N (solid lines) and Total N (g) (dashed lines) in litter of *Peltandra virginica* (□) and *Bidens laevis* (△) from the 1975 experiment.

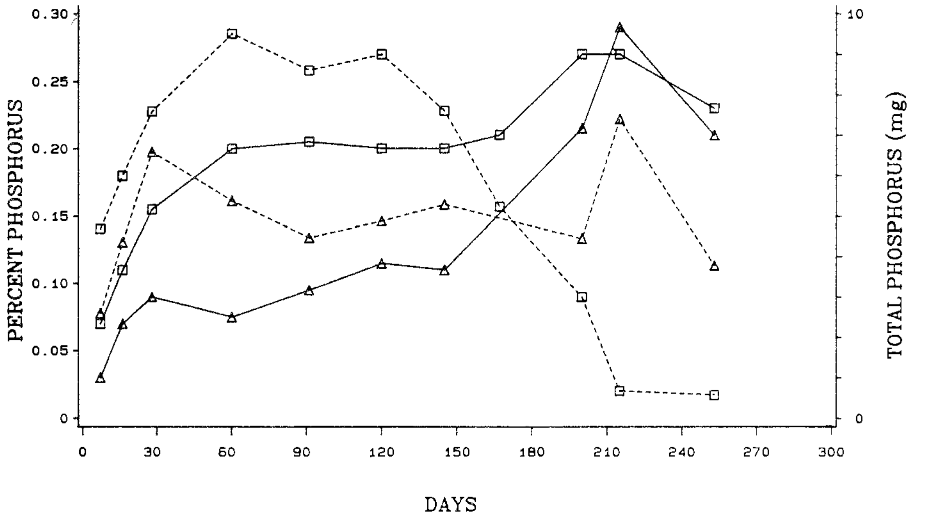


Fig. 7 Percent P (solid lines) and Total P (mg) (dashed lines) in litter of *Peltandra virginica* (□) and *Bidens laevis* (Δ), from the 1975 experiment.

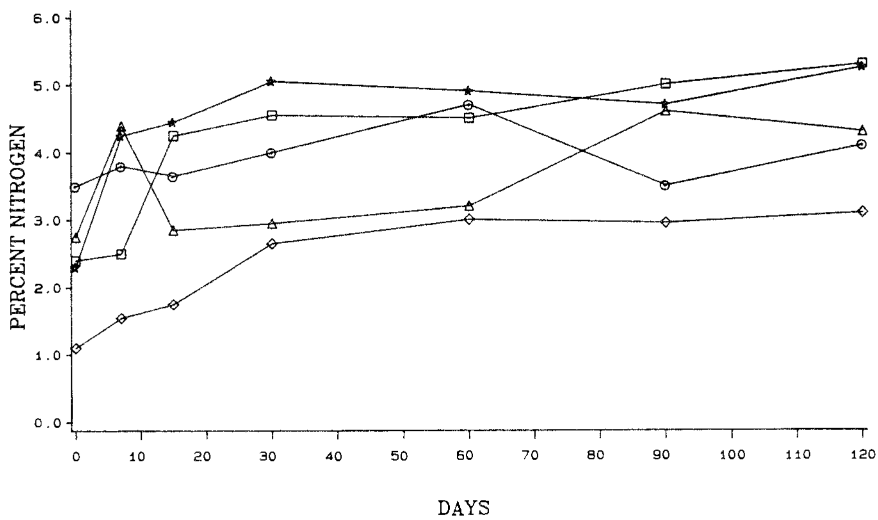


Fig. 8 Percent N in litter of *Peltandra virginica* (□), *Bidens laevis* (Δ), *Acorus calamus* (◇), *Sagittaria latifolia* (○), and *Polygonum arifolium* (∗) from the 1976 experiment.

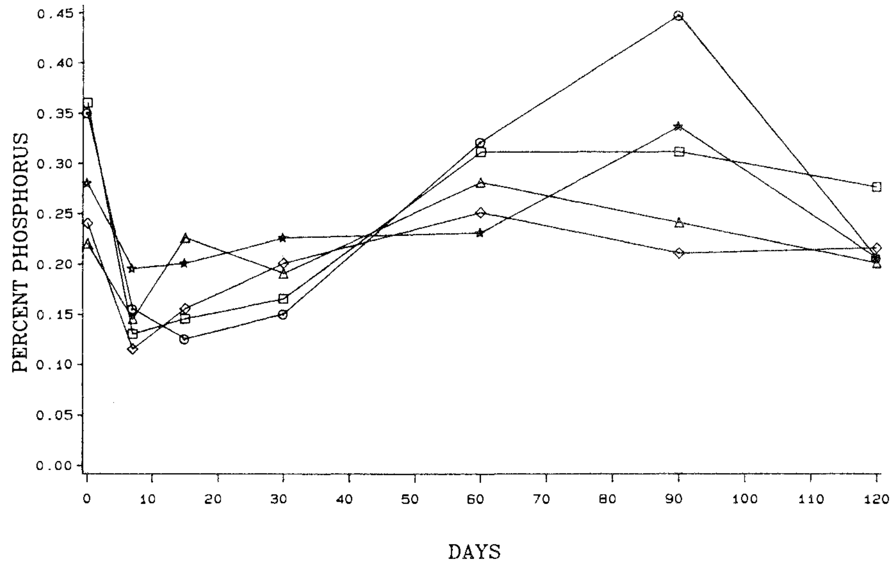


Fig. 9 Percent P in litter of *Peltandra virginica* (□), *Bidens laevis* (△), *Acorus calamus* (◇), *Sagittaria latifolia* (○), and *Polygonum arifolium* (∗) from the 1976 experiment.

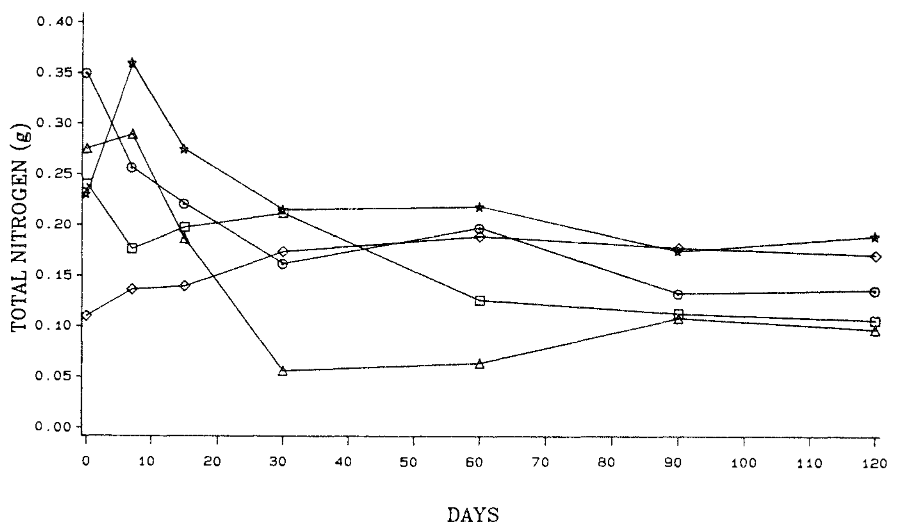


Fig. 10 Total N (g) in litter of *Peltandra virginica* (□), *Bidens laevis* (△), *Acorus calamus* (◇), *Sagittaria latifolia* (○), and *Polygonum arifolium* (∗) from the 1976 experiment.

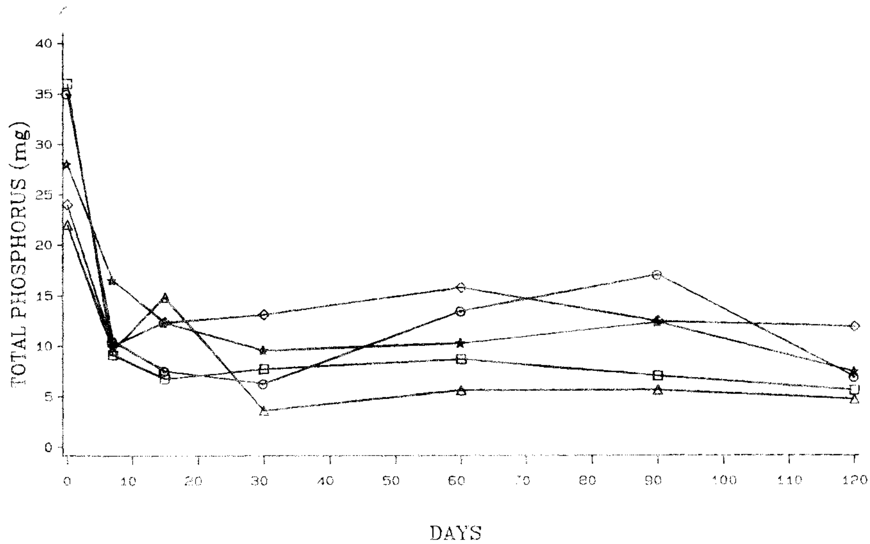


Fig. 11 Total P (mg) in litter of *Peltandra virginica* (□), *Bidens laevis* (△), *Acorus calamus* (◇), *Sagittaria latifolia* (○), and *Polygonum arifolium* (∗) from the 1976 experiment.

There were also differences in patterns for %P and Total P when leaf (Figs. 9 and 11) and leaf plus stem material were compared (Fig. 7). Leaf material of all species lost P during the first 30 days (Fig. 11). Phosphorus concentration declined sharply between day 0 and day 7 then increased in all species except *Polygonum* (Fig. 9). The pattern for %P was almost the same for leaf and stem material, but the pattern for Total P was different (Fig. 7). When leaves alone were used, Total P declined sharply for all species during the first 30 days and only changed gradually thereafter. There were no significant species differences for %P ($P \leq .55$) or Total P ($P \leq .47$). When leaf and stem material was used, Total P increased and remained high in *Bidens* while declining precipitously in *Peltandra* (Fig. 7). *Peltandra* had significantly higher %P ($F = 9.71$, df = 1, $P \leq .004$) than *Bidens*, but Total P was not significantly different ($P \leq .33$).

Litter N and P concentration data for time 0 and at 30 days were regressed against decay coefficients for the first 30 days and following 90 days for the 1976 study (Fig. 12). There was no pattern for the relationship between decay coefficients and P concentrations for either time period while the expected positive relationship (Melillo et al., 1984; DeBusk and Dieberg, 1984) for N was observed (Fig. 12). The regression coefficients were the same ($R^2 = 0.32$) for both time periods. Decay coefficients were greater and more variable during the first 30 days. Percent N of the litter was greater after the first 30 days, but the decay coefficients were lower and more uniform demonstrating that the differences between species were not as great and that the litter was more recalcitrant after the initial leaching period.

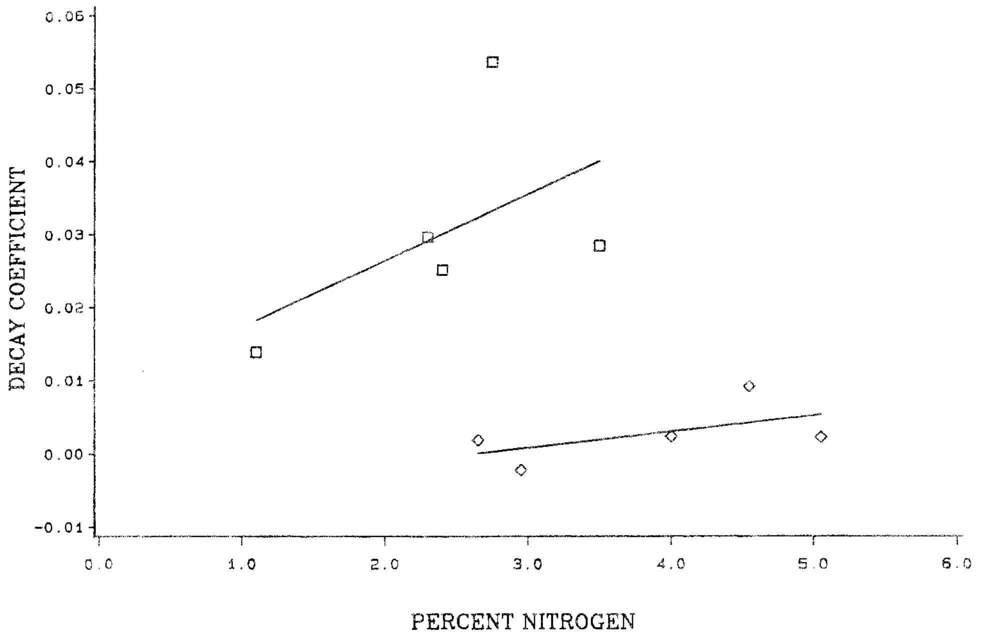
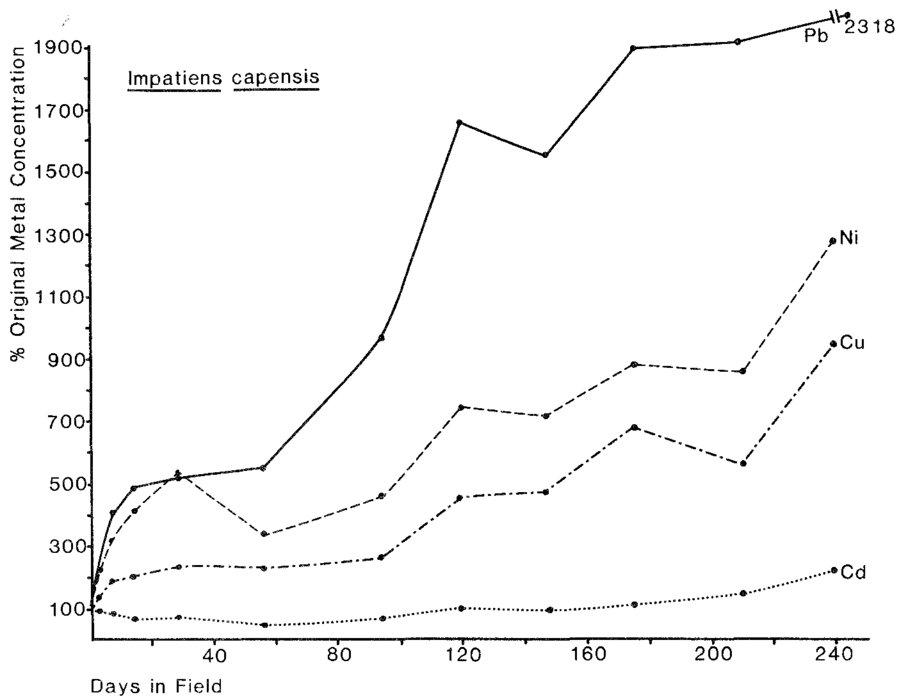


Fig. 12 Regression relationship between litter nitrogen (N) concentrations and decay coefficients (k) for 0–30 days (□) and >30 days (◇). The R^2 each time period was 0.32. The regression equations for the two time periods are: [0–30 days] k = 0.0082 + 0.009(N); [>30 days] k = −0.0058 + 0.00222(N).

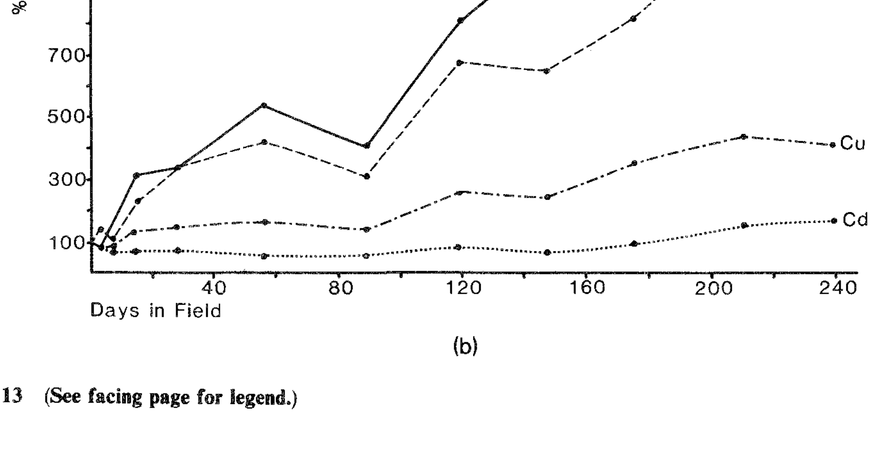
Changes in Metals

Initial and final metal concentrations of litter are given in Table 3 with the patterns of accumulation shown in Figs. 13a through 13d. Cadmium concentrations ranged from 0.4 to 2.7 $\mu g\ g^{-1}$ with *Zizania* having significantly less Cd than other species, while *Peltandra* contained significantly less than *Bidens* and *Impatiens*. In contrast, there were no significant species differences in final Cd concentrations. Cadmium accumulated (Figs. 13a through 13d) slowly in species (*Bidens* and *Impatiens*) which had the highest initial concentrations and rapidly in *Zizania* which had the lowest initial concentrations. A significant location by species interaction ($P \leqslant .05$) was due to significantly higher rates of Cd on litter placed at 5 m which was nearest the storm drain.

Initial Cu concentrations ranged from 2.5 to 15.9 $\mu g\ g^{-1}$ and were significantly ($P \leqslant .05$) lower in *Zizania. Peltandra* had significantly higher ($P \leqslant .05$) initial Cu concentrations. Final litter concentrations increased to between 36.1 to 61.4 $\mu g\ g^{-1}$ with *Bidens* having a significantly lower final concentration than the other three species. The rates of Cu accumulation were significantly higher for *Zizania* ($P \leqslant .01$) than other species, and there were no significant location differences.

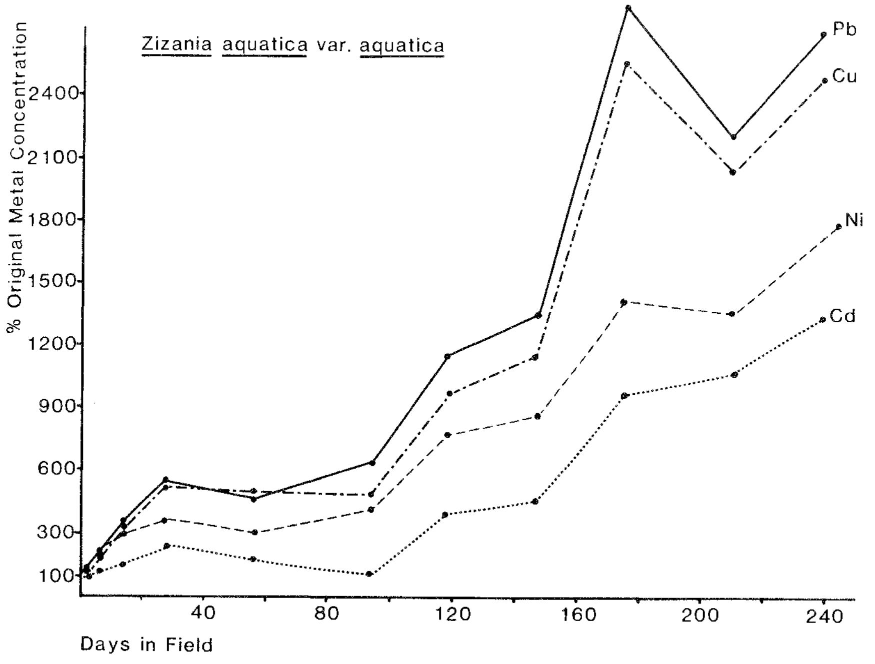


(a)

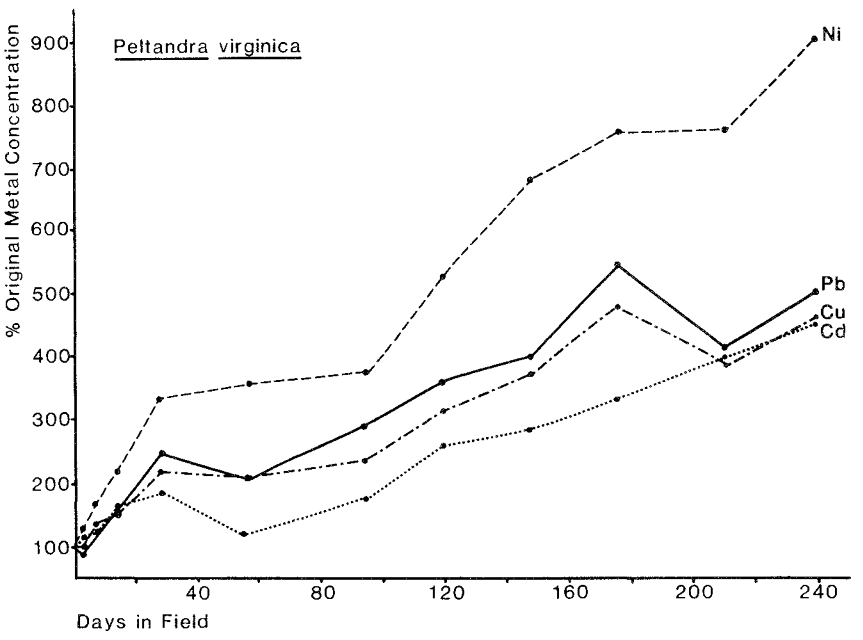


(b)

Fig. 13 (See facing page for legend.)



(c)



(d)

Fig. 13a-d Changes in the metal content as a percent of the initial concentrations for decomposing litter. (a) *Impatiens capensis*. (b) *Bidens laevis*. (c) *Zizania aquatica* var. *aquatica*. (d) *Peltandra virginica*.

TABLE 3

Initial and Final Metal Concentrations ($\mu g\ g^{-1}$ + 1 S.E.) in Litter of Four Species Used in 1980 Experiment

	Metal concentration, $\mu g\ g^{-1}$							
	Cd		Cu		Ni		Pb	
Species	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Bidens laevis	2.5 ± .1	4.1 ± .8	8.9 ± .6	36.1 ± 8.4*	2.8 ± .6	27.6 ± 4.4*	20.5 ± .5	445.8 ± 222.2
Impatiens capensis	2.7 ± .6	6.0 ± .7	6.6 ± .3	55.9 ± 4.2	3.8 ± .0	48.5 ± 4.8	19.7 ± 3.7	456.8 ± 121.1
Peltandra virginica	1.5 ± .1*	6.1 ± .8	15.9 ± 1.6*	61.4 ± 6.6	8.2 ± .7*	62.4 ± 6.0	158.0 ± 23.8*	657.0 ± 194.9
Zizania aquatica var. *aquatica*	0.4 ± .1*	5.3 ± .6	2.5 ± .2*	61.0 ± 1.7	3.0 ± .6	53.7 ± 3.7	25.0 ± 0.6	673.3 ± 147.1

*Means that are significantly different ($P \leqslant .05$) based on Duncan's new multiple range test.

Initial Ni concentrations ranged from 2.8 to 8.2 $\mu g\ g^{-1}$ with *Peltandra* significantly higher ($P \leq .05$) than any other species. Final concentrations ranged from 27.6 to 62.4 $\mu g\ g^{-1}$. Similar to Cu, Ni accumulations were significantly less on *Bidens* litter. Accumulation rates were significantly higher for *Zizania*, and there were no significant location differences in rates of Ni accumulation.

Initial Pb concentrations varied greatly (Table 3) with *Peltandra* significantly higher ($P \leq .05$) than other species. There were no significant species differences when final Pb concentrations were compared. *Peltandra* had a significantly lower ($P \leq .05$) rate of Pb accumulation and the highest initial concentrations. Similar to the other three metals, *Zizania* had the highest rates of accumulation. A significant species by location interaction ($P \leq .0001$) was caused by higher Pb levels in litter placed nearest the storm drain.

DISCUSSION

Decomposition rates measured in these studies were higher than those reported for most types of wetlands dominated by emergent macrophytes (Brinson et al., 1981) and the majority of terrestrial ecosystems (Swift et al., 1979; Lang and Forman, 1978). Compared to other aquatic environments, the rates were higher than those measured for most stream macrophytes and for terrestrial litter which falls into streams (Melillo et al., 1984; Elwood et al., 1981). In lakes and swamps, some species of submerged macrophytes decompose very rapidly (Godshalk and Wetzel, 1978a, 1978b, 1978c), particularly floating leaved species (Brock, 1984; DeBusk and Dieberg, 1984; Brock et al., 1985a, 1985b), while leaf litter of woody species decomposes more slowly (Day, 1982; Qualls, 1984). In almost all aquatic environments, however, the pattern of weight loss is very similar and seems to be related to the presence of large amounts of labile (nonstructural carbohydrates, proteinaceous material, phenolic compounds) and low amounts of resistant compounds (cellulose, hemicellulose, and lignin) contained in the tissues (Puriveth, 1980; Godshalk and Wetzel, 1978d; Brock et al., 1985b).

All species lost weight rapidly during an initial period that lasted for approximately 30 days. This pattern is similar to those measured for *Zizania* in a nontidal freshwater wetland (Sain, 1984) and for floating leaved species such as *Nymphaea*, *Nuphar*, and *Nymphoides* (Brock, 1984; Brock et al., 1985a, 1985b). Differences in weight loss during the initial stage of decomposition is attributed to differences in the chemical composition of the litter with the highest rates associated with litter containing high nutrient concentrations. This relationship was observed in the 1976 study where there were species differences in the decomposition rates during the first 30 days (Table 2). The positive relationship between decomposition rate and initial N (Fig. 12) during the first 30 days supports the conclusion that rapid initial weight loss is due mostly to loss of labile materials and species differences are due, in part, to differences in initial conditions. After the 30 days, decomposition rates slowed (Table 2). This pattern has also been observed for other macrophytes and represents a period when mineralization of the more refractive materials is the primary cause of weight loss (Melillo et al., 1984). Again, however, the rate of weight loss appears related to litter N conditions after the first 30 days (Fig. 12).

In addition to species, there were also differences based on the type of material used in the litter bags. Species which contain little structural tissue and have high initial nutrient concentrations (*Peltandra, Sagittaria,* and *Nuphar*) decomposed at a significantly faster rate than species which contain large amounts of structural materials *(Zizania)* and/or have low initial nutrient concentrations *(Acorus)* (Figs. 2 through 5). We also found that bags which only contained leaf litter (Fig. 4) lost weight faster than bags which contained equal amounts of leaf and stem material (Figs. 2 and 3). This same observation has been recorded for other species (Puriveth, 1980; Brock, 1984; DeBusk and Dieberg, 1984), and it is probably related to the fact that leaves normally contain less structural material than other plant parts (Esteves, 1979).

The site where the experiment was conducted was not as important as the species differences. These results were similar to those reported by Day (1982), who studied decomposition in different habitats within a swamp ecosystem, but contrasted with those of Odum and Heywood (1978), who conducted studies in a freshwater tidal wetland and reported that *Peltandra* decomposed faster at a submerged site compared to a high marsh site. Day (1982) found that there were site differences in weight loss of litter bags that contained mixed species litter. Similar to Odum and Heywood (1978), Day (1982) found that litter decomposed fastest when they were submerged. Others have found that the chemical composition of the water plays a very important role in the rates of decomposition (Qualls, 1984; Brock et al., 1985b).

Over periods of time longer than 1 year, differences in species decomposition rates disappear (Figs. 2 and 3), and only small amounts of litter remain. Beyond 1 year, the decomposition rates are much slower (Sain, 1984; Melillo et al., 1984). On high marsh sites, sediment deposition is generally less than stream levee areas, and litter may remain unburied long enough to decompose completely, releasing all nutrients (Bowden, 1986). Where sedimentation rates are high (stream banks and pond-like areas) and where the substrate is always waterlogged (pond-like areas), decomposition may not be complete. Litter samples that are covered by sediment may decompose slower, and there is a greater chance that litter and its nutrients will be incorporated into the sediments. In waterlogged areas, sediments are almost always anaerobic, and decomposition will be much slower (Chamie and Richardson, 1978). The litter and its nutrients are thus more likely to become incorporated into the substrate in waterlogged areas.

The patterns of nutrient and metal change indicate the potential role that decomposing litter might play in the retention of these materials in the wetland. An initial decline in N and P concentrations has been well documented for most types of decomposing plant materials (Holding et al., 1974; Davis and van der Valk, 1978, 1983; Godshalk and Wetzel, 1978a; Puriveth, 1980; Brock et al., 1985a, 1985b) due to leaching or microbial metabolism of labile materials. Both N and P concentrations increased following the initial changes and remained fairly constant thereafter (Figs. 6 through 9). For short time periods, litter accumulated both N and P (Figs. 10 and 11), but over longer time periods (Figs. 6 and 7) the litter lost both N and P. Thus the litter layer in freshwater tidal wetlands acts only as a short-term sink for N and P. Bowden (1986) has argued that a continuous litter layer may, however, play an important long-term role in regulating the loss of ammonium. This pattern contrasts to other types of emergent dominated wetlands where litter acts as long-term sink for both N and P (Chamie and Richardson, 1978; Davis and van der Valk, 1983; Sain, 1984; Bayley et al., 1985).

Similar to the findings of others (Banus et al., 1975; Pennenbarg, 1978; Drifmeyer et al., 1980; Gallagher and Kibby, 1980; Breteler et al., 1981; Larsen and Schierup, 1981; Simpson et al., 1983b), concentrations of all metals increased in litter with final concentrations ranging up to 20 times higher than initial concentrations (Table 3). Except for Cu and Ni concentrations of *Bidens* litter, there were not any significant species differences in final concentrations. Indeed, final Cd and Ni levels in the litter were quite similar to soil values (Simpson et al., 1983b), while Cu and Pb concentrations were approximately one-half to two-thirds those in the soil. The retention of metals in freshwater tidal wetlands, therefore, appears to be closely tied to interactions between metals and plants. The role is not direct, however, as the live vegetation sequesters only limited quantities of heavy metals. Decomposing litter, however, clearly accumulates metals. This is especially true in high marsh areas where litter is neither rapidly covered with sediments nor actively scoured from the wetland surface by tidal waters. Although rates of decomposition are high, up to 25% of the original material may remain after 1 year (Figs. 1 through 3) and is then either slowly incorporated into the substrate or completely decomposed. It is hypothesized that the buried litter is an important vehicle for incorporation of metals into the sediment which in turn serves as the long-term sink for heavy metals in freshwater tidal wetlands.

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