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PATTERNS OF RADIOPHOSPHORUS ACCUMULATION IN THE EVERGLADES AFTER ITS INTRODUCTION INTO SURFACE WATER

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BY

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EXECUTIVE SUMMARY

Various water management alternatives currently under consideration would increase the loads of nitrogen and phosphorus laden water to the Water Conservation Areas via east coast backpumping schemes. In order to assess the impacts of these water management alternatives on the Water Conservation Areas, it is important to understand the capacity of the marshes to assimilate nutrients, as well as the mechanisms and pathways of nutrient flow. This study is designed to determine the short term pathways of inorganic phosphorus assimilation in the marsh ecosystem.

Labeled inorganic phosphorus, ^{32}P, was introduced into enclosures in cattail and sawgrass stands in two areas of WCA2A which were subjected to either enriched or background concentrations of phosphorus in the ambient water.

After 10 days it was found that over half of the ^{32}P had entered the subsurface sediments (peat), but very little of that had penetrated below 10 cm in depth. Leaf litter overlying the sediment accumulated about 30% of the labeled phosphorus at the enriched site and 12-15% of the ^{32}P at the background site. Only 2-4% of the ^{32}P was incorporated into living plant tissue after 10 days, and 2-4% was recovered from the water (except where floating algal mats or periphyton were absent).

A follow-up study is planned in which labeled phosphorus will be traced after its introduction into the sediments to determine if it is recycled to other marsh components, or if the soil does function as a long term phosphorus sink.

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Under contract with Environmental Science and Engineering, Inc., Altanta, Georgia, Jerome J. Guidry coordinated radiophosphorus procurement, safety precautions, and radiophosphorus analyses. Laboratory ^{32}P analyses were performed by Terry A. Kuykendall.

ABSTRACT

Radiophosphorus was used to trace the movement of inorganic P from surface water into the living vegetation, plant litter, algae, and subsurface sediments in Water Conservation Area 2A. Polyethylene enclosures were placed in sawgrass and cattail stands at locations which were subjected to enriched and background P concentrations in the water. Radiophosphorus was added to the water within the enclosures, and ten days later the marsh components in the enclosures were sampled and analyzed for ^{32}P.

Very little of the ^{32}P which was recovered from the enclosures remained in the surface water. Only two to four percent of the ^{32}P was found in the water at the sites where floating algal mats or calcareous periphyton were present. Sixteen percent remained in the water at the site which lacked these algal communities.

Over half of the ^{32}P moved into the subsurface sediments. Little ^{32}P penetrated below the upper ten centimeters of subsurface sediments at three of the sites; however, at one site most of the ^{32}P in the sediments had progressed downward to the 10-30 cm layer.

The living sawgrass and cattail plants accumulated negligible amounts of ^{32}P; only two to four percent of the recovered ^{32}P was found in living plant tissue. The leaf litter of these plants was more effective in ^{32}P uptake. Sawgrass and cattail leaf litter accumulated over 30 percent of the ^{32}P at the enriched location and 12-15 percent at the background location.

INTRODUCTION

The Water Conservation Area system encompasses about 3500 km^2 of diked Everglades marshland in southern Florida (Figure 1). These areas are managed by the South Florida Water Management District for a variety of purposes including flood control, water conservation storage, groundwater recharge, preservation of fish and wildlife resources, and recreational benefits. Much of the water entering the Water Conservation Areas is runoff from agricultural lands, and this water contains high phosphorus concentrations compared to the water of the interior marshes. The 547 km^2 marsh of Water Conservation Area 2A (WCA2A) receives a particularly large supply of high-phosphorus water through the S-10 inflow structures because of the large canal system which converges on these inflows (Figure 2). The absence of interior canals in WCA2A forces this water to flow across the marsh. The potential backpumping of additional canal water into the Water Conservation Areas would further increase the phosphorus supply of WCA2A. Gleason (1974) reported that WCA2A plant communities adjacent to the S-10 structures effectively reduced elevated ortho-phosphate levels in inflowing water. However, the ability of the marsh to store the additional phosphorus supplies which would result from backpumping is not known. This study is one of a series of investigations in WCA2A to determine the effects of increased phosphorus supply on sawgrass and cattail communities and on their efficiencies as phosphorus sinks. The roles of the principle marsh ecosystem components in the storage of phosphorus within 10 days after its introduction into the surface water are examined here.

Previous studies on phosphorus uptake in the Everglades have concentrated on the role of macrophyte vegetation. Stewart and Ornes (1975) concluded

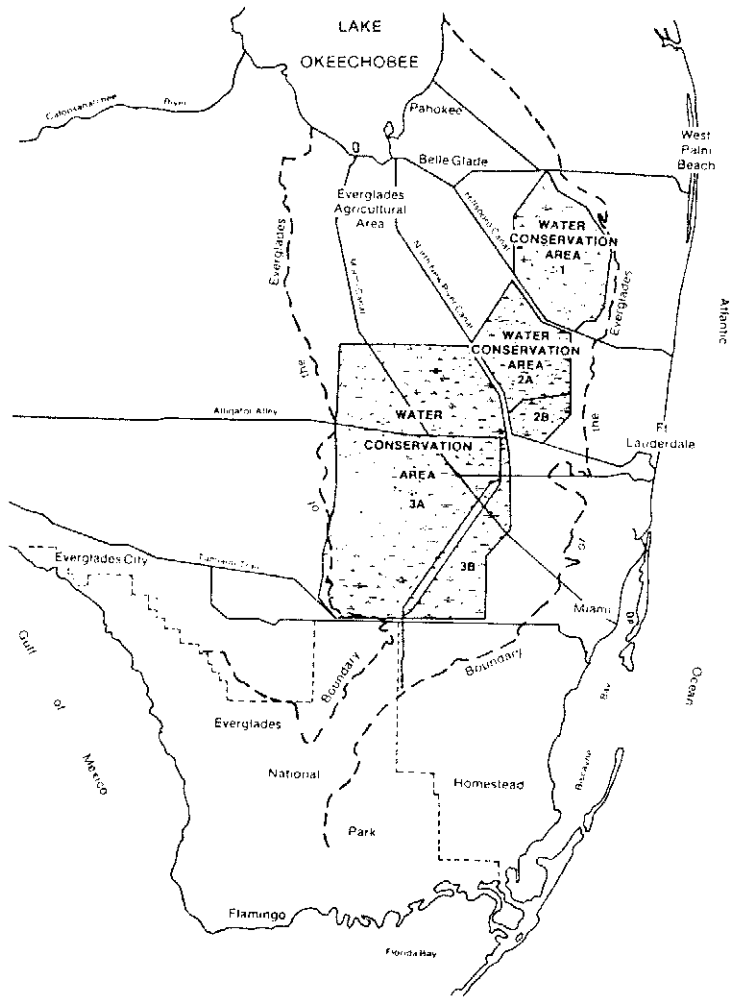

FIGURE 1 LOCATION OF EVERGLADES WATER CONSERVATION AREAS AND BOUNDARY OF ORIGINAL EVERGLADES IN SOUTH FLORIDA. (Adapted From Smith, 1968)

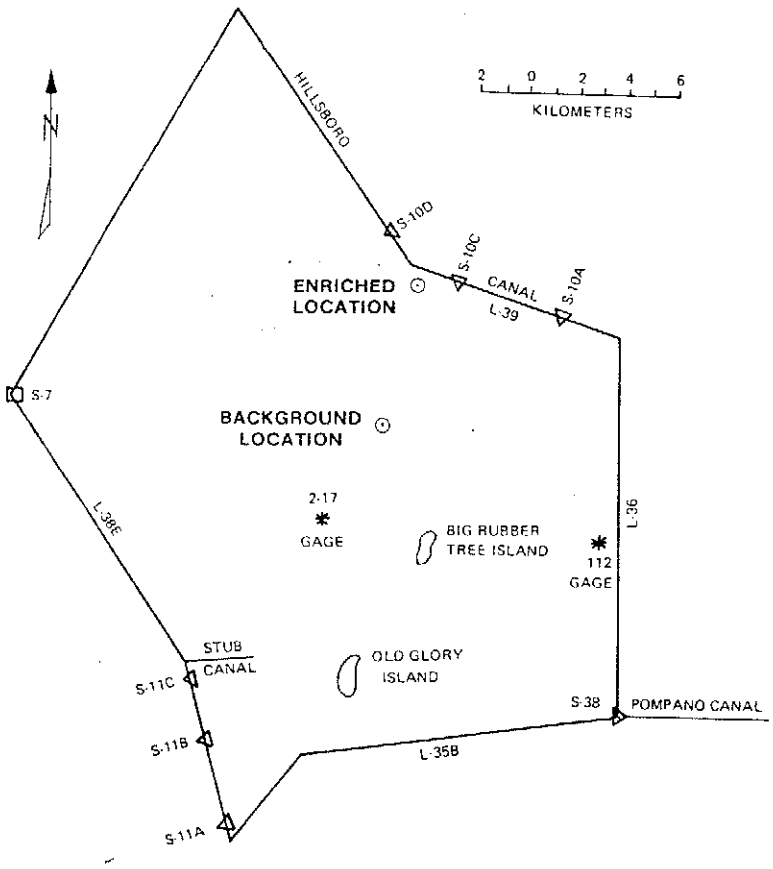

FIGURE 2 LOCATIONS OF RADIOTRACER STUDIES IN WATER CONSERVATION AREA 2A.

that sawgrass phosphorus requirements are low and that these low requirements may partially explain the dominance of this species in the Everglades plant community. Preliminary estimates of phosphorus flux during plant growth, mortality, and decomposition by Davis and Harris (1978) suggested that plant uptake could lead to long term phosphorus retention only through the accumulation of detritus as peat. Ecosystem components other than the macrophytes have received little attention in Everglades phosphorus uptake studies.

Tracer studies utilizing radiophosphorus (^{32}P) have proven to be particularly useful in the investigation of phosphorus flux within aquatic ecosystems. A variety of aquatic systems which have been studied through the use of ^{32}P appear to possess similar characteristics in their modes of phosphorus uptake and cycling. The most consistent of these characteristics is the importance of micro-organisms, particularly bacteria, in radiophosphorus uptake and turnover in the water column, detritus, and sediments. Pomeroy et al. (1966) concluded that ^{32}P enters the biota of a Georgia salt marsh primarily at the level of the bacteria and the consumers that feed upon them. Planktonic bacteria along with ultraplankton are responsible for most of the initial uptake of radiophosphorus from lake water within minutes after its introduction (Rigler, 1973). Hayes and Phillips (1958) demonstrated that planktonic bacteria can successfully compete with macrophytes and sediments for ^{32}P available in the water. Uptake of ^{32}P by planktonic bacteria represents a turnover of phosphorus every one to eight minutes rather than an accumulation (Rigler, 1973). The bacteria which inhabit decomposing plant litter also rapidly assimilate and recycle ^{32}P with turnover times as low as two minutes (Barsdate et al., 1974). Barsdate et al. also showed that grazing by protozoa promotes more rapid assimilation

as well as circulation of ^{32}P by the detritus bacteria. Hayes and Phillips (1958) demonstrated that soil bacteria can accelerate the return of ^{32}P from bottom sediments to the overlying water.

After initial uptake and recycling by bacteria and other micro-organisms, radiophosphorus more slowly accumulates and is turned over within a few hours to a few days in attached algae (Whittaker, 1961; Confer, 1969), in macrophyte vegetation (Hutchinson and Bowen, 1947; Coffin, et al., 1949), in subsurface sediments (Hayes and Phillips, 1958; Whittaker, 1961), and in invertebrates and fish (Pomeroy et al., 1969; Harris, 1957; Saurev et al., 1973).

Radiophosphorus uptake appears to result from physical adsorption as well as metabolic absorption in bacteria and sediments (Pomeroy et al., 1966) and in algae (Fuhs and Canelli, 1972; Stromberg and Goodnight, 1971; Odum et al., 1958). Uptake resulting from physical adsorption proceeds at a more rapid rate than metabolic uptake (Davis and Foster, 1958).

Radiophosphorus which enters subsurface sediments of lakes may be capable of vertical movement through as much as 15 cm of soil (Holden, 1961; Hynes and Greib, 1970). This movement was found by Hynes and Greib to be an abiotic process. In contrast, other studies have reported little movement of ^{32}P within subsurface lake sediments (Hayes et al., 1952; Hayes, 1955; Zicker et al., 1956).

Many species of aquatic macrophytes appear capable of assimilating ^{32}P directly from the surface water through the foliage (McRoy and Barsdate, 1970; Schults and Maleug, 1971; Demarte and Hartman, 1974), although others may be restricted to uptake from subsurface sediments through the roots (Carignan and Kalff, 1980). Radiophosphorus which is absorbed from sediments by macrophyte roots may be translocated to the shoots and subsequently

released into the surrounding water from the living foliage (Reimold, 1972; Demarte and Hartman, 1974; McRoy and Barsdate, 1970; Schults and Maleug, 1971) or from the decomposing leaf material after mortality (Pomeroy et al., 1969). Much of the ^{32}P which is recycled by living macrophyte leaves and by the microflora of the decomposing leaf litter is in an organic form which can be subsequently re-assimilated by the plants and microflora (Tukey and Mecklenburg, 1964; Barsdate et al., 1974).

This study was undertaken to trace the accumulation of ^{32}P in the major ecosystem components of the WCA2A marsh after its introduction into the surface water. Radiophosphorus was introduced into enclosures which were placed in WCA2A. Accumulations in the living macrophyte vegetation, algal mats, plant litter, subsurface sediments, and surface water within the enclosures were determined by sampling these components after ten days and analyzing them for ^{32}P concentrations. The period of ten days was chosen to show major patterns of phosphorus accumulation in the ecosystem rather than initial uptakes or turnovers, which presumably would occur during a shorter time period.

METHODS

Radiotracer experiments were conducted at two locations representing extremes in water phosphorus concentrations in WCA2A (Figure 2). A site subjected to high phosphorus concentrations from S-10 water (referred to as the enriched site) was located 2.3 km and 150° SSE of inflow structure S-10D, from which it appeared to receive most of its surface water flow. Another site, subjected to much lower phosphorus concentrations in WCA2A (referred to as the background site), was located 7.9 km and 182° SSW of S-10D. Phosphorus concentrations at the two sites and in S-10 inflows were monitored monthly for 12 months prior to the experiment.

Three replicate enclosures were placed in sawgrass (*Cladium jamaicense*) and cattail stands at the enriched and background sites during June - July 1979. The cattail stands consisted primarily of *Typha domingensis* with some *Typha latifolia*. The enclosures consisted of polyethylene drums 86.5 cm high and 55.5 cm in diameter with the bottoms removed. The base of each drum was sunk 30-34 cm into the soil. Water depths at the drum locations ranged from 29 to 47 cm. A radiophosphorus spike containing 2.039 - 2.904 μCi of ortho- $^{32}PO_4$ dissolved in sterilized, dilute HCl was introduced into the surface water of each enclosure between the hours of 0915 and 1115 one day after the drums had been placed in the marsh.

Ten days after the addition of radiophosphorus, water depths were measured and the marsh components within each enclosure were sampled as follows. An unfiltered water sample was collected approximately mid-depth and immediately placed on ice. A dip net was used to remove floating algal mats or calcareous periphyton. Plant litter covering the marsh floor was removed by hand and drained in a bucket-sieve. Three soil cores 7 cm

in diameter and 50 cm deep were collected. Living plants, dead plants, and root systems were harvested using a shovel to excavate the roots. A dip net was swirled in the water numerous times in an attempt to capture fish, although none were found. Water samples and soil cores were frozen within five hours of collection.

In the laboratory, on the day after collection, the samples from each enclosure were divided into the following components. The frozen soil cores were cut into layers 0-10 cm, 10-30 cm, and 30-50 cm below the soil surface. The triplicate soil cores from an enclosure were combined to give a composite sample of each layer. Live plant material was divided into living leaves, adventitious roots, below-ground roots, and rhizomes. Dead plant material was divided into leaves and roots/rhizomes. Much of the dead leaf material appeared to fall into the water and decompose while still remaining attached to the base of the living plants. For this reason, dead attached leaves and leaf litter were combined as one component.

Each solid marsh component was weighed and ground in a Wiley mill after oven-drying for 72 h at 90°C. Measured dry weights were dissolved using fuming nitric acid. Phosphorus was then extracted from the digested solid and water samples using the procedure described by Silker (1956), except that the step for removal of arsenates was deleted because of the negligible occurrence of arsenates in the Everglades. Hydrochloric acid was added to 400 ml of sample until a 0.05 N solution was obtained. One milliliter of 20% sodium thiosulfate solution was then added. After letting the sample stand for five minutes, 20 ml of 10 N sulfuric acid, 30 ml of 10% ammonium molybdate reagent, and 0.25 ml of phosphate carrier were added. The solution was then extracted by shaking with 35 ml of 10% 1-butanol in diethyl ether. The organic phase was separated and washed by

shaking with 15 ml of 1.3 N sulfuric acid. After final separation, the organic phase was evaporated on a 5.08 cm stainless steel planchet. Activity of extracted phosphorus was measured on a low background beta counter according to procedures prescribed by EPA Manual 300, Health and Safety Laboratory, U.S. Dept. of Energy (1972). Corrections for background radiation were made daily, and all counts were corrected for counting efficiency and chemical recovery. Activity was corrected for radioactive decay to the dates when the radiophosphorus was introduced into the enclosures. Radiophosphorus concentrations were calculated from the counts as pCi per gram dry weight of solids or per milliliter of water.

The radiophosphorus content (pCi) of each marsh component within an enclosure was estimated by multiplying the radiophosphorus concentration by the dry weight or water volume. The total amount of radiophosphorus which was recovered from an enclosure was calculated by summing the contents of the marsh components. The radiophosphorus contents of the marsh components were expressed as the percent of the total amount recovered from an enclosure.

Dry weights and radiophosphorus concentrations were log-transformed prior to statistical analysis. Radiophosphorus contents, expressed as percents of totals within enclosures, were arcsin-transformed. Homogeneity of variance was tested using Hartley's F max statistic. Analysis of variance and the Newman-Keuls multiple range test were performed on the transformed data.

RESULTS

Phosphorus Concentrations in Surface Water

Phosphorus concentrations in surface water at the sample sites and at S-10D during the year before the experiment are compared in Table 1. Mean concentrations of 0.126 mg/l total P and 0.081 mg/l dissolved inorganic P at the enriched location actually exceeded those in S-10D inflows during this period. Thus, this site represented a high extreme of phosphorus concentration in WCA2A surface water. Dissolved inorganic P was the predominant phosphorus fraction at the enriched site. In contrast, surface water at the background site contained only 0.006 mg/l total P and non-detectible amounts of the three fractions. It can be assumed that the majority of this total P was organic because the dissolved inorganic fraction was below the 0.002 mg/l limit of detection.

The S-10 inflow structures were closed during the June - July experiment period. Total P concentrations of 0.116 mg/l at the enriched site and 0.010 mg/l at the background site during the experiment were comparable to the mean values observed the previous year (Table 2). The phosphorus in the water at the enriched site was mostly organic during the experiment, in contrast to the large inorganic fraction found during the previous year. Most of the phosphorus at the background site appeared to remain in an organic form during the experiment, as it had done the previous year.

Standing Crop of Marsh Components

Dry weight standing crops of each marsh component (Table 3) did not differ significantly between the enriched and background locations with the exception of sawgrass dead leaf material ($\alpha = 0.05$). Since the enriched and background locations were similar in the weights of most marsh components,

TABLE 1. PHOSPHORUS CONCENTRATIONS (mg P/l) IN SURFACE WATER AT THE S-10D INFLOW GATE AND THE SAMPLE LOCATIONS DURING THE 12-MONTH PERIOD (JUNE 1978 - MAY 1979) PRIOR TO THE EXPERIMENT. VALUES GIVEN ARE MEANS AND RANGES.

	S-10 D Inflow	Enriched Site	Background Site
Total P	.101 (.031-.171)	.126 (.038-.348)	.006 (.003-.010)
Dissolved Inorganic P	.064 (.010-.100)	.081 (.006-.189)	≤.002 -
Dissolved Organic P	.021 (≤.010-.042)	.028 (≤.010-.067)	≤.010 -
Particulate P	.018 (≤.010-.053)	.025 (≤.010-.145)	≤.010 -

TABLE 2. MEAN PHOSPHORUS CONCENTRATIONS (mg P/l) IN SURFACE WATER AT SAMPLE LOCATIONS DURING THE JUNE-JULY 1979 EXPERIMENTAL PERIOD.

	Enriched Site	Background Site
Total P	.116	.010
Dissolved Inorganic P	.005	≤.002
Dissolved Organic P	.044	≤.010
Particulate P	.067	≤.010

TABLE 3. DRY WEIGHTS (g/m^2) OF MARSH COMPONENTS IN SAWGRASS AND CATTAIL ENCLOSURES AT SITES SUBJECTED TO HIGH AND LOW PHOSPHORUS SUPPLIES FROM S-10 WATER. VALUES GIVEN ARE MEAN AND STANDARD ERROR. N = 3 UNLESS NOTED OTHERWISE.

	Sawgrass		Cattail	
	Enriched	Background	Enriched	Background
Living leaves	700 ± 65	644 ± 22	965 ± 244	366 ± 76
Adventitious roots	14 ± 2	18 ± 7	2 *	6 ± 4
Below ground roots	491 ± 53	453 ± 139	323 ± 147	1106 ± 206
Rhizomes	49 ± 15	77 ± 44	314 ± 128	61 ± 20
Dead leaf material	3379 ± 219	1813 ± 216	4340 ± 1193	2474 ± 460
Dead roots & rhizomes	430 ± 167	478 ± 49	583 ± 350	1213 ± 622
Soil 0-10 cm	3948 ± 605	3885 ± 238	4330 ± 583	2903 ± 213
Soil 10-30 cm	17,550 ± 1308	14,939 ± 2027	16,778 ± 740	19,355 ± 2213
Soil 30-50 cm	23,231 ± 2158	25,655 ± 507	23,663 ± 935	---†
Floating mat	24 ± 2	---	31 ± 11	---
Periphyton	---	697 ± 96	---	---

* N = 2

† The single sample of 30-50 cm soil which was obtained from this cattail stand was incomplete and could not be used for weight estimation.

data from the two locations were combined to increase the sample size in the analysis of standing crop differences among the marsh components (Table 4). Differences among the plant components were consistent for both sawgrass and cattail. The majority of the plant standing crop consisted of dead leaf material. Dead leaf material was about four times more abundant than living leaves in sawgrass and about five times more abundant in cattail. Dead leaf standing crops of 2594 g/m^2 for sawgrass and 3404 g/m^2 for cattail significantly exceeded ($\alpha = 0.01$) those of any of the other plant components. Standing crops of living leaves, below ground roots and dead roots/rhizomes were similar and did not differ significantly from one another; mean dry weights of these components varied from 453 to 671 g/m^2 in sawgrass and from 644 to 892 g/m^2 in cattail. These standing crops were significantly larger ($\alpha = 0.01$) than rhizome weights which averaged 63 g/m^2 in sawgrass and 188 g/m^2 in cattail. Adventitious roots comprised the lowest standing crops of 16 g/m^2 in sawgrass and four g/m^2 in cattail. These values were significantly less ($\alpha = 0.01$) than the weights of any of the other plant components. The adventitious root system was the only component which differed significantly ($\alpha = 0.01$) between sawgrass and cattail in standing crop.

Soil densities significantly increased with depth below the soil surface (Table 4). When the dry weights of soil layers collected from the cores were expanded to g/m^2 of marsh surface, sediments 0-10 cm below the soil surface averaged 3762 g/m^2. Dry weights of 10 cm strata from the lower layers of sediments averaged 8570 g/m^2 between 10 and 30 cm below the soil surface and 12,079 g/m^2 between 30 and 50 cm. Soil from 10-50 cm consisted of compacted dark-colored peat, while 0-10 cm soil appeared to contain coarser, lighter colored organic material which was partially unconsolidated.

TABLE 4. DIFFERENCES AMONG THE MARSH COMPONENTS IN DRY WEIGHT (g/m^2). VALUES GIVEN ARE MEANS FOR SAWGRASS, CATTAIL AND SOIL, SITES COMBINED. SOIL VALUES REPRESENT WEIGHTS PER 10 CM LAYER.

SAWGRASS

Dead Leaf Material		Living Leaves		Belowground Roots		Dead Roots & Rhizomes		Rhizomes		Adventitious Roots
2594	** >	671		472		453	** >	63	** >	16

CATTAIL

Dead Leaf Material		Dead Roots & Rhizomes		Belowground Roots		Living Leaves		Rhizomes		Adventitious Roots
3404	** >	892		714		644	** >	188	** >	4

SOIL

30-50 cm Layer		10-30 cm Layer		0-10 cm Layer
12,079	** >	8570	** >	3762

** > Significantly different from lower values on same line ($\alpha = 0.01$) based on Newman - Keuls' multiple range test.

Floating mats covered much of the water surface at the enriched location. These mats consisted primarily of the blue-green algae Microcoleus lyngbyaceus and the vascular plants Lemna sp. and Wolffiella sp. Other common algal species in these mats included Schizothrix calcicola, Oedogonium sp., and a variety of diatoms. This community is referred to herein as the floating algal mat. Dry weight standing crops of the floating algal mats averaged 24 to 31 g/m^2 in the sawgrass and cattail stands at the enriched location (Table 3). These mats were not present at the background location. Instead, a calcareous periphyton community existed in the sawgrass stand. This periphyton was dominated by the blue-green algae Schizothrix calcicola. The standing crop of this periphyton averaged 697 g/m^2. Neither floating algae mats nor periphyton occurred in the cattail stand at the background location.

Radiophosphorus Concentrations in Marsh Components

Radiophosphorus entered every marsh component during the ten-day period following its introduction into the water (Table 5). The water column contained particularly low concentrations of radiophosphorus. The highest concentrations were found in the floating algal mats in the enriched sawgrass and cattail stands. The calcareous periphyton community in the background sawgrass stand also accumulated a high concentration of ^{32}P relative to the other marsh components. Neither floating mats nor periphyton were found in the background cattail stand, where radiophosphorus concentrations in the water exceeded those at the other locations.

No significant differences ($\alpha = 0.05$) were found between the sawgrass and cattail stands in the ^{32}P concentrations of the marsh components. The enriched and background locations were also similar in the ^{32}P concentrations

TABLE 5. RADIOPHOSPHORUS CONCENTRATIONS IN SAWGRASS AND CATTAIL ENCLOSURES AT SITES SUBJECTED TO HIGH AND LOW PHOSPHORUS SUPPLIES FROM S-10 WATER. VALUES GIVEN ARE MEAN AND STANDARD ERROR. N = 3 UNLESS NOTED OTHERWISE.

	Sawgrass		Cattail	
	Enriched	Background	Enriched	Background
pCi/ml				
Water	0.81 ± 0.41	0.60 ± 0.17	0.54 ± 0.18	1.44 ± 0.60
pCi/g				
Living leaves	179 ± 50	34 ± 17	61 ± 50	15 ± 1
Adventitious roots	861 ± 379	2434 ± 2238	1285 ± 35*	241 ± 103
Below ground roots	426 ± 188	74 ± 44	171 ± 78	227 ± 177
Rhizomes	128 ± 22	116 ± 83	170 ± 94	20 ± 1
Dead leaf material	1197 ± 430	333 ± 106	646 ± 223	378 ± 164
Dead roots & rhizomes	83 ± 28	27 ± 9	28 ± 9	27 ± 8
Soil 0-10 cm	647 ± 243	632 ± 114	756 ± 431	264 ± 243
Soil 10-30 cm	95 ± 47	61 ± 10	106 ± 52	78 ± 54
Soil 30-50 cm	94 ± 41	17 ± 3	35 ± 17	23†
Floating mat	25,800 ± 5934	---	29,400 ± 2784	---
Periphyton	---	2022 ± 1462	---	---

* N = 2

† N = 1

of most marsh components: the only significant differences (α = 0.05) were the higher concentrations at the enriched site in sawgrass living leaves and cattail adventitious roots. Because of this similarity between the enriched and background locations, data from the two locations were combined to increase sample sizes in the analysis of differences among the marsh components in ^{32}P concentration.

Adventitious roots, dead leaf material, and surface sediments 0-10 cm deep contained relatively high ^{32}P concentrations in both the sawgrass and cattail stands (Table 6). Mean concentrations ranging from 640 to 1648 pCi/g in these components in sawgrass did not differ significantly from one another; however, they were significantly higher (α = 0.05) than concentrations ranging from 55 to 250 pCi/g in the other sawgrass plant and soil components. A similar ranking of ^{32}P concentrations in plant and soil components also occurred in cattail; values of 510 to 659 pCi/g in adventitious roots, dead leaf material, and surface sediments exceeded concentrations of 28 to 199 pCi/g in the other components. Statistically significant differences among the plant and soil components were less clear for cattail than for sawgrass.

Radiophosphorus Contents of Marsh Components

The distribution of radiophosphorus among the marsh components (Table 7) depended on radiophosphorus concentrations as well as the weights of the components. This distribution became more clear when the ^{32}P contents of individual components were summed into larger groupings of soil, detritus, living plants, water, and floating algae mats or periphyton (Table 8). Dead below-ground root and rhizome material was included in the soil grouping.

TABLE 6. DIFFERENCES AMONG THE MARSH COMPONENTS IN ^{32}P CONCENTRATION (pCi/g). VALUES GIVEN ARE MEANS FOR SAWGRASS AND CATTAIL, SITES COMBINED. MEANS NOT UNDERSCORED BY SAME LINE ARE SIGNIFICANTLY DIFFERENT (α = 0.05) BASED ON NEWMAN - KEUL'S MULTIPLE RANGE TEST.

SAWGRASS

Dead Roots and Rhizomes	Soil 30-50 cm	Soil 10-30 cm	Living Leaves	Rhizomes	Belowgr. Roots	Soil 0-10 cm	Dead Leaf Material	Advent. Roots
55	56	78	106	122	250	640	765	1648

CATTAIL

Dead Roots and Rhizomes	Soil 30-50 cm	Living Leaves	Soil 10-30 cm	Rhizomes	Belowgr. Roots	Soil 0-10 cm	Dead Leaf Material	Advent. Roots
28	32	38	92	95	199	510	512	659

TABLE 7. RADIOPHOSPHORUS CONTENT OF MARSH COMPONENTS, EXPRESSED AS PERCENT OF TOTAL ^{32}P RECOVERED FROM ENCLOSURES, AT SAWGRASS AND CATTAIL SITES RECEIVING HIGH AND LOW PHOSPHORUS SUPPLIES FROM S-10 WATER. VALUES GIVEN ARE MEAN AND STANDARD ERROR. N = 3 UNLESS NOTED OTHERWISE.

	Sawgrass		Cattail	
	Enriched	Background	Enriched	Background
Water	2.2 ± 0.8	3.6 ± 0.5	2.2 ± 0.2	15.5 ± 4.9
Living leaves	1.2 ± 0.7	0.4 ± 0.2	0.5 ± 0.4	0.1
Adventitious roots	0.1	0.2 ± 0.1	<0.1	<0.1
Below ground roots	1.7 ± 0.2	0.5 ± 0.4	0.7 ± 0.3	4.3 ± 2.7
Rhizomes	<0.1	0.1	0.6 ± 0.5	<0.1
Dead leaf material	33.2 ± 4.9	11.5 ± 5.5	30.4 ± 10.6	16.3 ± 7.0
Dead roots & rhizomes	0.5 ± 0.2	0.2 ± <0.1	0.2 - <0.1	0.6 ± 0.2
Soil 0-10 cm	25.7 ± 9.6	41.0 ± 4.2	28.7 ± 5.7	14.0 ± 11.8
Soil 10-30 cm	11.4 ± 4.0	16.9 ± 5.1	17.6 ± 3.2	31.3 ± 16.3
Soil 30-50 cm	16.8 ± 6.1	7.6 ± 1.4	8.3 ± 2.0	17.8*
Floating mat	6.7 ± 3.0	---	10.7 ± 4.3	---
Periphyton	---	17.8 ± 10.0	---	---

*Radiophosphorus content was estimated from the mean dry weight of 30-50 cm soil at other sites multiplied by the ^{32}P concentration in a single sample of this soil layer at this site.

TABLE 8. DIFFERENCES AMONG THE MARSH COMPONENTS IN RADIOPHOSPHORUS CONTENT, EXPRESSED AS PERCENT OF TOTAL ^{32}P RECOVERED FROM THE ENCLOSURES. VALUES GIVEN ARE MEANS FOR SAWGRASS AND CATTAIL STANDS AT SITES RECEIVING HIGH AND LOW PHOSPHORUS SUPPLIES FROM S-10 WATER.

Site	Soil		Dead Leaf Material		Floating Mat or Periphyton	Plants	Water
Enriched, sawgrass	54.4	** >	33.2	** >	6.7	3.4	2.2
Enriched, cattail	54.8	** >	30.4	* >	10.7	1.9	2.2
Background, sawgrass	65.7	** >	11.5		17.8	1.3	3.6
Background, cattail	63.7	** >	16.3		--	4.6	15.5

> = significantly different from lower values at same site, based on Newman - Keuls' multiple range test.

* α = 0.05

** α = 0.01

The ^{32}P content of the marsh water comprised only two to four percent of the total amounts recovered from the chambers at three of the four sites (Table 8). Each of the three sites with low radiophosphorus retention in the water contained either floating algal mats or calcareous periphyton. The floating mats in the sawgrass and cattail stands at the enriched location held seven to eleven percent of the ^{32}P which was recovered there. The periphyton in the background sawgrass stand held 18 percent of the ^{32}P which was recovered there. The cattail stand at the background location differed from the above three sites in that the water contained 16 percent of the ^{32}P which was recovered. This retention of ^{32}P in the water significantly exceeded ($\alpha = 0.05$) the retentions of two to four percent of the radiophosphorus in the water at the other three sites. The background cattail stand was also unique in that neither floating mats nor calcareous periphyton were present.

The soil contained the largest portion of radiophosphorus at each site (Table 8). Between 54 and 66 percent of the ^{32}P which was recovered from the enclosures had accumulated in the soil. Soil ^{32}P content significantly exceeded ($\alpha = 0.01$) that of any other marsh components at each site. Radiophosphorus was largely concentrated in the upper ten centimeters of soil, with the exception of the background cattail stand where most of the soil ^{32}P had moved into the 10-30 cm layer (Table 7).

Dead leaf material was second only to the soil in radiophosphorus accumulation at the enriched location (Table 8). The dead leaf material contained about one-third of the ^{32}P which was recovered from both the sawgrass and cattail stands at that location. This ^{32}P accumulation significantly exceeded ($\alpha = 0.05$) the lesser accumulations in the floating mats, living plants, or water. Dead leaf material at the background location

stored smaller amounts of radiophosphorus. Only 12-16 percent of the ^{32}P which was recovered from the sawgrass and cattail stands at the background location had accumulated in the dead plant material. These values did not differ significantly from those of periphyton, living plants, or water.

Living sawgrass and cattail plants accumulated relatively small amounts of radiophosphorus at each site (Table 8). Storages within the living plants comprised only one to five percent of the total amounts of ^{32}P recovered. Below ground roots accumulated more ^{32}P than the other plant components at each site (Table 7). In spite of the high radiophosphorus concentrations which were found in adventitious roots, these structures contained negligible amounts of ^{32}P because of their small standing crops.

DISCUSSION

The small amounts of ^{32}P which were recovered from the surface water indicate that the suspended microorganisms and sediments in the water column were ineffective in holding appreciable amounts of radiophosphorus, even through they had early access to the inorganic ^{32}P after its introduction. This is not surprising, considering the findings of Rigler (1973), Whittaker (1961), and Hayes and Phillips (1958) that most of the ^{32}P taken up initially by suspended material was subsequently released rather than stored, after which it entered the other ecosystem components. The ^{32}P which was found in the surface water probably had been recycled by the marsh biota within the chambers during the previous ten days, since radiophosphorus turnover times of a few hours to a few days have been previously reported for aquatic systems (Rigler, 1973; Barsdate et al., 1974; Hayes and Phillips, 1958; Pomeroy et al., 1966).

The larger amount of ^{32}P which remained in the water column at the background cattail site may have been related to the absence of floating algal mats or periphyton there. Perhaps these algal communities removed a portion of the introduced inorganic ^{32}P which otherwise would have escaped uptake and remained dissolved in the water throughout the 10-day experiments, however this seems unlikely considering the short turnover times of ^{32}P discussed above. It also seems unlikely that the algal communities were in competition with the macrophyte vegetation, plant litter, or soil for the introduced ^{32}P because the ^{32}P contents of these components were similar at all four sites whether or not the algal communities were present. Another explanation, and perhaps a more plausible one, is that in the absence of the algal communities a certain amount of the ^{32}P was initially taken up

by the suspended microorganisms and sediments in the water column, after which it continued to be tightly recycled between the suspended material and the water. Where floating algal mats or periphyton were present, they apparently accumulated most of the ^{32}P which otherwise would have been stored and recycled by the suspended microorganisms and sediments. This conclusion is supported by the similar ^{32}P contents of the periphyton at the background sawgrass site and of the water, in the absence of periphyton, at the adjacent background cattail site. This conclusion also explains why the ^{32}P storages in the macrophyte vegetation, plant litter, and soil were not noticeably affected by the presence or absence of the floating or periphytic algal communities.

Much of the radiophosphorus which was recovered appeared to have moved downward from the water column through the layer of leaf litter and into the underlying soil. The findings of Barsdate et al. (1974) provide evidence that radiophosphorus was rapdily recycled between the microflora and the interstitial water within the leaf litter. Thus, the radiophosphorus flux within the leaf litter appeared to involve recycling more than retention and a gradual downward movement of recycled phosphorus into the soil beneath. The sawgrass and cattail leaf litter retained more radiophosphorus at the enriched location. This increased retention resulted from a larger standing crop of dead leaf material as well as from a higher radiophosphorus concentration in the dead leaf material. Reasons for the higher radiophosphorus concentrations in the litter at the high phosphorus site are not yet clear. Possibly larger population densities of detritus biota were capable of retaining and/or recycling more phosphorus within the litter. Another possible explanation is that more rapid litter breakdown at the enriched site increased detrital surface areas which enabled more physical adsorption.

It can be concluded that phosphorus uptake by living sawgrass and cattail plants is not directly responsible for the initial removal from the water column, since little radiophosphorus entered them during the ten days following its introduction into the water. Highest radiophosphorus activity in the roots, particularly the adventitious roots, indicates that these were major pathways of uptake by the plants. The adventitious roots for the most part grew upward between the dead leaf bases of the plants into the litter layer rather than in the open water column. The particularly high radiophosphorus concentrations in the adventitious roots resembled concentrations in the leaf litter in which they were growing. The layer of leaf litter appeared to represent an important source of phosphorus nutrition for the plants.

The movement of most of the ^{32}P into the soil at each site supports the findings of Hynes and Greib (1970) and Holden (1961) that phosphorus can move vertically through several centimeters of lake mud. The soft peat and gyttja studied by Hynes and Greib would appear to be particularly comparable to the partially consolidated organic material which composed the 0-10 cm soil layer in this study. The 4 cm vertical downward movement of ^{32}P reported by these authors agrees well with the concentration of ^{32}P in the upper ten centimeters of soil in this study. The mechanism for this movement is unclear, although Hynes and Greib showed that it can be abiotic and that it is not necessarily retarded by biotic immobilization. Possible explanations include molecular diffusion and the downward movement of water. It is not known if the ^{32}P would continue to move downward into lower soil layers given more time than the ten-day experimental periods. Hynes and Greib found vertical movement was largely limited to four centimeters upward or downward during 60-70 day experiments. In contrast to their

findings, the concentration of ^{32}P in the 10-30 cm layer at the background site showed that major downward movement below the surface ten centimeters of soil is possible in WCA2A.

If the downward movement of radiophosphorus could penetrate into soil layers below the sawgrass and cattail root zones, then the soil would appear to be a major sink for phosphorus in WCA2A. Yates (1974) reported little sawgrass root and rhizome growth below the soil surface at continuously flooded sites in WCA2A, where the plants grew largely on tussocks. An additional tracer study will investigate the movement of radiophosphorus after it enters the soil in order to determine if soil phosphorus is recycled back into the surface water or if the soil does indeed function as a sink for the phosphorus which moves into it from the overlying surface water.

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