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Nitrogen, Phosphorus and Organic Carbon Pools in Natural and Transplanted Marsh Soils[1]

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ABSTRACT: Total nitrogen, phosphorus and organic carbon were compared in natural and transplanted estuarine marsh soils (top 30 cm) to assess nutrient storage in transplanted marshes. Soils were sampled in five transplanted marshes ranging in age from 1 to 15 yr and in five nearby natural marshes along the North Carolina coast. Dry weight of macroorganic matter (MOM), soil bulk density, pH, humic matter, and extractable P also were measured. Nutrient pools increased with increasing marsh age and hydroperiod. Nitrogen, phosphorus and organic carbon pools were largest in soils of irregularly flooded natural marshes. The contribution of MOM to marsh nutrient reservoirs was 6–45%, 2–22%, and 1–7% of the carbon, nitrogen and phosphorus, respectively. Rates of nutrient accumulation in transplanted marshes ranged from 2.6–10.0, 0.03–1.10, and 84–218 kmol ha^{-1} yr^{-1} of nitrogen, phosphorus and organic carbon, respectively. Accumulation rates were greater in the irregularly flooded marshes compared to the regularly flooded marshes. Approximately 11 to 12% and 20% of the net primary production of emergent vegetation was buried in sediments of the regularly flooded and irregularly flooded transplanted marshes, respectively. Macroorganic matter nutrient pools develop rapidly in transplanted marshes and may approximate natural marshes within 15 to 30 yr. However, development of soil carbon, nitrogen and phosphorus reservoirs takes considerably longer.

Introduction

Salt- and brackish-water marshes contribute to the high productivity of estuaries by providing habitat and nursery grounds for aquatic organisms, waterfowl and furbearers, and detritus for the estuarine food web (Teal 1962; de la Cruz 1973; Woodwell et al. 1973; Crow and Macdonald 1978; Marinucci 1982). Tidal marshes are an integral component of global and estuarine biogeochemical cycles. Marshes are sites of nutrient transformation in estuaries (Nixon 1980), converting particulate materials into dissolved forms (Jordan et al. 1983). Marsh soils and other wetlands serve as sinks in the global C cycle (Schlesinger 1977; Armentano 1980) and as reservoirs of organic material for estuaries (Friedman and DeWitt 1978). The high net primary production (NPP) of emergent vegetation and water-saturated conditions favor accumulation of organic matter in marsh soils.

Establishment of estuarine marsh vegetation has been used to reduce shoreline erosion, stabilize dredged material, and replace habitat lost to mining activities (Woodhouse et al. 1974; Broome et al. 1982, 1983, 1986). Establishment of transplanted marshes requires grading the area to the appropriate elevation for colonization by emergent vegetation, planting greenhouse-grown or field-dug transplants of *Spartina* spp. and, if necessary, fertilizing with N and P (Woodhouse et al. 1974; Broome et al. 1983, 1986). Transplanted marsh vegetation frequently develops a continuous cover which stabilizes sediments and has NPP comparable to adjacent natural marshes (Broome et al. 1986). However, the function of these marshes as nutrient reservoirs is not known.

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Lindau and Hossner (1981) compared substrate properties of an experimental and three natural estuarine marshes in Texas. During a 68-wk period, soil organic matter, total Kjeldahl nitrogen and NH_4-nitrogen in the experimental marsh increased at rates that would equal the natural marshes within 2–5 yr. However, the low soil organic matter (1.8–2.9%) and N (0.56–0.71 mg g^{-1}) content of the natural marshes studied by Lindau and Hossner (1981) is not representative of many organic-rich marsh soils along the Atlantic and Gulf coasts (Coultas and Gross 1975; Coultas 1980; Hatton et al. 1983; Bowden 1984; Craft et al. 1986).

The objective of this study was to compare soil nitrogen (N), phosphorus (P) and organic carbon (C) pools in transplanted and nearby natural estuarine marshes. The contribution of soil and macroorganic matter (living and dead root material >2 mm diameter) was assessed. Macroorganic matter was sampled because it may be a major component of marsh organic matter reservoirs, especially in young marshes. Rates of organic matter accumulation also were compared in transplanted marsh soils.

Methods

SITE DESCRIPTION

Soil and macroorganic matter (MOM) were sampled at five locations along the North Carolina coast during the summer of 1984 (Fig. 1). Each location consisted of a natural and a nearby transplanted marsh. The sampling locations included three regularly flooded and two irregularly flooded estuarine marshes which differed in tidal amplitude, salinity, plant species composition, age of the transplanted marsh, and soil type (Table 1). Three of the natural marshes (North Carolina Phosphate, Snow's Cut, Texasgulf) were classified as organic soils (Typic Medisaprists) based on the organic matter content (22–50%) and thickness (>1 m) of the organic horizon (USDA 1975). The Oregon Inlet and Pine Knoll Shores natural marshes were underlain by mineral soils (Typic Psammaquents). The transplanted marshes had hydrology and salinity regimes that were similar to the comparable natural marshes. However, the two irregularly flooded, transplanted marshes differed from the natural marshes in plant species composition and fertilizer history (Table 1).

SAMPLE COLLECTION AND ANALYSIS

Soils were sampled using a corer 8.5 cm diameter by 30 cm deep. Ten to twenty cores for soil analyses were randomly collected from each marsh (Table 1) and divided into 0–10 and 10–30 cm sections. Cores were air dried, weighed, then ground, passed through a 2-mm sieve, and analyzed for total N, P, and organic C.

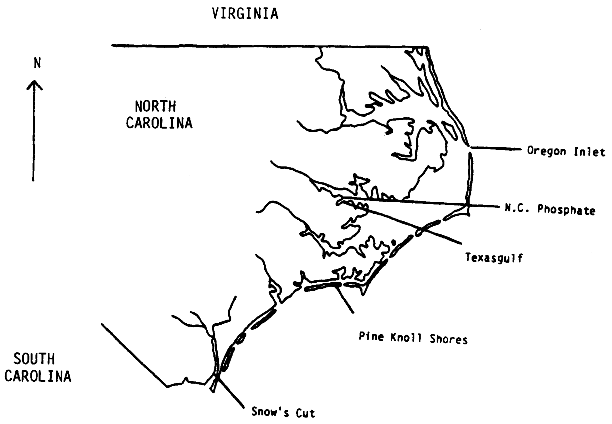

Fig. 1. Location of sampling sites.

Organic matter was measured by loss on ignition at 450 °C and converted to organic C by multiplying by 0.45 (Nixon 1980). Total N (organic plus NH_4-N) was determined by Kjeldahl digestion (Bremner and Mulvaney 1982). Total P was measured in perchloric acid digests (Sommers and Nelson 1972) using the method of Murphy and Riley (1962). Bulk density was estimated by weighing the air-dried cores and applying a correction factor determined by drying a subsample at 105 °C. Soil pH was measured in a 1:1 soil : water volume ratio. Extractable P was determined by the Mehlich 3 method (Mehlich 1984a). Humic matter (humic and fulvic acids) was extracted with 0.2 M NaOH and measured by photometric methods as described by Mehlich (1984b).

Macroorganic matter was sampled by taking a second core from each sampling point. Cores were divided into 0–10 and 10–30 cm sections and washed on a 2-mm sieve. The organic matter retained on the screen was dried at 70 °C for 48 h and weighed. The MOM collected from the two sampling depths was combined and analyzed for total N, P, and organic C using the methods described previously.

Nitrogen, P, and organic C pools in MOM were determined by multiplying dry weight of MOM by the concentration of N, P, or organic C. Nutrient pools in soil were calculated by the equation:

$$\text{Nutrient pool} = \sum_{i=1}^{n} ((X - Y) * Z)/n$$

where X = dry weight (105 °C) of the soil core, Y = dry weight (105 °C) of MOM collected from the MOM core, Z = N, P, or organic C concentration of the soil core, and n = number soil or MOM samples taken from the marsh. Accumulation rates of N, P, and organic C in MOM were determined

TABLE 1. Selected characteristics of the five sampling locations.

Location	n[a]	Vegetation	Salinity (g/l^{-1})	Tidal Regime (m)	Soil Classification[b]	Use and Year of Establishment[c]	Fertilization History[c]
Oregon Inlet	10	*Spartina alterniflora* Loisel	20–35	0.2–0.3 astronomical range with extensive wind effect (Regularly flooded)	Carteret series (Mixed, Thermic Typic Psammaquents)	Research of viability of marsh establishment (1969)	None
Snow's Cut	10	*Spartina alterniflora*	7–10	1.2 astronomical range with moderate wind effect (Regularly flooded)	Lafitte series[d] (Euic, Thermic Typic Medisaprists) Carteret series[c]	Stabilization of dredged material (1971)	None
Pine Knoll Shores	10	*Spartina alterniflora*	25–35	0.8–1.0 astronomical range with moderate wind effect (Regularly flooded)	Carteret series	Stabilization of an eroding shoreline (1974)	None
Texasgulf	15	*Juncus roemerianus* Scheele, *Distichlis spicata* (L.), *Spartina cynosuroides* (L.), *Spartina patens* (Ait.) Muhl.[d]	0–15	<0.1 astronomical range with extensive wind effect (Irregularly flooded)	Lafitte series[d]	Demonstration project for mitigation of marsh habitat (1980)	8 kmol N ha^{-1} as $(NH_4)_2SO_4$ and 1.6 kmol P ha^{-1} as concentrated superphosphate at the time of establishment. Four inches of topsoil were spread over the marsh surface prior to establishment.
		Spartina alterniflora, S. cynosuroides, S. patens[c]			Carteret series[c]		
N.C. Phosphate	15[e]	*J. roemerianus, S. cynosuroides, Cladium jamaicense* (Crantz)[d]	0–15	<0.1 astronomical range with extensive wind effect (Irregularly flooded)	Lafitte series[d]	Demonstration project for mitigation of marsh habitat (1983)	16 kmol N ha^{-1} as $(NH_4)_2SO_4$ and 3.2 kmol P ha^{-1} as concentrated superphosphate at the time of establishment.
		S. alterniflora, S. patens, S. cynosuroides[c]			Carteret series[c]		

[a] Number of soil or MOM cores collected from each marsh.
[b] From Daniels et al. (1984).
[c] Transplanted marsh.
[d] Natural marsh.
[e] Twenty soil and twenty MOM cores each were collected from the natural marsh.

by dividing the MOM nutrient pools by the age of the respective transplanted marsh. Rates of nutrient accumulation in the soil component were based on the assumption that N, P, and organic C pools in the 10–30 cm depth represented the nutrient pool at the time of establishment. Rates of soil nutrient accumulation were calculated by the equation:

$$\text{Accumulation rate} = (A - B)/T$$

where A = amount of soil N, P, or organic C (0–30 cm depth), B = (amount of soil N, P, or organic C (10–30 cm depth)•1.5), and T = age of the transplanted marsh.

STATISTICAL ANALYSES

Natural and transplanted marshes within each location were analyzed using ANOVA. The MOM data were analyzed using a one-way ANOVA based on marsh type (natural vs. transplanted). The soil data were analyzed by a two-way ANOVA based on marsh type and sampling depth. Marsh type by

TABLE 2. Mean dry weight, carbon, nitrogen, phosphorus and C:N ratios of marsh macroorganic matter.

Location	Marsh Type	Dry Weight (kg ha^{-1}) by Depth 0–10 cm	Dry Weight (kg ha^{-1}) by Depth 10–30 cm	Carbon (mol kg^{-1})	Nitrogen (mmol kg^{-1})	Phosphorus (mmol kg^{-1})	Carbon : Nitrogen[a] (wt:wt)
Oregon Inlet	Natural	35,350**[e]	17,980**	31.8	520	14.8	62.8
[R][b] {15}[c]	Transplanted	17,960	5,530	32.4	463	18.9	73.1
Mean square error (degrees of freedom)		1.61×10^8 (18)	5.00×10^7 (18)	5.59 (18)	9,168 (18)	112.8 (18)	189.4 (18)
Snow's Cut	Natural	19,610	14,980	33.0	510*	16.8	65.4
[R] {13}	Transplanted	21,150	11,230	32.5	458	18.7	71.7
Mean square error (degrees of freedom)		3.86×10^7 (17)	3.36×10^7 (18)	1.41 (18)	2,684 (18)	16.9 (18)	60.1 (18)
Pine Knoll Shores	Natural	17,680	10,240***	32.1	580***	25.3***	55.8
[R] {10}	Transplanted	14,540	2,100	32.3	426	17.1	76.8***
Mean square error (degrees of freedom)		2.32×10^7 (18)	1.20×10^7 (18)	4.17 (18)	3,437 (18)	14.1 (18)	55.4 (18)
Texasgulf	Natural	28,340***	36,030***	34.8*	529*	12.9	66.2
[I] {4}	Transplanted	10,390	1,990	33.6	463	25.2***	75.4
Mean square error (degrees of freedom)		9.81×10^7 (28)	9.75×10^7 (28)	1.72 (28)	5,012 (28)	43.5 (28)	170.0 (28)
N.C. Phosphate	Natural	19,580***	29,590***	35.0	654***	14.1	54.6
[I] {1}	Transplanted	1,560	650	—[d]	410	20.6***	—
Mean square error (degrees of freedom)		7.04×10^7 (33)	1.32×10^8 (33)	— (—)	12,177 (33)	24.7 (33)	— (—)

[a] Atomic C:N ratios.

[b] Tidal inundation: R = regularly flooded; I = irregularly flooded.

[c] Age (in years) of the transplanted marsh.

[d] Insufficient macroorganic matter to perform this analysis.

[e] *, **, ***; Significant at the 0.05, 0.01 and 0.001 levels, respectively.

depth means (soil) within each location were compared using Student-Newman-Keuls test (Sokal and Rohlf 1969).

Results and Discussion

MACROORGANIC MATTER

Dry weight of MOM in the upper 10 cm was significantly less in the 15-, 4-, and 1-yr-old transplanted marshes compared to the nearby natural marshes (Table 2). With the exception of the 13-yr-old marsh, macroorganic matter content (10–30 cm depth) was significantly less in the transplanted marshes. Total dry weight of MOM in the 13-yr-old transplanted marsh (32,380 kg ha^{-1}) was comparable to that of the nearby natural marsh (34,590 kg ha^{-1}). Of the transplanted marshes, the two oldest ones, Oregon Inlet (23,490 kg ha^{-1}) and Snow's Cut (32,380 kg ha^{-1}), contained the most MOM while the youngest marsh, N.C. Phosphate (2,210 kg ha^{-1}), had the least. Macroorganic matter content (per volume basis) decreased with depth in natural and transplanted marshes, although the amount of MOM in the 10–30 cm depth was much less in the younger transplanted marshes.

With the exception of the Texasgulf location, C content of MOM was similar in transplanted and nearby natural marshes (Table 2). Differences in plant species composition (Table 1) or inorganic contaminants in MOM collected from the low-soil-organic-matter transplanted marsh could account for the difference in MOM C levels at this site.

Macroorganic matter collected from natural marshes contained significantly higher N levels compared to the nearby transplanted marshes at four of the five locations (Table 2). Only the 15-yr-old transplanted marsh (Oregon Inlet) exhibited N concentrations similar to the comparable natural marsh (Table 2). The higher N levels in natural marsh MOM were attributed to a greater proportion of decaying roots in these older marshes. The concentration of nitrogen in marsh emergent vegetation increases during decomposition (de la Cruz and Gabriel 1974; Hackney and de la Cruz 1980) as microbial proteins and exudates are bound by carbohydrates and phenolic plant constituents (de la Cruz 1975; Rice and Tenore 1981). Organic C:N ratios in MOM were lower in natural (61.0) than transplanted marshes (74.2). However, Pine Knoll Shores was the only site where significant differences in MOM C:N ratios were observed.

In contrast to nitrogen, phosphorus concentrations were higher in MOM collected from four of the five transplanted marshes (Table 2). The transplanted marshes are less than 15 yr old and presumably have a greater proportion of live root and rhizome material than natural marsh MOM. de la Cruz and Hackney (1977) have found that live plant material has greater P concentrations than decomposing plant tissue. The application of P fertilizers during establishment of the N.C. Phosphate and Texasgulf marshes (see Table 1) may have contributed to the significantly higher MOM P levels at these sites.

TABLE 3. Mean bulk density, pH and total and extractable nutrients in marsh soils.

Location	Marsh Type	Depth (cm)	Bulk Density ($Mg\ m^{-3}$)	pH	Carbon ($mol\ kg^{-1}$)	Carbon ($mol\ m^{-3}$)
Oregon Inlet	Natural	0–10	0.82 a[c]	4.5 a	2.1 a	1,431 a
		10–30	1.50 b	4.0 a	0.6 b, c	719 b
[R][a] {15}[b]	Transplanted	0–10	0.83 a	4.6 a	0.9 b	982 b
		10–30	1.53 b	4.7 a	0.1 c	112 c
Mean square error (degrees of freedom)			0.026 (36)	0.735 (36)	0.434 (36)	172,322 (36)
Snow's Cut	Natural (organic)	0–10	0.34 a	4.5 a	7.2 b	4,167 b
		10–30	0.37 a	3.4 c	8.8 a	4,863 a
[R] {13}	Transplanted	0–10	0.72 b	4.0 b	1.5 c	1,446 c
		10–30	1.23 c	3.7 b, c	0.4 c	555 d
Mean square error (degrees of freedom)			0.005 (36)	0.185 (36)	1.51 (36)	354,378 (36)
Pine Knoll Shores	Natural	0–10	1.03 a	6.1 a	0.5 a	540 a
		10–30	1.36 c	6.5 a, b	0.2 b	322 b
[R] {10}	Transplanted	0–10	1.19 b	7.0 b	0.5 a	577 a
		10–30	1.50 d	7.1 b	0.2 b	210 c
Mean square error (degrees of freedom)			0.020 (36)	0.395 (36)	0.010 (36)	14,569 (36)
Texasgulf	Natural (organic)	0–10	0.21 a	5.3 b	16.5 a	3,482 a
		10–30	0.20 a	5.4 a, b	18.3 a	3,565 a
[I] {4}	Transplanted	0–10	1.27 b	5.5 a	1.9 b	2,048 b
		10–30	1.34 b	5.0 c	1.4 b	1,561 c
Mean square error (degrees of freedom)			0.016 (56)	0.058 (56)	24.36 (56)	179,004 (56)
N.C. Phosphate	Natural (organic)	0–10	0.13 a	4.8 a	18.0 a	3,923 b
		10–30	0.17 a	5.0 a	19.1 a	4,712 a
[I] {1}	Transplanted	0–10	1.21 c	4.8 a	0.4 b	465 c
		10–30	1.07 b	4.0 b	0.4 b	455 c
Mean square error (degrees of freedom)			0.023 (66)	0.229 (66)	12.56 (66)	666,033 (66)

[a] Tidal inundation: R = regularly flooded, I = irregularly flooded.

[b] Age (in years) of the transplanted marsh.

[c] Means within the same site followed by the same letter are not significantly different (a = 0.05) according to Student-Newman-Keuls Test.

SOIL

Soil organic matter content was greater in the natural marshes, resulting in significantly lower bulk densities and greater amounts of N, P, and organic C (Table 3). The three organic natural marsh soils (Snow's Cut, Texasgulf, and N.C. Phosphate) had significantly lower bulk densities and higher C, N, and P concentrations than the comparable transplanted marshes (Table 3). In contrast to the three organic natural marshes, the Oregon Inlet natural marsh had soil N concentrations (volume basis, top 10 cm) and bulk densities that were similar to the transplanted marsh (Table 3). Likewise, the Pine Knoll Shores natural marsh contained C, N, and total P (volume basis) levels (0–10 cm depth) that were comparable to the adjacent transplanted marsh.

The similarity in soil bulk density and elemental concentrations in the natural and transplanted marshes at these two sites may be attributed to the young age of the natural marshes and the dynamic hydrologic regime of these sites. The Oregon Inlet and Pine Knoll Shores marshes are located on the back side of barrier islands (Fig. 1) and periodic sound-side flooding scours the marshes, removing organic matter and depositing sand on the marsh surface. In addition, the steady rise in sea level and subsequent migration of barrier islands landward (Leatherman 1982) generally precludes the development of old, organic marshes on barrier islands.

The total soil P content (volume basis) of the Pine Knoll Shores marshes was much greater than that of other sites (Table 3). The high concentration of P in these marshes may have resulted from fixation with calcium. The high soil pH (6.4–7.1) and presence of oyster cultch (which contain $CaCO_3$) in both Pine Knoll Shores marshes provide a favorable environment for formation of low solubility calcium phosphates. Total and extractable soil P and MOM phosphorus concentrations were higher in the natural than the transplanted marsh at Pine Knoll Shores. Presumably, these findings reflect greater accumulation with time in the older natural marsh.

Surface soil C:N ratios (0–10 cm) were significantly higher in the two youngest transplanted marshes compared to the nearby natural marshes; subsurface C:N ratios (10–30 cm) were significantly higher in the 1-, 4-, 10-, and 13-yr-old transplanted marshes (Table 3). These findings suggest that surface soil C:N ratios are rapidly modified by

TABLE 3. Continued.

Humic Matter ($g\ m^{-3}$)	Nitrogen ($mmol\ kg^{-1}$)	Nitrogen ($mol\ m^{-3}$)	C:N (wt:wt)	Phosphorus ($mmol\ kg^{-1}$)	Phosphorus ($mol\ m^{-3}$)	Extractable P ($mol\ m^{-3}$)
150 a	120 a	85 a	16.8 a	6.6 a	4.9 a	0.5 a
95 b	36 b, c	42 b	17.6 a	2.9 b	3.4 b	0.3 c
79 b	66 b	73 a	13.7 a, b	3.2 b	3.6 b	0.4 b
20 c	8 c	12 c	10.7 b	1.1 c	1.5 c	0.1 c
2,071 (36)	1,633 (36)	658 (36)	21.8 (36)	3.58 (36)	1.07 (36)	0.018 (36)
501 b	268 b	156 b	26.8 a, b	18.4 a	10.8 a	1.6 a
1,423 a	372 a	206 a	23.7 b	15.1 b	8.4 b	0.5 c
299 b, c	61 c	60 c	24.8 b	6.8 c	6.7 c	1.6 a
128 c	15 d	19 d	30.7 a	3.3 d	4.1 d	1.3 b
92,960 (36)	2,205 (36)	629 (36)	27.6 (36)	5.47 (36)	2.27 (36)	0.083 (36)
83 a	26 a	31 a	17.7 a	19.2 a	23.0 a	3.0 a
90 a	11 b	15 b	22.4 a	15.5 b	20.3 a, b	2.4 a
88 a	23 a	29 a	20.3 a	16.2 b	20.3 a, b	1.1 b
91 a	5 c	7 c	34.8 b	12.9 b	17.5 b	1.1 b
896 (36)	36 (36)	51 (36)	93.5 (36)	8.88 (36)	14.88 (36)	0.513 (36)
744 c	918 a	204 a	17.4 a	35.4 a	8.5 a	1.6 a
1,779 b	971 a	185 a	19.7 a	18.1 b	3.7 b, c	0.3 b
2,953 a	61 b	66 b	31.1 b	4.1 c	4.5 b	1.3 a
2,453 a	45 b	49 b	31.9 b	2.1 c	2.3 c	0.2 b
641,205 (56)	70,302 (56)	781 (56)	21.5 (56)	33.14 (56)	3.73 (56)	0.292 (56)
883 b	1,156 a	253 a	15.6 a	48.1 a	11.0 a	1.9 a
1,320 a	1,074 a	265 a	18.6 a	21.5 b	5.6 b	0.6 b
62 c	17 b	19 b	25.7 b	3.4 c	4.0 b	0.5 b
66 c	11 b	13 b	37.4 c	3.0 c	3.6 b	0.2 b
53,836 (66)	44,917 (66)	3,498 (66)	49.0 (66)	70.06 (66)	9.79 (66)	0.340 (66)

transplanted marsh vegetation and associated organisms, producing organic C:N ratios comparable to natural marshes within 10 to 15 yr.

With the exception of the Texasgulf location, humic matter content was equal to or greater in natural than transplanted marsh soils. The high soil humic matter levels in the Texasgulf transplanted marsh probably resulted from topsoil applied during establishment (see Table 1). Humic matter, which consists of humic and fulvic acids (Mehlich 1984b), accounted for <1–6% of the total soil organic C.

CARBON, NITROGEN, AND PHOSPHORUS POOLS

Because of their age, total (soil plus MOM) C and N pools were much larger in natural marshes (Fig. 2), with the greatest accumulation in the organic marsh soils. The relative contribution of MOM to total marsh nutrient pools amounted to 6–45%, 2–22%, and 1–7% of the C, N, and P, respectively. The 13-yr-old transplanted and nearby natural marsh (Snow's Cut) contained similar macroorganic matter C, N, and P pools, which suggests that MOM nutrient reservoirs develop in about 15 to 30 yr. There was little difference among P pools of organic and adjacent mineral (transplanted) marsh soils. Soil P accumulation in the Pine Knoll Shores marshes (58–62 kmol ha^{-1}) were comparable to that of N and probably reflects fixation of P as Ca phosphates. Application of fertilizer to the Texasgulf and N.C. Phosphate transplanted marshes (see Table 1) could account for up to 4–36% of the N and 14–30% of the P in the soil-MOM reservoir.

Rates of N, P, and organic C accumulation in transplanted marshes ranged from 2.6 to 10.0, 0.03 to 1.10, and 84 to 218 kmol ha^{-1} yr^{-1}, respectively (Fig. 3). Accumulation rates were greater in the irregularly flooded marshes compared to the regularly flooded marshes. The lower accumulation rates in the regularly flooded transplanted marshes could result from removal of NPP by tidal flushing or from overestimating the initial nutrient pools at the time of establishment. The three regularly flooded transplanted marshes are 10 to 15 yr old. Using the 10–30 cm sampling depth as an estimate of nutrient pools at time zero could result in overestimating nutrient reservoirs (and underestimating rates of accumulation) in these older transplanted marshes. Macroorganic matter accounted for 47–72%, 10–42%, and 9–100% of the C, N, and P retained by the marsh. Cammen (1975) cal-

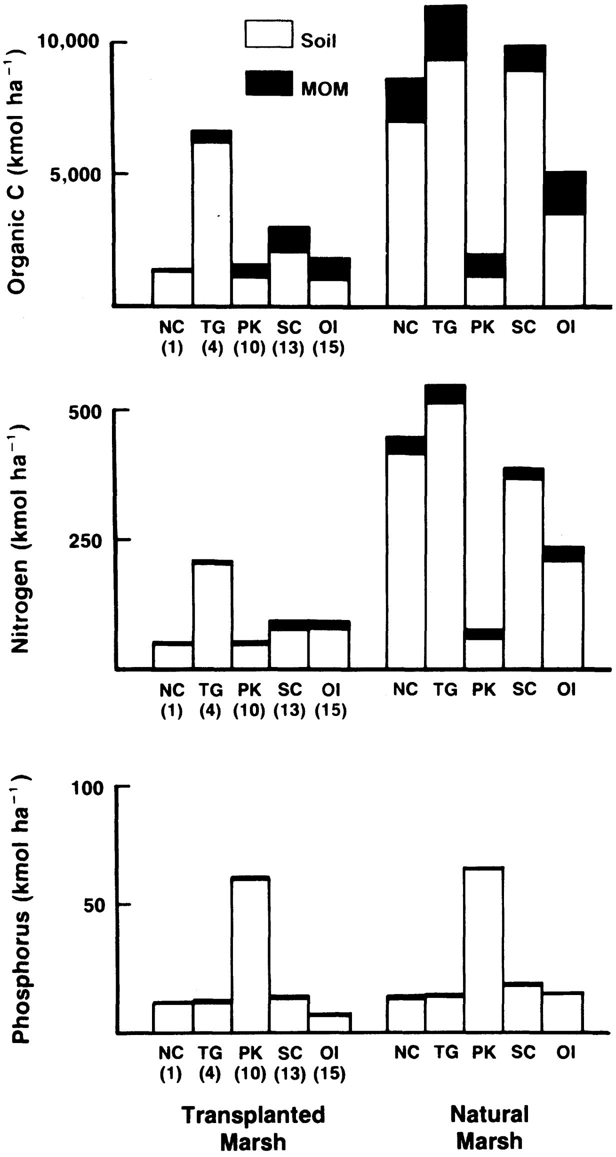

Fig. 2. Soil carbon, nitrogen, and phosphorus pools in the top 30 cm of natural and transplanted marshes. (The MOM organic C pool in the N.C. Phosphate transplanted marsh was estimated assuming a C content of 34 mol kg^{-1}.)

culated greater rates of soil C accumulation (72 kmol ha^{-1} yr^{-1}, top 13 cm) in a regularly flooded transplanted marsh near Drum Inlet, North Carolina, compared to the regularly flooded marshes in this study (29–37 kmol C ha^{-1} yr^{-1}).

Organic matter accumulation in marsh soils is dependent on hydroperiod (Gosselink and Turner 1978) and marsh age (Friedman and DeWitt 1978). The three organic marsh soils apparently are much older than the other natural marshes as the organic layer of these soils extends to a depth > 1.5 m. Two organic marsh soils, Texasgulf and N.C. Phos-

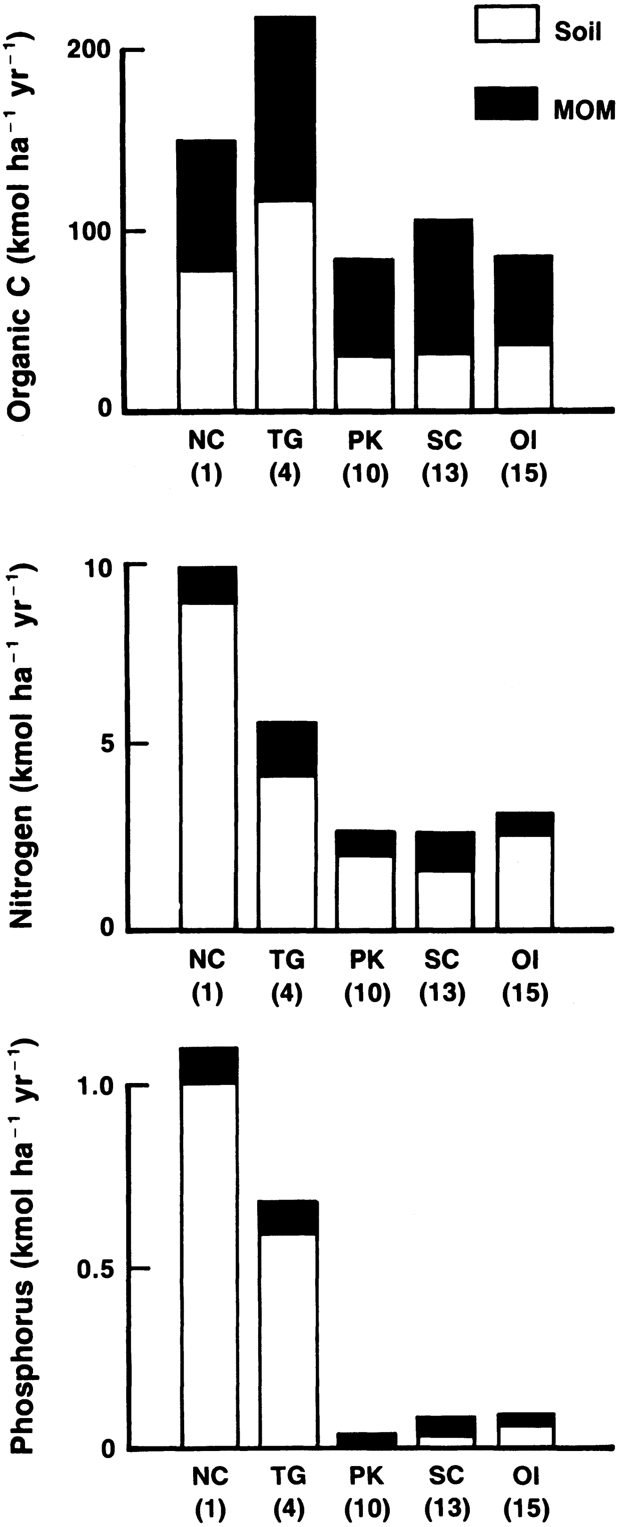

Fig. 3. Accumulation rates (top 30 cm) of carbon, nitrogen, and phosphorus in transplanted marsh soils.

TABLE 4. Net primary production (NPP) of emergent vegetation in transplanted marshes.[a]

Location	Net Primary Production[b] (kmol C ha^{-1} yr^{-1}) Aboveground	Net Primary Production[b] (kmol C ha^{-1} yr^{-1}) Belowground	% of NPP Buried
Snow's Cut (1972–1982)[c] [R][d] {13}[e]	439	526	11
P.K. Shores (1976–1983) [R] {10}	318	354	12
N.C. Phosphate (1984) [I] {1}	283	481	20

[a] NPP of the Pine Knoll Shores marsh is from Broome et al. (1986). NPP of the Snow's Cut and N.C. Phosphate marshes was estimated using the methodology of Broome et al. (1986).

[b] Dry weight values were converted to C by multiplying by 0.45.

[c] Years net primary production was measured.

[d] Tidal inundation: R = regularly flooded; I = irregularly flooded.

[e] Age (in years) of the transplanted marsh.

phate, were characterized by low tidal amplitude and irregular flooding. Rates of nutrient accumulation were greatest in these irregularly flooded transplanted marshes. Organic matter content of marsh soils generally increases with decreasing frequency of inundation (Gosselink and Turner 1978). In irregularly flooded marshes, a greater proportion of NPP accumulates on the marsh and less is exported by tidal action (Hackney and de la Cruz 1982).

Net primary production of emergent vegetation ranged from 672 to 965 kmol C ha^{-1} yr^{-1} in three of the transplanted marshes (Table 4). Based on these estimates, 11–20% of the NPP was buried in marsh sediments. A greater proportion of the NPP accumulated in the irregularly flooded transplanted marsh compared to the regularly flooded transplanted marshes. These values are comparable to other estimates of NPP accumulation (9–40%) in marsh soils (Woodwell et al. 1979; Jordan et al. 1983; Smith et al. 1983; Howes et al. 1985; Morris and Bowden 1986).

In conclusion, macroorganic matter and soil nutrient reservoirs were smaller in transplanted (1–15 yr old) than comparable natural marshes. Macroorganic matter C, N, and P pools develop rapidly in transplanted marsh soils and may approximate natural marshes within 15–30 yr. However, soil nutrient pools take considerably longer to develop. Transplanted marshes are accumulating organic materials and, over time, may serve as reservoirs of C, N, and P for estuarine ecosystems.

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