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FINAL
CONTRACT REPORT
VTRC 09-CR10

**UNDERSTANDING CATTAIL (*TYPHA SPP.*)
INVASION AND PERSISTENCE
IN FORESTED WETLANDS CREATED
BY THE VIRGINIA
DEPARTMENT OF TRANSPORTATION**

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16. Abstract: <p>Common cattail (<i>Typha latifolia</i>) is a native plant species listed as an invasive weed by some regulatory agencies. While it is not listed as a noxious weed by the Commonwealth of Virginia, control of cattail populations in created forested wetlands is still mandated by some regulatory permit requirements and requires either mechanical removal, treatment with herbicide, or both. Permitting agencies reason that cattail removal will prevent interspecies competition between cattails and desirable planted tree species. This regulatory requirement has added significantly to the Virginia Department of Transportation's (VDOT) cost of wetland compensation and mitigation. However, some researchers have questioned spending resources on cattail removal since the data do not support the hypothesis that cattails retard or inhibit planted tree growth. Rather, created wetland vegetation communities demonstrate more complex relationships than can be explained by simple interspecies competition. A site's hydrology (generally, water that is too deep) appears to be the driving force in an increase in planted tree morbidity and/or a decrease in woody growth.</p> <p>Because of conflicting information in the literature, this study was undertaken to help clarify the environmental conditions (biological, chemical, and physical) that enable <i>Typha</i> spp. to rapidly colonize primary succession (created mitigation) forested wetlands. The vegetation of 20 VDOT-created forested wetlands was collected and analyzed during the 2006-2007 growing seasons. Further, the hydrology, nutrient dynamics, and vegetation were studied at four of those sites.</p> <p>The data showed that cattails, while present in young sites, were rare in mature created hardwood wetlands. Woody vegetation, particularly specific volunteer species, became prominent after 10 to 15 years. In addition, species such as bald cypress, black willow, and red maple trees were common dominants in the older sites. Preliminary data showed that the growth of planted bald cypress trees in cattail-dominated areas was not significantly different than in those surrounded by non-cattail herbaceous perennials. Environmental data indicated a weak relationship (trend) in cattail dominance and water depth, but there was no significant difference in environmental parameters.</p> <p>The study concludes that the resources used to eradicate cattails, except where the hydrology has been compromised, are better spent on seeding and/or planting woody species such as bald cypress, black willow, river birch, and red maple that are better adapted to the draw-down, plant, and then flood conditions that are frequently encountered on these sites. Additional research on the direct effect of perennial herbaceous plants on planted woody species growth is recommended.</p>			
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ABSTRACT

Common cattail (*Typha latifolia*) is a native plant species listed as an invasive weed by some regulatory agencies. While it is not listed as a noxious weed by the Commonwealth of Virginia, control of cattail populations in created forested wetlands is still mandated by some regulatory permit requirements and requires either mechanical removal, treatment with herbicide, or both. Permitting agencies reason that cattail removal will prevent interspecies competition between cattails and desirable planted tree species. This regulatory requirement has added significantly to the Virginia Department of Transportation's (VDOT) cost of wetland compensation and mitigation. However, some researchers have questioned spending resources on cattail removal since the data do not support the hypothesis that cattails retard or inhibit planted tree growth. Rather, created wetland vegetation communities demonstrate more complex relationships than can be explained by simple interspecies competition. A site's hydrology (generally, water that is too deep) appears to be the driving force in an increase in planted tree morbidity and/or a decrease in woody growth.

Because of conflicting information in the literature, this study was undertaken to help clarify the environmental conditions (biological, chemical, and physical) that enable *Typha* spp. to rapidly colonize primary succession (created mitigation) forested wetlands. The vegetation of 20 VDOT-created forested wetlands was collected and analyzed during the 2006-2007 growing seasons. Further, the hydrology, nutrient dynamics, and vegetation were studied at four of those sites.

The data showed that cattails, while present in young sites, were rare in mature created hardwood wetlands. Woody vegetation, particularly specific volunteer species, became prominent after 10 to 15 years. In addition, species such as bald cypress, black willow, and red maple trees were common dominants in the older sites. Preliminary data showed that the growth of planted bald cypress trees in cattail-dominated areas was not significantly different than in those surrounded by non-cattail herbaceous perennials. Environmental data indicated a weak relationship (trend) in cattail dominance and water depth, but there was no significant difference in environmental parameters.

The study concludes that the resources used to eradicate cattails, except where the hydrology has been compromised, are better spent on seeding and/or planting woody species such as bald cypress, black willow, river birch, and red maple that are better adapted to the draw-down, plant, and then flood conditions that are frequently encountered on these sites. Additional research on the direct effect of perennial herbaceous plants on planted woody species growth is recommended.

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INTRODUCTION

Cattails (*Typha* spp.), particularly the broad-leaf cattail (*T. latifolia*), are listed as an invasive weed by the U.S. Army Corps of Engineers (COE) (PMIS 2003) and numerous other sources (Southern Weed Science Society 1998, Stubbendieck et al.1994, Whitson et al.1996). Cattails have been identified locally as a noxious pest species that may invade created and restored non-tidal wetlands (S. Martin, personal communication; Perry et al. 2001). While cattails are not listed as noxious weeds by the Commonwealth of Virginia (Virginia Noxious Weed Law, Sec. 3.1-296.12, and Virginia Seed Law, Sec. 3.1-271, of the *Code of Virginia*), some regulatory permit requirements still mandate cattail population control in created forested wetlands in Virginia; such permits require mechanical removal, treatment with herbicide, or both. Permitting agencies reason that cattail removal will prevent interspecies competition between cattails and desirable planted tree species. This regulatory requirement has added significantly to the Virginia Department of Transportation's (VDOT) cost of wetland compensation and mitigation. However, authors such as Baldwin (2008) and Perry et al. (2009) have questioned the wisdom of spending resources on cattail removal; they assert that research data do not support the hypothesis that cattails retard or inhibit planted tree growth. Both argue that data from created wetland vegetation communities demonstrate more complex relationships than can be explained by simple interspecies competition. Rather, the authors note that a site's hydrology (generally, water that is too deep) appears to be the driving force in an increase in planted tree morbidity and/or a decrease in woody growth.

Four cattail species are found in Virginia: *Typha angustifolia* (narrow leaf cattail); *T. domingensis* (southern cattail, found in a few northeastern counties of Virginia); *T. x glauca* (a hybrid between *T. angustifolia* and *T. latifolia* in the coastal plain and piedmont regions of Virginia); and *T. latifolia* (common or broad-leaf cattail) (Townsend 2007). Cattails can be found in damp soil or shallow water where sufficient nutrients are available. They are common along expressways, in artificial ditches and shallow ponds, at the edges of calm waters, in consistently damp patches of rural and suburban yards, and in freshwater marshes. They are prolific, reproducing sexually by seed and vegetatively by the production of rhizomes. The flower head of the parent plant can produce 250,000 wind-dispersed seeds, which can remain viable in the seed bank for up to 100 years. Common cattail seeds prefer freshwater, and will not germinate unless saturated in at least 0.5 to 1 inch of water. Sunlight affects germination rates; seeds will remain quiescent if the area does not receive the proper amount of sunlight. Because of its reproductive capabilities, cattail is a dominant component of early succession stages in wetlands and rapidly colonizes exposed wet mineral soils. Therefore, common cattails can quickly dominate a wetland plant community and produce monotypic stands that can reduce the overall habitat value.

Various studies have examined environmental factors that either promote or limit the growth of cattail communities. Common cattail is tolerant of continuous inundation and seasonal draw-downs, but is generally restricted to areas where the water depth never exceeds about 2.5 inches. Constant water levels seem to help maintain relatively stable common cattail communities. However, the literature suggests that water levels alone are not sufficient to facilitate cattail invasion (Woo and Zedler 2002). Several studies have shown that cattail populations advance with elevated nutrients (Miao and Sklar 1998, Newman et al. 1996). Woo and Zedler (2002) also found that *T. glauca* (a hybrid of *T. latifolia* and *T. angustifolia*) responded positively to increased nutrients by nearly doubling its above ground biomass, while a native sedge did not respond to the same treatment. They concluded that an increase in nutrients from fertilizer would favor the expansion of *T. glauca* over *T. latifolia*, the native species. However, Bevington (2007), in a greenhouse experiment on *T. glauca* from a southeastern Virginia created forested wetlands, found that an increase in nutrients did not enhance cattail growth. None of these studies examined the relationship between cattails and woody tree growth rates.

Due to conflicting information in the literature, this study was undertaken to help clarify the environmental conditions (biological, chemical, and physical) that enable *Typha* spp. to rapidly colonize primary succession (created mitigation) forested wetlands. By doing so, we hoped to provide the VDOT non-tidal wetland creation designers with new tools/methods to help minimize, or possibly eliminate, rapid colonization, and possibly dominance, of *Typha* spp. in created wetlands. Currently, control of *Typha* spp. colonization is mandated by regulatory permit and requires either mechanical removal, treatment with herbicide, or both. This regulatory requirement adds significantly to VDOT's cost of wetland compensation and mitigation.

PURPOSE AND SCOPE

Overall, the purpose of this research effort was to determine if the current emphasis on cattail eradication is necessary to ensure the success of VDOT mitigation sites (i.e., does not reduce species diversity and richness). More specifically, the objectives of this study were:

1. To assess the invasiveness of different *Typha* species, their relationships, and relative dominance within the vegetation community, as well as water quality and soil conditions at a range of VDOT non-tidal forested wetland mitigation sites. Field and laboratory work was used to investigate the distinguishing field characteristics of 3 *Typha* species in 3 created wetlands in Virginia (to better facilitate precise identification of plants considered “invasive” and therefore regulated by COE and the Virginia Department of Environmental Quality (DEQ)). *Typha* coverage in 2 younger created forested wetlands was mapped using GIS to serve as a baseline for tracking *Typha* growth over time.
2. To develop a model of *Typha* spp. invasion dynamics vs. site conditions
3. To help identify potential methods for VDOT mitigation planners to minimize *Typha* spp. colonization
4. To collect preliminary data on the effect of cattail dominance on the growth of planted *Taxodium distichum* (bald cypress) in created forested wetlands.

METHODS

VDOT Field Sites

The 20 sites used for overall vegetation analysis are listed in Table 1. While vegetation surveys were completed in all 20 created wetlands, the following four sites were identified for more intensive investigation: Suffolk Bypass, Courtland West, Courtland East, and Sandy Bottom Nature Park. The bulk of this report deals with the vegetation and environmental conditions at those four sites.

Table 1. VDOT field sites chosen for initial study, including data on their location, size, age, and access.

#	AGE When Measured	PROJECT NAME	CITY/ CO.	SIZE (Ha)	YEAR BUILT	NOTES
1	17	Sleeter Lake	Loudoun	2.3	1989	Access from adjacent neighborhood
2	13	664 Site 7	Chesapeake	11.02	1992	Access off of Joliff Rd. near I-664 (pull off) - walk along highway and duck under fence
3	13	664 Site 1	Suffolk	1.25	1992	
4	13	Springfield Bypass, RT. 7	Fairfax	2.5	1992	Access - pull off side of Rte. 7 west-bound just beyond off-ramp from Parkway
5	12	Courtland Bypass Site 1	Southampton	5.1	1993	Pull off on north side of 58 bypass - rock-surfaced access road with a gate at the end. Follow small path access east to site
6	12	Courtland Bypass Site 2	Southampton	4.1	1993	Pull off on north side of 58 bypass -
7	11	Proctor's Creek (Site 19)	Chesterfield	4.1	1994	Access from neighborhood to north; road turns into dirt path - drivable for about 500 feet. Foot access from there.
8	11	Franklin Bypass Site 2	Southampton	6.48	1994	Short pull-off on south side of 58 bypass
9	8	RT. 199 Charles City Site	Charles City	20.9	1997	Gravel driveway access; portion of study site is along the eastern perimeter
10	6	Stony Creek	Sussex	2.6	2000	Pull off from Rt 40
11	7	Fort Lee	Prince George	13.76	1997	Pull off from I-295
12	18	Powhite Parkway	Chesterfield	9.1	1987	Pull off from Piney Lane; foot-path to VDOT fence.
13	5	Manassas Rt. 234 Mit. Site	Prince William	12.92	2000	Access from Clover Hill Drive (?) off of 234 bypass - construction not complete - front gate combination = 7602 or 7734; back gate combo is whatever the front one wasn't
14	3	White Oak Swamp (Rt 156)	Henrico	0.12	2003	Access of Rt 156 approx. 2mi. South of Rt 60.
15	5	Rt. 106	Charles City	0.77	2001	Access of Rt 60 just north of RR tracks
16	3	Mount Sterling Mit. Site	Charles City	13	2001	Access from pull-off on Rt.155 (Mount Sterling Farm)
17	3	Southwest Suffolk	Suffolk	6	2002	Access from neighborhood cul-de-sac.
18	2	Mattaponi Bank	Caroline	25.07	2003	Access on foot from gate/pull off.
19	1	Reedy Creek	Chesterfield	18.21	2003	Access road from 602 - Combo is 7345; study site is all the way in the back along the river
20	1	Sandy Bottom Nature Park	Hampton	17.48	2005	Access from Nature Center-corner of Hampton Roads Center Parkway (West) and Big Bethel Road (600).

The four sites identified for intensive investigation were designed as created forested palustrine wetlands and were constructed in the Virginia coastal plain region by VDOT. We selected these four sites specifically since each had areas dominated by *Typha* as well as areas dominated by other wetland species to use for comparison. These sites also allowed for a comparative view of cattail population dynamics between wetlands of different ages and maturation stages.

1. *Southwest Suffolk Bypass*: Located within the City of Suffolk, Virginia, this mitigation site is adjacent to Lake Kilby and the Kilby Shores subdivision (Figure 1). It is 6 ha and has nearly level topography and mineral soils of maritime origin. Created in 2002, this site was previously used as a borrow pit and is surrounded by slopes of up to 10 m, as well as a moderate-density residential community, agricultural and forested land. The top 12 inches of the finished soil was amended with compost yard waste (5% minimum organic content by volume). Adjacent forested wetlands are approximately 50 years old. This created wetland functions as a gently-graded slope wetland, with surface runoff and groundwater as its major water sources. The site was designed to be 85% forested, and designers planted a variety of woody species; organic amendments were also added to the soil prior to planting. Although the site was initially planted with trees typically found in a forested wetland, it was subsequently invaded by *Typha* spp. due in large part to the site drainage being blocked for a period by adjacent residents to create a lake at the site. The blockage has since been removed.
2. *Courtland Bypass Site 2 (Courtland West)*: Located near Courtland, Virginia, this 5.1 ha site was completed in 1993 (Figure 2). This site has gentle topography; its perimeter is composed of sandy soils underlain by silty clay loam substrates with high organic accumulations. Finished soil in created wetland was capped with 6 inches of topsoil containing approximately 1% organic content. Adjacent to the Nottoway River floodplain, the surrounding area is mainly agricultural with large forested areas. Nearby natural forested wetlands are approximately 80 years old. The created wetland captures water from surface runoff, and discharges via groundwater and two rip-rapped outlets that flow northeastward into the Nottoway River. It was planted with woody, shrubby, and herbaceous species.
3. *Courtland Bypass Site 1 (Courtland East)*: Located near Courtland, Virginia, this 4.1 ha site was also completed in 1993 (Figure 2). This site has essentially the same characteristics as Courtland West, but it has only one outlet that drains northward into the Nottoway River. Finished soil in the created wetland was also capped with 6 inches of topsoil containing approximately 1% organic content. .
4. *Sandy Bottom Nature Park*: This 17.48 ha site is located in Hampton, Virginia, and is part of a 456 acre environmental education and management facility (Figure 3). During its construction, the site was filled and graded to achieve the desired elevation; imported subsoil was used as fill and subsequent compaction (combined with the fill's higher clay content than soils of surrounding natural wetlands) led to water perching in the surface soil layers. Compost amended topsoil was subsequently

added and disked into the site. Forested, scrub-shrub, and emergent vegetation were planted in the fall of 2004.



Figure 1. Aerial photograph of Suffolk Bypass mitigation site (outlined by red/gray line), with insert highlighting the study area. Typha and Non-Typha Associations are outlined in white.

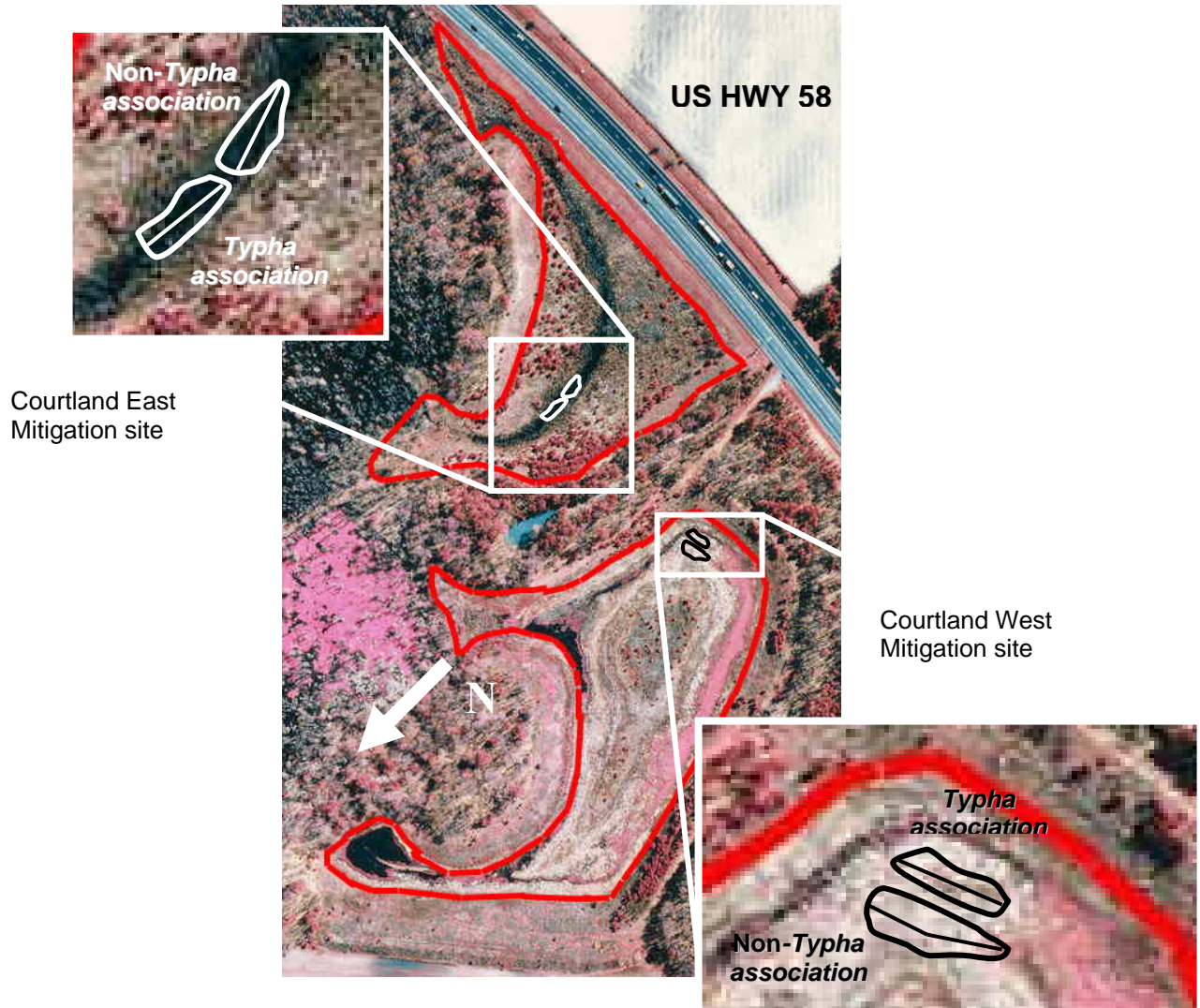


Figure 2. Aerial photograph of Courtland East and West mitigation sites (outlined by red/gray line), with inserts highlighting study areas. Typha and Non-Typha Associations are outlined in white (Courtland East) and black (Courtland West) and shown with their delineated baselines.

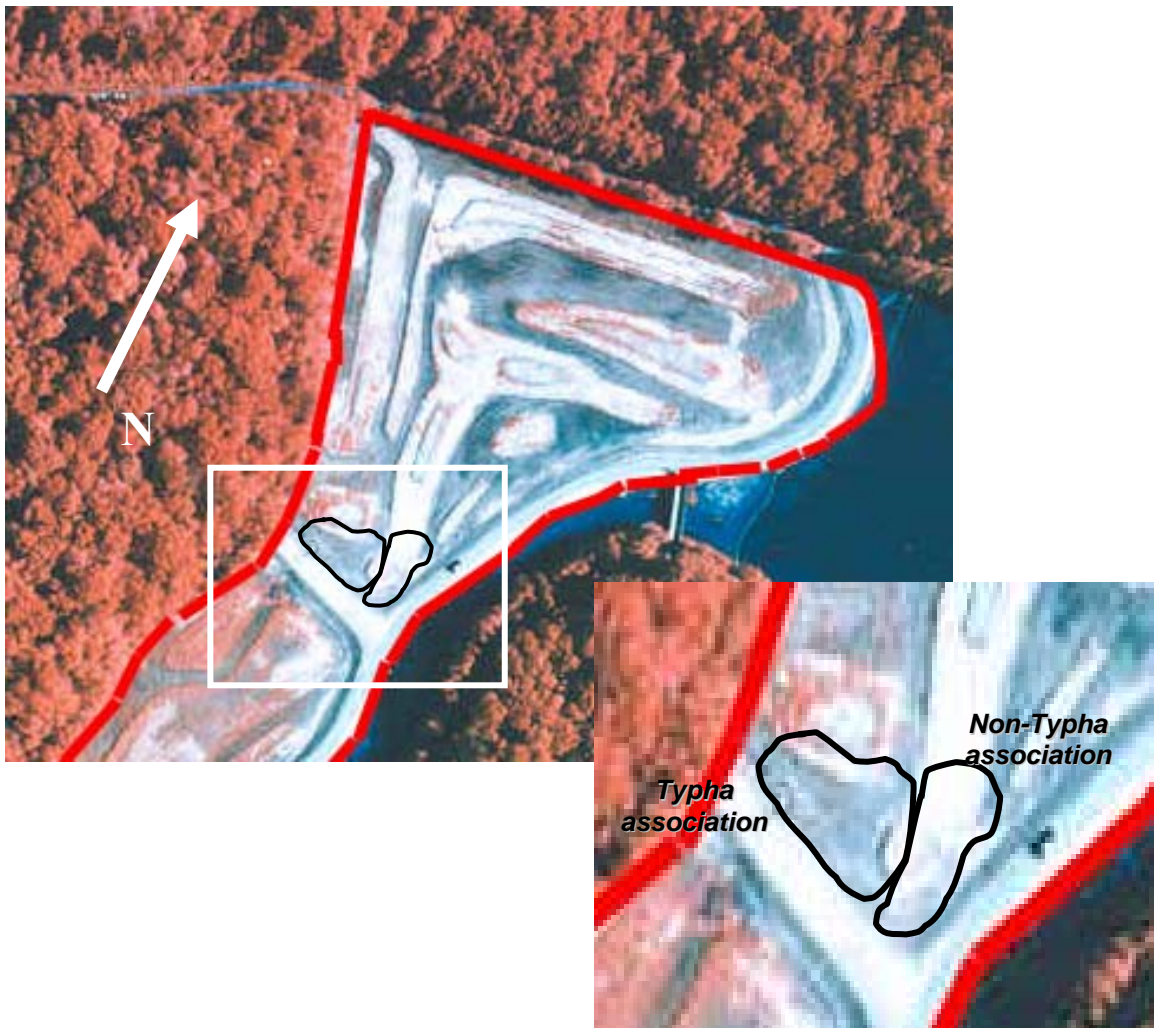


Figure 3. Aerial photograph of Sandy Bottom Nature Park mitigation site (outlined by red/gray line), with insert highlighting study areas. Typha and Non-Typha Associations are outlined in black and shown with baselines delineated.

Vegetation Analysis

Overall Vegetation

Importance values (IVs) were calculated from vegetation sampled from within a predetermined one-hectare segment of each of the 20 sites during late summer 2005. At each site, a baseline was established along the wetland perimeter and divided into segments of approximately 30 m in length. A transect was set within each segment oriented perpendicular to the baseline and extending into the wetland. Single plots were established on each transect based on a similar random numbers draw, taking the transect length as the domain for the available

random numbers set. A species area curve was constructed at each site to certify that nine quadrats provided an adequate sample of the vegetation at that site. Trees, including woody species greater than 10cm diameter at breast (dbh), were sampled from random 0.04-hectare plots (11.3 m radius; 5 plots per site). Saplings, shrubs, and woody vines greater than 1m in height but less than 10cm dbh were sampled from a 5m radius sub-plot centered on each 0.04-hectare plot. Herbaceous vegetation (including woody plants less than 1m in height) was sampled from three randomly placed 1m² quadrats at each 0.04-hectare plot (DeBerry 2006) using a modified Braun-Blanquet cover scale: <1% = trace, (1-5%) = 2.5%, (6-10%) = 7.5%, (11-25%) = 17.5%, (26-50) = 37.5%, (51-75%) = 62.5%, (76-98%) = 87.5%, and (98 to 100%) = 99% (Daubenmire 1959, DeBerry and Perry 2004). Relative Cover and Relative Frequency (determined from cover; see the Appendix for the formula) were summed to calculate importance values (IV) for each species in both non-Typha and Typha Associations at each site (Mueller-Dombois and Ellenberg 1974) (see the Appendix, Formula 1). Relative IV was also calculated across all plots throughout the growing season to obtain relative IVs for each site (Perry and Hershner 1999). Species were then ranked in order of decreasing IV. Dominant species in a site were then identified as those comprising the first 50% of the total IV, as well as any additional species that made up greater than 20% of each sample (US Army Corps of Engineers 1987). Plant taxonomy and nomenclature follows the Natural Resources Conservation Service PLANTS Database (USDA, NRCS 2006).

Species richness was determined as the total number of species m⁻¹. Evenness (J') and the Shannon Diversity Index (H') (Zar 1999) were calculated using the relative IV data for each stand (Appendix, Formula 2). The Ellenberg Community Coefficient Similarity Index (SI_E) (Mueller-Dombois and Ellenberg 1974) was calculated and used to compare the similarity of the plant communities both between stands within a site and between stands at different sites (Appendix, Formula 3).

Weighted averages for each species were calculated as the product of the sum of per stand IV for each month and the wetland indicator index of that species (Reed 1988, Atkinson et al. 1993). Indicator values ranged from 1 (obligate, OBL) to 5 (upland, UPL) with intermediate indicators assigned between (see Bailey et al. 2007). These monthly values were averaged over the course of the growing season to determine the similarity of the USFWS wetland indicator status (Reed 1988, Atkinson et al. 1993) of the plants within each site using formula 4 shown in the Appendix

Finally, we calculated the total IV of annuals, perennials, and facultative annuals to compare with proposed models of primary succession (van der Valk 1981, Noon 1996, DeBerry and Perry 2004, in press).

Comparison Between Typha and Non-Typha Associations

Species Identification

To identify species of *Typha* present in each created wetland, we collected a minimum of 20 plant samples from each of the four sites; a sample was defined as a whole plant, cut off at soil surface, with a mature flowering head. At each site, we sampled across the range of visible

morphological variability; therefore, we took more samples at sites that appeared more morphologically diverse. For each sample, we measured plant height, leaf width, male flower length, female flower length, and length of “gap” (the space between the male and female flowers). We also noted whether leaves exceeded the inflorescence in each sample. These characteristics were chosen as they are the main characteristics used in botanical keys for the genus (see Fernald 1950, Radford et al. 1968, Wofford 1989, Gleason and Cronquist 1991, Weakley 2002); specifically, we followed the characteristics described in Weakley (2002). We used a Trimble GeoExplorer 3 portable Global Positioning System (GPS) unit (set to record horizontal positional accuracy between 0.5 and 3 meters) to collect data on the boundary coordinates for Sandy Bottom and Suffolk Bypass, as well as the boundaries of *Typha* assemblages within these sites. These data were incorporated into GIS mapping software (ArcGIS 9) to delineate a baseline from which to track future *Typha* growth.

Comparison of Typha Associations

To compare *Typha* dominance within and between our 4 study sites, we first identified and delineated 2 geographically close areas or “Associations” with similar water depth at each site. One Association was dominated by *Typha* spp. (designated “Typha”) and the other by wetland species other than *Typha* (designated “Non-Typha”). For clarity in this report, we italicize “*Typha*” only when referring to the species itself and not when referring to Associations designated as study areas. Dominance was determined visually as 20% aerial cover (Environmental Laboratory 1987). There were no vegetated sites at Sandy Bottom that contained less than 20% *Typha*. Therefore, transects of Non-Typha Associations were established in sites where *Typha* had an IV of less than 25%. No attempt was made to identify individual *Typha* plants to the species level in this study since our work on field identification of *Typha* species relationships indicated that such distinctions are impractical to make in the field (see Results – *Typha* spp. *Morphological Findings*).

A baseline transect, a minimum of 30m long, was established in the center of each site. All subsequent sampling within an assemblage (including the hydrologic, soil, and water quality sampling described later) was done at three stratified-random distances along transects. A random number was chosen from 1 to 10 m, 11 to 20 m, and 21 to 30 m and established along the baseline. A second random number was generated from 0 to 10 m to determine distance from the baseline. A third random number was used to determine the direction of the data plot from the baseline: odd numbers meant to the left of the transect and even numbers to the right.

IVs, species richness, evenness (J'), Shannon Diversity Index (H'), Ellenberg Community Coefficient Similarity Index (SI_E), Weighted average, and was calculated and used to compare the similarity of the plant communities both between stands within a site and between stands at different sites (Appendix, Formula 3) were calculated using the same methods as for the total vegetation analysis.

Cattail Dominance and Bald Cypress Growth

Preliminary data were collected to examine the effect of *Typha* spp. dominance on growth of planted *Taxodium distichum* (bald cypress) in the Southwest Suffolk Bypass created

wetland. Two parallel transects were randomly located along a baseline (existing gravel road) in the wetland. Ninety-one bald cypress saplings were randomly sampled along each transect. One meter circular plots were centered on each sapling and percent cattail cover in each plot was measured. Tree morphometrics (basal diameter, height, average canopy diameter) measured for each sapling (Bailey et al. 2007). Cattail dominance was defined as any circular plot with a cattail cover greater than or equal to 20% (Environmental Laboratory 1987). Morphometrics between cattail dominated (n=21) and non-dominated (n=20) plots were compared using a 1-way analysis of variance (ANOVA) in the Statistical Package of the Social Science.

Hydrology of Typha and Non-Typha Associations

Monthly measurements of water depth were collected in June-October 2006 at three of the study sites (Courtland East and West and Suffolk Bypass) as well as in April-September 2007 at all four sites. Water depth was determined as the average of three locations within each randomly placed 1m² vegetation quadrat in both Typha and Non-Typha Associations. Typha and Non-Typha Association hydrographs were compared for each site using Repeated Measures ANOVA.

To study the effects of cattails on *T. distichum* growth, we collected a one-time measurement of water depth from each of the 91 sample plots. For saturated plots, depth was measured to the water table (negative number) in three small holes (5 cm diameter) and averaged. For standing water, three measurements were taken from soil to water surface and measured.

Soil Properties of Typha and Non-Typha Associations

Monthly samples of the top 10 cm of soil within three 1 m² quadrats were collected from June-October 2006 at three sites (Courtland East and West and Suffolk Bypass) as well as in April-September 2007 at all four sites. Sampling could not be done at Sandy Bottom site in 2006 due to ongoing construction. Soil samples were refrigerated and then freeze dried or dried in a Fisher Scientific Isotemp drying oven at 80°C. They were subsequently ground by mortar and pestle, homogenized, and passed through a 2mm sieve to determine silt/sand/clay content. A subsample of each was weighed, combusted in a Fisher Scientific Muffle Furnace, and weighed again to determine ash free dry mass (AFDM). We analyzed a second subsample for acid extractable phosphorus by conducting an 18 hour 1 N HCl extraction at room temperature (Solorzano and Sharp 1980). A third subsample, taken to determine soil total phosphorus, was combusted and extracted in 1 N HCl following the same procedure as for acid extractable phosphorus. Phosphate concentration in both soil subsamples were quantified using ascorbic acid colorimetric phosphate determination (Parsons et al. 1984). The difference between soil total phosphorus and acid extractable phosphorus was the organic phosphorus soil fraction. Finally, we measured total nitrogen and total carbon in the soil samples using the Perkin-Elmer CHN 2400 Series II Elemental Analyzer.

Repeated measures of analysis of variance (SPSS, Inc. 2007) were used to calculate differences between the values for soil organic matter, total carbon, total nitrogen, acid

extractable phosphorus, total phosphorus, and organic phosphorus in Typha and Non-Typha Associations within a given site.

Porewater Analysis of Typha and Non-Typha Associations

Porewater samples were collected from both Typha and Non-Typha Associations at all sites in April, June, and August 2007. We placed two diffusion samplers (peepers) at random locations in the soil in both Association types to measure porewater nutrient concentrations. The diffusion samplers were allowed to equilibrate for a minimum of 3 weeks before removal and collection of water samples. Samples from the first two wells in each row were filtered through a 0.45 µm filter. Samples were then preserved with 0.5mL 1N HCl and stored in the refrigerator for no more than 3 weeks until phosphate and ammonium analyses were conducted. Porewater pH was measured in the field from water in the third well using a hand-held Beckman Instruments model #123133 pH meter.

Porewater samples were analyzed for dissolved inorganic phosphate (DIP) using the ascorbic acid colorimetric phosphate determination (Parsons et al. 1984). Concentration of total dissolved phosphorus was estimated by evaporating 10mL of the filtered samples and combusting the evaporate in a Fisher Scientific Isotemp Muffle Furnace at 400°C for three hours. The combusted evaporate was then resuspended in 5mL of 0.2 N HCl, capped, and extracted for 1 hour at 80°C. The samples were then diluted and phosphate concentrations determined by ascorbic acid colorimetric determination. Porewater ammonium was quantified using a sodium citrate colorimetric determination (Parsons et al. 1984).

RESULTS

Relative Stand Dominance – Overall Vegetation

We collected 155 species from the herbaceous stratum of the 20 created wetland sites. There were nine overall dominants (overall relative IV in parentheses): *Juncus effusus* (10.4), *Scirpus cyperinus* (7.6), *Ludwigia palustris* (6.4), *Eleocharis obtusa* (5.3), *Polygonum hydropiperoides* (4.9), *Murdannia keisak* (4.1), *Microstegium vimineum* (4.0), *Galium tinctorium* (3.8), and *Panicum dichotomiflorum* (3.6). Shrubs common in herbaceous stratum included: *Salix nigra*, *Acer rubrum*, *Liquidambar styraciflua*, and *Betula nigra*.

There were 11 county records, including two Virginia state records: *Cuphea carthagenensis* and *Ludwigia bonariensis* (both from the Southwest Suffolk site) (Virginia Botanical Associates 2005, DeBerry and Perry 2007). In addition, we found a new population of *Aeschynomene indica* in Southampton County (Franklin Bypass), previously reported as a state record in 1998 on a nearby site (Perry et al. 1998). This new location is significant because the previous site, a portion of the Franklin Bypass mitigation area north of U.S. Route 58, has recently been impacted by beaver activity, and therefore the population reported in 1998 has most likely been extirpated due to excessive beaver activity.

Vegetation Analysis of *Typha* and Non-*Typha* Associations

Morphological Findings *Typha* spp.

Examination of the morphological characteristics of the *Typha* samples revealed a broad continuum of variation in morphology. We found multiple *Typha* species in each of the sites studied (Courtland, Suffolk Bypass, and Sandy Bottom). The created wetland at Courtland appeared to have *T. latifolia* and either *T. angustifolia* or *T. domingensis*, or both. At Suffolk Bypass, we observed *T. latifolia* and *T. angustifolia*, and one plant of the hybrid *T. x glauca*. Samples from the Sandy Bottom site were identified as *T. x glauca* and *T. latifolia*.

Samples from both Courtland sites demonstrated expected variation in morphology according to Weakley (2002). There was a strong division in the length of the gap between male and female flowers in species with 1-celled (found in *T. angustifolia* and *T. glauca*) as opposed to 4-celled pollen (found in and *T. domingensis* and *T. latifolia*); those plants with 4-celled pollen had no gap, while those with 1-celled pollen had gaps ranging from 4.0 to 4.5 cm. In addition, only the plants with 1-celled pollen had bracts. While the presence of leaves above the inflorescence varied, the heights of the male flowers and those of the female flowers were similar for all samples. Male flower length ranged from 9.5 to 13.0 cm for plants with 1-celled pollen and from 10.5 to 12.0 cm for plants with 4-celled pollen. Female flower length ranged from 5.5 to 21.0 cm for plants with 1-celled pollen, and all flowers were 11.0 cm in samples with 4-celled pollen. Overall plant height ranged from 138.5 to 169.0 cm for plants with 1-celled pollen, and from 149.0 to 179.0 cm for plants with 4-celled pollen. Table 2 depicts the morphological data collected from Courtland in 2007.

Table 2. *Typha* spp. morphology data. Samples collected from Courtland on July 2, 2007.

Sample	Plant height (cm)	Length of gap (cm)	Male flower (cm)	Female flower (cm)	Pollen (# cells)	Bracts	Leaves above inflorescence
1	154	4	9.5	5.5	1	yes	Yes
2	169	4.25	13	21	1	yes	No
3	138.5	4	11	14	1	yes	No
4	156	4.5	9.5	11	1	yes	No
5	149	0	10.5	11	4	no	Yes
6	179	0	12	11	4	no	Yes
Mean	157.6	2.8	10.9	12.3			

Samples from Suffolk Bypass did not demonstrate as clearly defined morphologies as those from Courtland. The length of gap between the male and female flowers ranged from 0 to 4.0 cm. In addition, one sample had bracts while the other three did not. All plants had leaves above the inflorescence. Plant height ranged from 185.0 to 258.0 cm, and all samples collected had 4-celled pollen. Male flower length ranged from 10.5 to 20.0 cm, while female flower length ranged from 10.5 to 24.0 cm. Table 3 depicts the morphological data collected from Suffolk Bypass in 2007.

Table 3. *Typha* spp. morphology data. Samples collected from Suffolk Bypass on July 2, 2007.

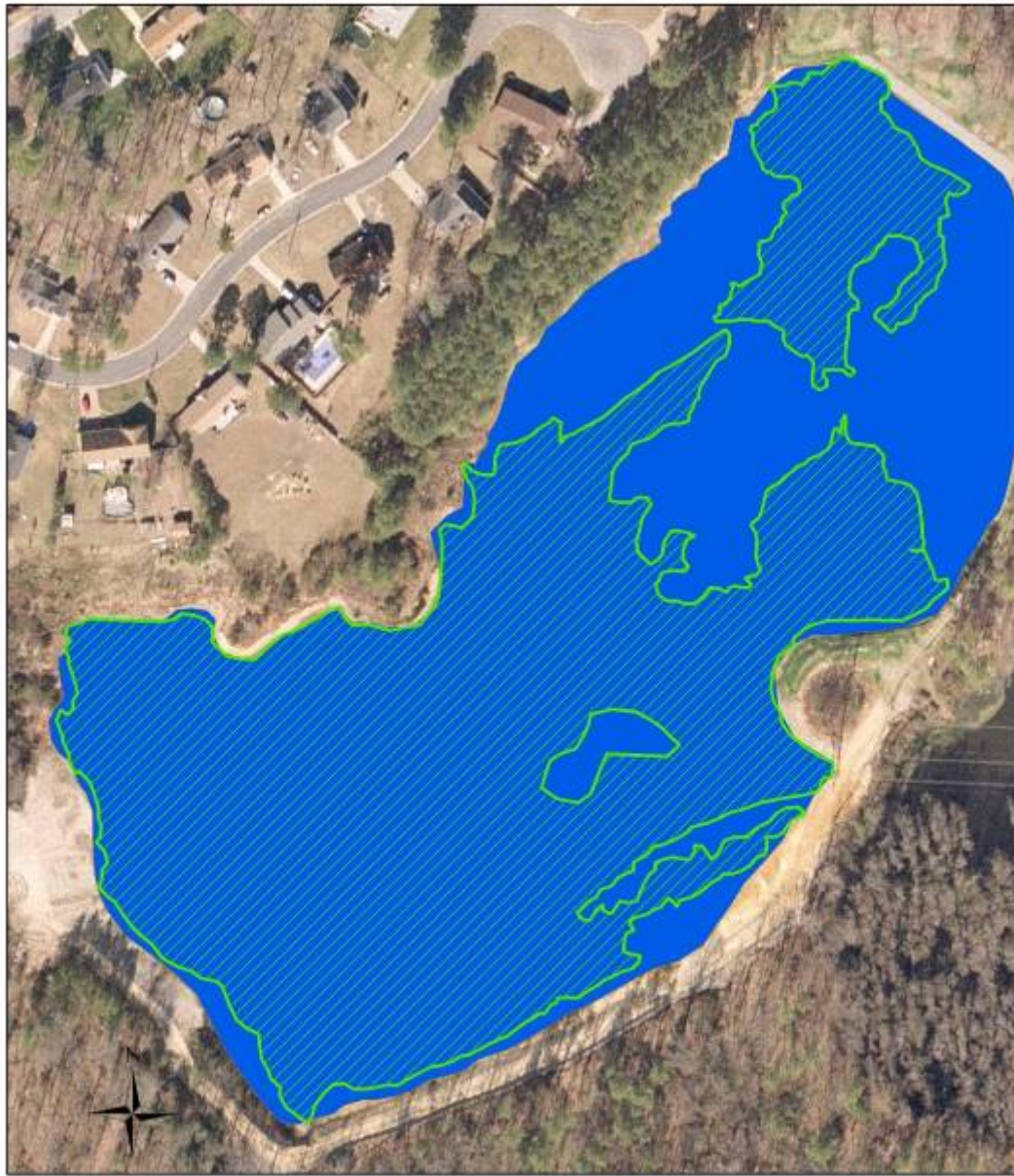
Sample	Plant height (cm)	Length of gap (cm)	Male flower (cm)	Female flower (cm)	Pollen (# cells)	Bracts	Leaves above inflorescence
1	191	2	10.5	14	4 celled	no	Yes
2	185	0	10.5	10.5	4celled	no	Yes
3	191	4	17	15	4celled	no	Yes
4	258	1.25	20	24	4celled	yes	Yes
Mean	206.3	1.8	14.5	15.9			

In summary, it was evident that there was a large range in morphological characteristics for plants classified as *T. latifolia* and *T. angustifolia*; this made it impossible to distinguish individual species present in the wetland using only morphological characteristics observable in the field.

In addition, we delineated and mapped the boundaries of the Suffolk Bypass (Figure 4) and Sandy Bottom (Figure 5) sites, as well as the extent of *Typha* coverage within them. These maps can be used as a baseline for future studies of *Typha* growth in these created wetlands.

Comparison between *Typha* and Non-*Typha* Plant Associations

Our comparative study of *Typha* and Non-*Typha* plant Associations in the four created wetlands found that other species besides *Typha* were co-dominant within the *Typha* Associations in three of the four sites (except Sandy Bottom); in other words, despite dense *Typha* growth the vegetation communities within these stands were not *Typha* monocultures. In fact, while two *Typha* Associations had less dominant species (i.e., fewer species included in the top 50% of IV) than their respective Non-*Typha* Associations, one site had an equal number and one had more. When we calculated importance values for each species, we found that the total importance value of all perennial species in each site was higher in *Typha* than in Non-*Typha* Associations at all four sites. Perennial species also had higher importance values in both types of stands at the older sites (Courtland East and West) as compared to the younger sites (Suffolk Bypass and Sandy Bottom). Table 4 lists the dominant species and their importance values for each stand type within all four study sites.



0 5 10 20 30 40 Meters

Legend



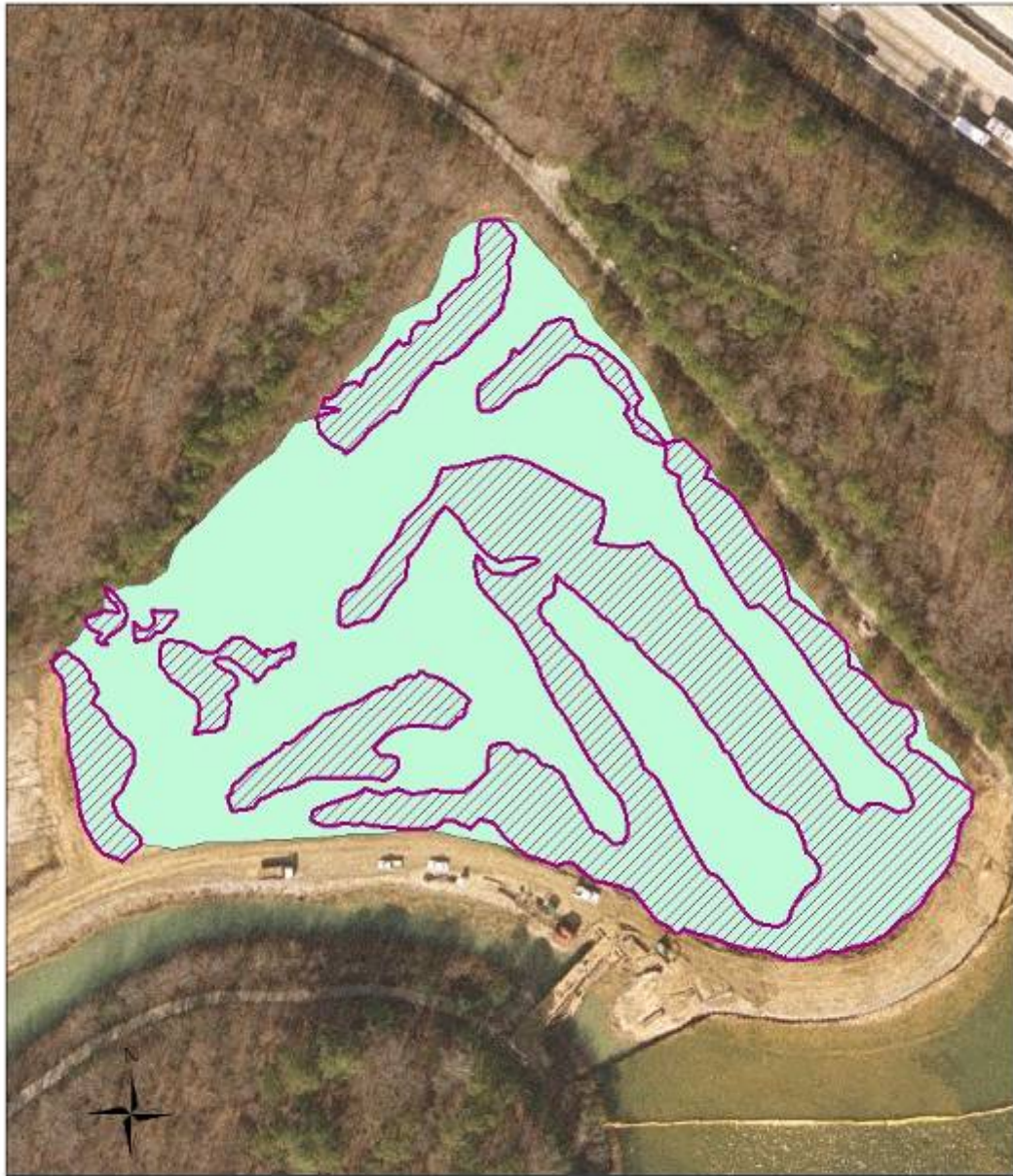
-  Suffolk Mitigation Site Study Area
-  Typha Stands (Greater Than 20% Cover)

Figure 4. Aerial photo of Suffolk Bypass mitigation site. The study area appears in blue/dark gray, while areas of >20% *Typha* cover (as of 2006) are cross-hatched.



0 5 10 20 30 40 Meters

Legend



-  Typha Stands (Greater than 20% Cover)
-  Sandy Bottom Mitigation Site Study Area

Figure 5. Aerial photo of Sandy Bottom mitigation site. The study area appears in light green/light gray, while areas of >20% *Typha* cover (as of 2006) are cross-hatched.

Table 4. Dominant species and relative importance values (IV), determined by the 50/20 Rule (Environmental Lab 1987).

	<i>Typha</i> Associations	Non-<i>Typha</i> Associations
Courtland West	<i>Hydrocotyle umbellata</i> (IV 24.59) <i>Typha</i> (IV 24.23)	<i>Hydrocotyle umbellata</i> (IV 16.79) <i>Scirpus cyperinus</i> (IV 13.58) <i>Juncus effusus</i> (IV 10.34) <i>Leersia oryzoides</i> (IV 7.34)
Courtland East	<i>Typha</i> (IV 59.17) <i>Pontedaria cordata</i> (IV 20.93)	<i>Pontedaria cordata</i> (IV 36.71) <i>Peltandra virginica</i> (IV 21.48)
Suffolk Bypass	<i>Typha</i> (IV 39.59) <i>Juncus effusus</i> (IV 23.98)	<i>Juncus effusus</i> (IV 50.96)
Sandy Bottom	<i>Typha</i> (IV 58.87)	<i>Typha</i> (IV 24.90)* <i>Juncus acuminatus</i> (IV 14.93) <i>Eleocharis obtusa</i> (IV 14.59)

* When original plot was chosen it did not have large amount of *Typha*. However, the *Typha* population had expanded significantly at the time vegetation was sampled.

The vegetation communities of all of the *Typha* and Non-*Typha* plant Associations were composed primarily of hydrophytes; i.e., facultative and wetter species composed more than 80% of the total relative importance value within each Association. Most were dominated by obligate and facultative wet species. There was no significant difference in the portion of wetland indicator species or in their indicator status between *Typha* and Non-*Typha* Associations at any research site (Table 5). Mean weighted average values (WA) (calculated based on weighting the wetland indicator index by IV, see the Appendix, Formula 4) fall between 1 and 1.5, indicating that the sites were dominated by obligate (OBL) and facultative wet (FACW) species, indicating that the plant Associations used for this study were on the wet end of the hydrology continuum.

Table 5. Summary of total number of species observed, mean (± 1 SE) relative importance value (IV) of all wetland indicator species (OBL, FACW, and FAC) for each stand, and mean (± 1 SE) weighted average over 2007 growing season (April to September).

	Courtland East		Courtland West		Suffolk Bypass		Sandy Bottom	
	<i>Typha</i>	Non- <i>Typha</i>	<i>Typha</i>	Non- <i>Typha</i>	<i>Typha</i>	Non- <i>Typha</i>	<i>Typha</i>	Non- <i>Typha</i>
Total Species observed	11	18	17	31	16	17	7	10
Total IV of OBL, FACW, and FAC species	91.61 ± 4.27	98.19 ± 1.81	88.96 ± 2.34	91.56 ± 2.78	81.15 ± 4.46	90.26 ± 3.44	94.28 ± 5.72	100.00 ± 0
Weighted Average	1.02 ± 0.020	1.02 ± 0.011	1.22 ± 0.029	1.07 ± 0.022	1.05 ± 0.019	1.03 ± 0.037	1.00 ± 0	1.00 ± 0

In two of the four research sites, *Typha* Associations had significantly higher peak season aboveground standing crop biomass, while in two sites there was no significant difference (Suffolk Bypass and Courtland West). In the sites where there was no difference, Non-*Typha* Associations were dominated by species of emergent perennials (such as *Juncus effusus* and *Scirpus cyperinus*). These species are known to produce a large amount of both above- and belowground biomass. Figure 6 shows values for peak season standing crop biomass for both Associations types at all sites in 2007.

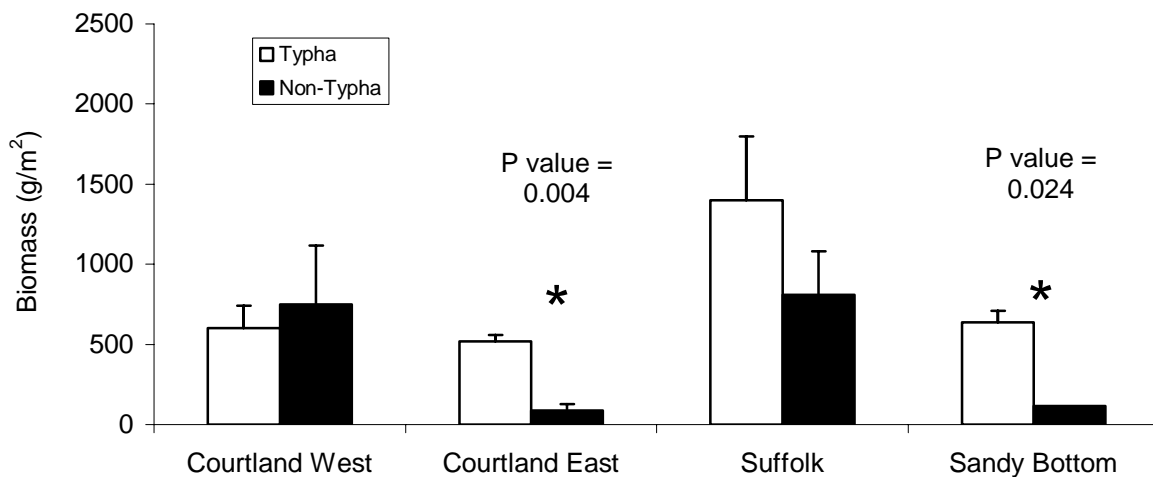


Figure 6. Mean (± 1 SE) peak season standing stock aboveground biomass, 2007. * indicates significant difference between *Typha* and Non-*Typha* Associations at the same site.

There was no clear trend in either species richness or diversity between *Typha* and Non-*Typha* Associations. In Courtland West, we observed significantly higher species richness in Non-*Typha* Associations. However, there was no significant difference or general trend in species richness at the other three research sites. Interestingly, Courtland West had significantly higher diversity in *Typha* Associations as compared to Non-*Typha* Associations. In Courtland East and Sandy Bottom the opposite was observed; these sites demonstrated significantly higher diversity in Non-*Typha* Associations. At Suffolk, there was no significant difference in diversity

between stand types. These data indicate that evenness, rather than richness, played a larger role in determining diversity in the different stand types at three of the four sites. At Courtland West, a higher diversity measurement in Typha Associations indicates that species were more evenly distributed, despite species richness being lower than in Non-Typha Associations. In Courtland East and Sandy Bottom, the significantly higher diversity in Non-Typha Associations can also be attributed to evenness, as there was no significant difference in richness between the two stand types (Tables 6 and 7).

Table 6. Mean species richness (SR) (± 1 SE) including results of statistical analysis of difference between Typha and Non-Typha Associations. * indicates significant difference in SR between stands at a given site, as indicated by t-test ($\alpha = 0.05$).

Sites	<i>Typha</i> Association Species Richness (SR)	Non- <i>Typha</i> Association Species Richness (SR)
Courtland West* P value = 0.035	5.67 \pm 0.45	7.11 \pm 0.48
Courtland East	3.22 \pm 0.33	4.17 \pm 0.57
Suffolk	4.06 \pm 0.36	3.50 \pm 0.25
Sandy Bottom	2.22 \pm 0.19	2.28 \pm 0.19

Table 7. Shannon diversity index (H'), including results of statistical analysis of difference between Typha and Non-Typha Associations. * indicates significant difference in H' between stands at a given site, as indicated by Hutcheson's modified t-test ($\alpha = 0.05$).

Sites	<i>Typha</i> Association Shannon Diversity (H')	Non- <i>Typha</i> Association Shannon Diversity (H')
Courtland West* P value < 0.001	2.28	0.38
Courtland East* P value < 0.001	1.33	2.15
Suffolk	1.91	1.87
Sandy Bottom* P value < 0.001	1.28	2.14

Similarity calculations indicated that the vegetation communities of Typha and Non-Typha Associations within a site were more strongly similar than those of Typha or Non-Typha Associations at different sites (Table 8). This indicates that the vegetation in two Typha Associations at different sites was less similar than the vegetation present in Typha and Non-Typha Associations at the same site; although different vegetation can dominate across a single site, there is still homogeneity of the plant communities within a site. This finding suggests that vegetation communities should be evaluated on a site-by-site basis.

Table 8. Matrix of Ellenberg Community Coefficient Similarity Index (SI_E) values calculated from mean relative IV of species over 2007 growing season (April-September). * indicates stand between the sites are similar (SI_E > 0.50), boxes enclose similarity values for comparisons across sites. CE=Courtland East, CW=Courtland West, SF=Suffolk Bypass, SB=Sandy Bottom.

SB	Typha	0.79*						
		SB		SF		CW		CE
		Non-Typha	Typha	Non-Typha	Typha	Non-Typha	Typha	Non-Typha
CE	Typha	0.37	0.46	0.45	0.47	0.36	0.44	0.77*
	Non-Typha	0.12	0.29	0.19	0.24	0.39	0.41	
CW	Typha	0.20	0.28	0.45	0.47	0.82*		
	Non-Typha	0.29	0.28	0.48	0.51*			
SF	Typha	0.41	0.36	0.82*				
	Non-Typha	0.39	0.21					

Cattail Dominance and Bald Cypress Growth

In our study of cattails and *T. distichum* growth at Suffolk Bypass, we found no significant difference in *Taxodium distichum* (bald cypress) growth in Typha and Non-Typha Associations. There were no significant differences in tree height, diameter above buttress, diameter at breast height, or canopy diameter in Typha and Non-Typha Associations. Table 9 lists the average tree height and median measurements of the remaining three parameters for both *Typha* dominated and non-dominated Associations. Linear regressions comparing tree morphology parameters to water depth indicated that average tree height ($R = -0.26$, $P = 0.015$) and average canopy diameter ($R = -0.26$, $P = 0.01$) were negatively influenced by increasing water depth. The results of a 2 way ANOVA showed no significant difference in how *Typha* changed with depth, when comparing the percent water content of soils and water depth in cattail dominated and non-dominated assemblages.

Table 9. *Taxodium distichum* morphology data collected at Suffolk Bypass in 2006. Values for *Typha* dominated (D, n=21) and non-dominated (ND, n=20) plots are shown. The mean (± 1 SD) was calculated for tree height; all other values are medians (± 1 CI, 25%). The P-value results from t-tests comparing D and ND are also shown.

	D	Error	ND	Error	P-value
Tree height (cm)	180.476	+/- 45.102	172.95	+/- 38.563	0.57
Diameter breast height (cm)	0.6	+0.675, -0.425	0.75	+0.55, -0.45	0.77
Canopy diameter (cm)	63.8	+29.417, -11.217	81.75	+26.533, -29.3	0.58
Diameter above buttress (cm)	3.4	+0.75, -0.975	3.2	+1.2, -0.85	0.98

Hydrology of Typha and Non-Typha Associations

Water depth in Typha and Non-Typha Associations showed that there was a significant difference between Associations during the 2007 growing season. Three of the four sites were dry in both Typha and Non-Typha Associations during at least 1 month of the growing season. Water depths ranged from 0-33 cm at Sandy Bottom, 0-7 cm at Suffolk Bypass, 0-25 cm at Courtland East, and 14-28 cm at Courtland West Typha Associations; Non-Typha Associations exhibited ranges of 0-28 cm, 0-5 cm, 0-18 cm, and 7-14 cm respectively for each site (Table 10).

Table 10. Range of water depths in Typha and Non-Typha Associations, 2007 growing season (April to September). Soils of all stands were saturated 100% of growing season

	Typha	Non-Typha
Sandy Bottom	0 – 33 cm	0 – 28 cm
Suffolk Bypass	0 – 7 cm	0 – 5 cm
Courtland East	0 – 25 cm	0 – 18 cm
Courtland West	14 – 28 cm	7 – 14 cm

Overall, we did see that Typha Associations seemed to occur in deeper water, although there was no identifiable maximum water depth at which Non-Typha Associations occurred. Although there were periods during the growing season when the soil surface was dry, we found that the soil at all sites was consistently saturated or inundated; therefore, the sites exhibited

wetland hydrology and chemically reduced conditions throughout the growing season (Figures 7a-d).

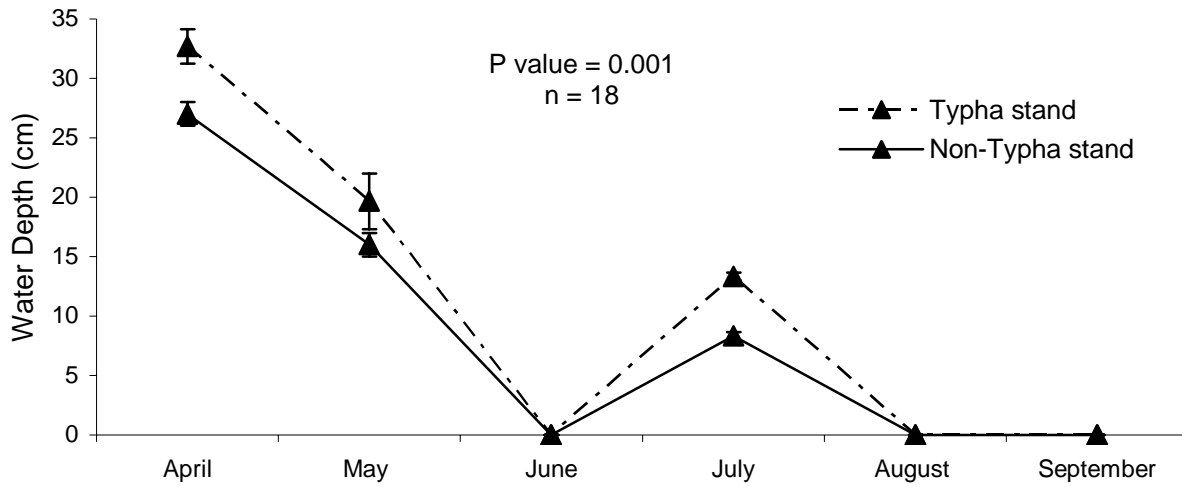


Figure 7a. Mean (± 1 SE) monthly water depth at Sandy Bottom, summer 2007 growing season (April to Sept.).

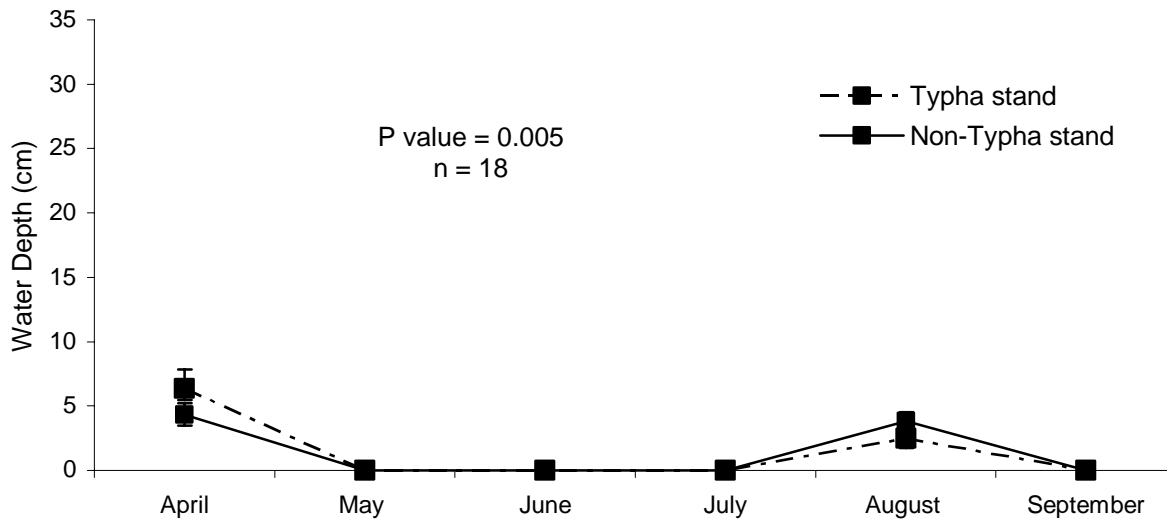


Figure 7b. Mean (± 1 SE) monthly water depth at Suffolk, summer 2007 growing season (April to Sept.).

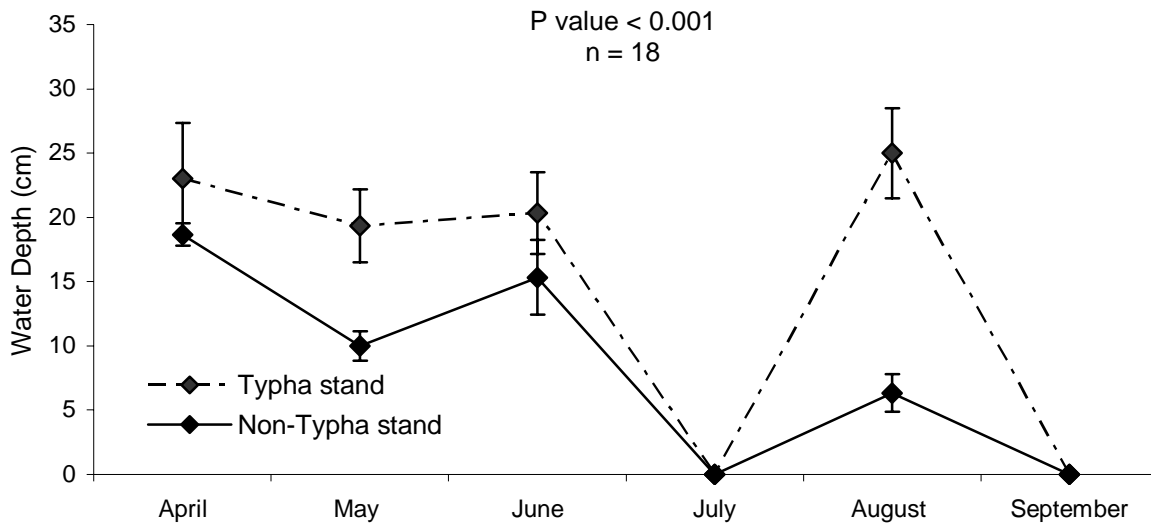


Figure 7c. Mean (± 1 SE) monthly water depth at Courtland East summer 2007 growing season (April to Sept.).

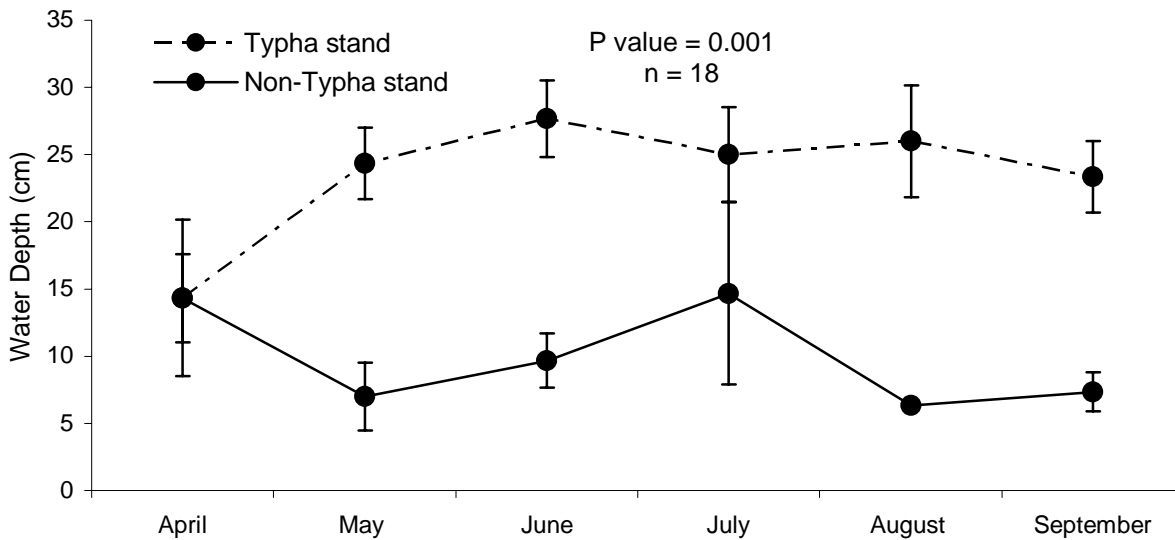


Figure 7d. Mean (± 1 SE) monthly water depth at Courtland West summer 2007 growing season (April to Sept.).

Chemical Analysis of Typha and Non-Typha Associations

Percent Organic Matter

There was no significant difference in percent soil organic matter (OM) between Typha and Non-Typha associations within any of the four study sites. However, Tukey's Honestly Significant Difference test (Zar 1999) revealed that there were significant differences between the sites. In 2006, Suffolk Bypass had significantly higher OM content than either Courtland East or Courtland West. While the differences were not significant in 2007, Suffolk Bypass again appeared to have higher percent organic matter content (Figures 8a-c, 9a-d).

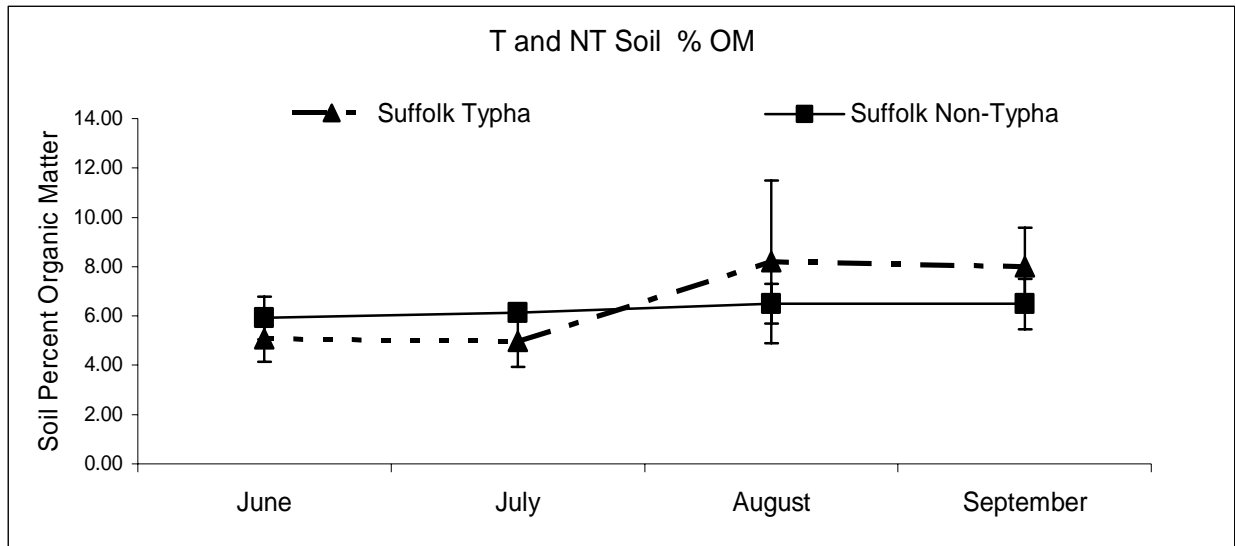


Figure 8a. Mean (± 1 SE) percent soil organic matter in Typha and Non-Typha associations at Suffolk Bypass, 2006 growing season (June to Sept.).

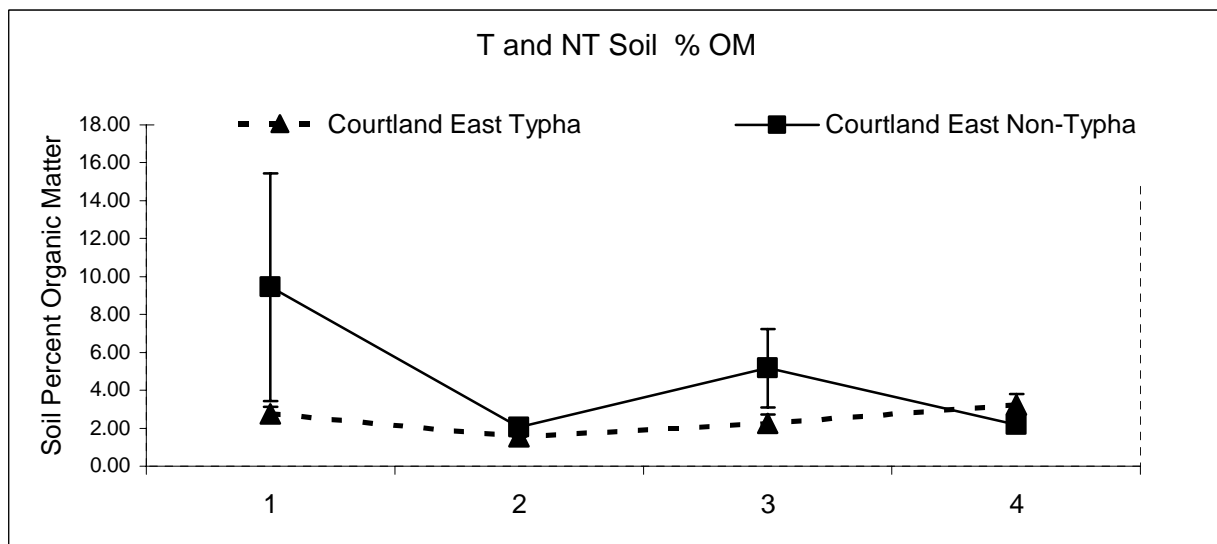


Figure 8b. Mean (± 1 SE) percent soil organic matter in Typha and Non-Typha associations, Courtland East Site, 2006 growing season (June to Sept.).

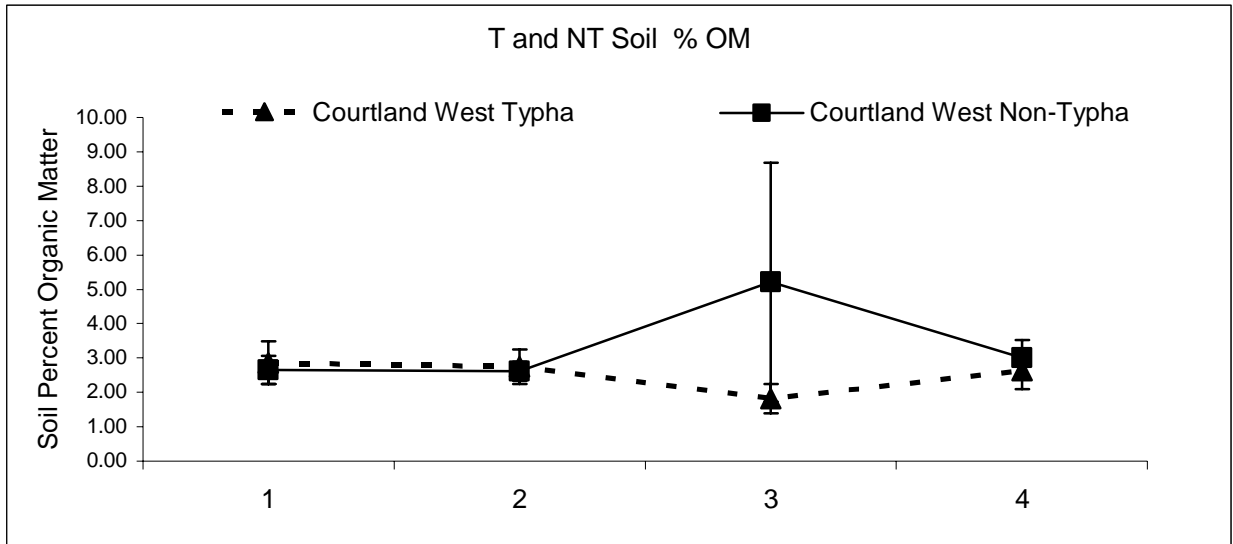


Figure 8c. Mean (± 1 SE) percent soil organic matter in Typha and Non-Typha associations, Courtland West Site, 2006 growing season (June to Sept.).

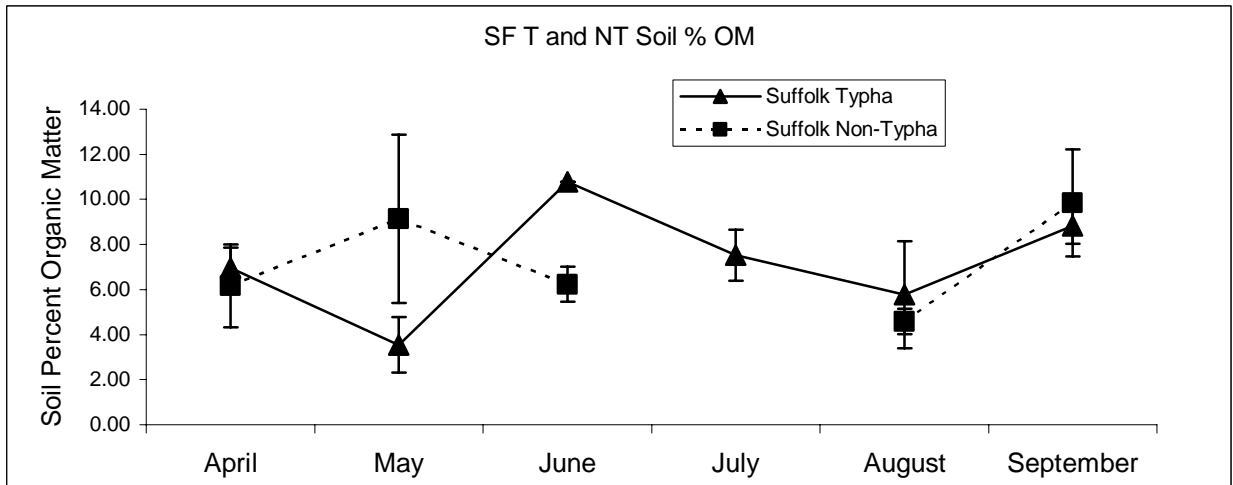


Figure 9a. Mean (± 1 SE) percent soil organic matter in Typha and Non-Typha associations, Suffolk Bypass Site, 2007 growing season (April to Sept.).

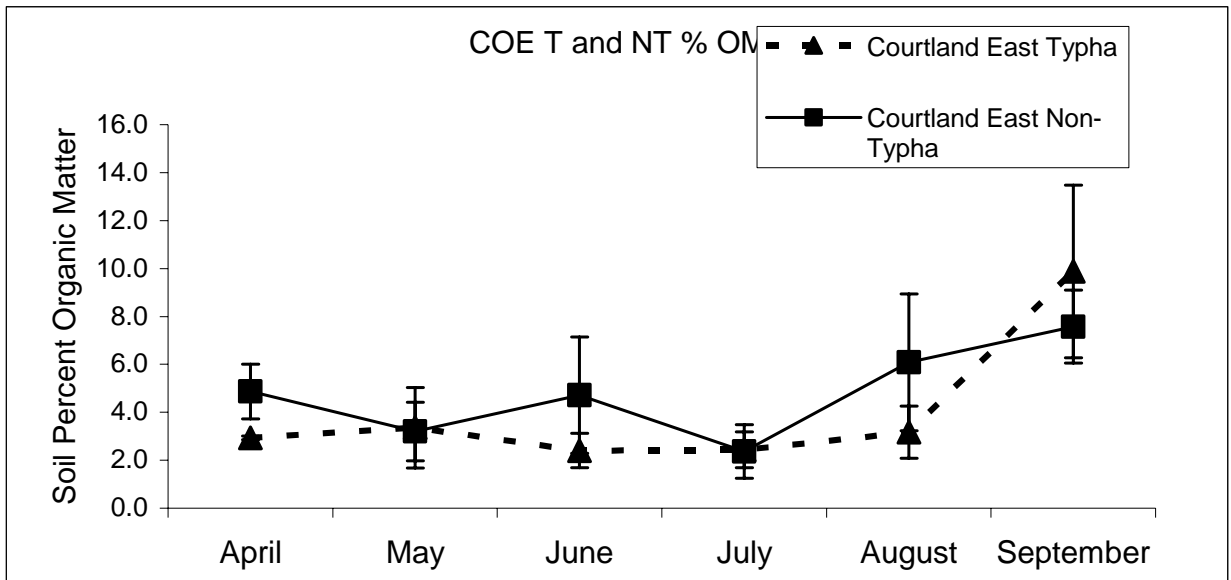


Figure 9b. Mean (± 1 SE) percent soil organic matter in Typha and Non-Typha associations, Courtland East Site, 2007 growing season (April to Sept.).

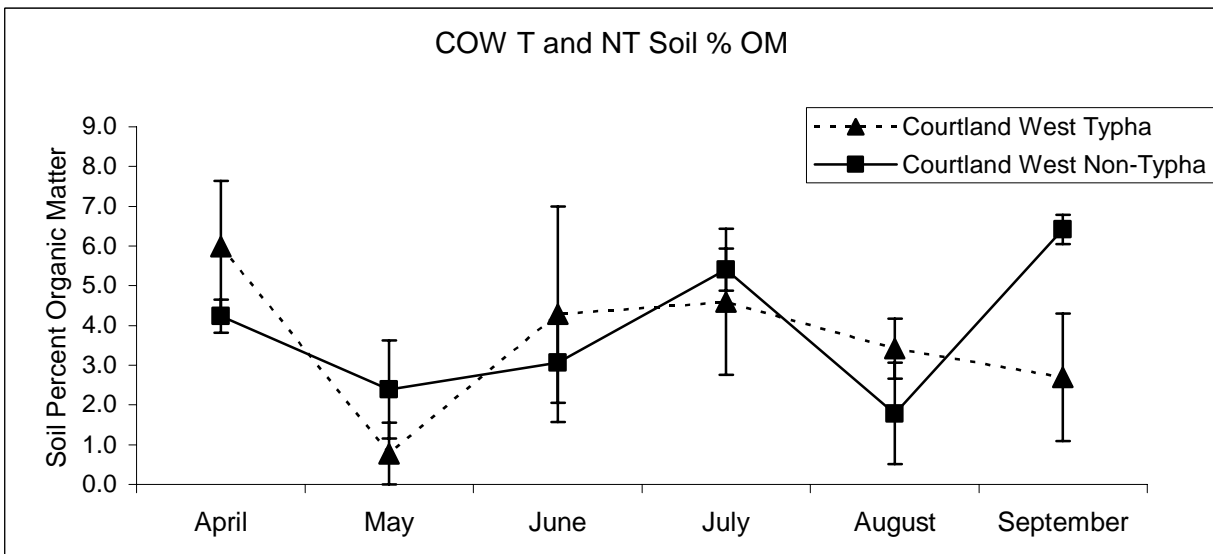


Figure 9c. Mean (± 1 SE) percent soil organic matter in Typha and Non-Typha associations, Courtland West Site, 2007 growing season (April to Sept.).

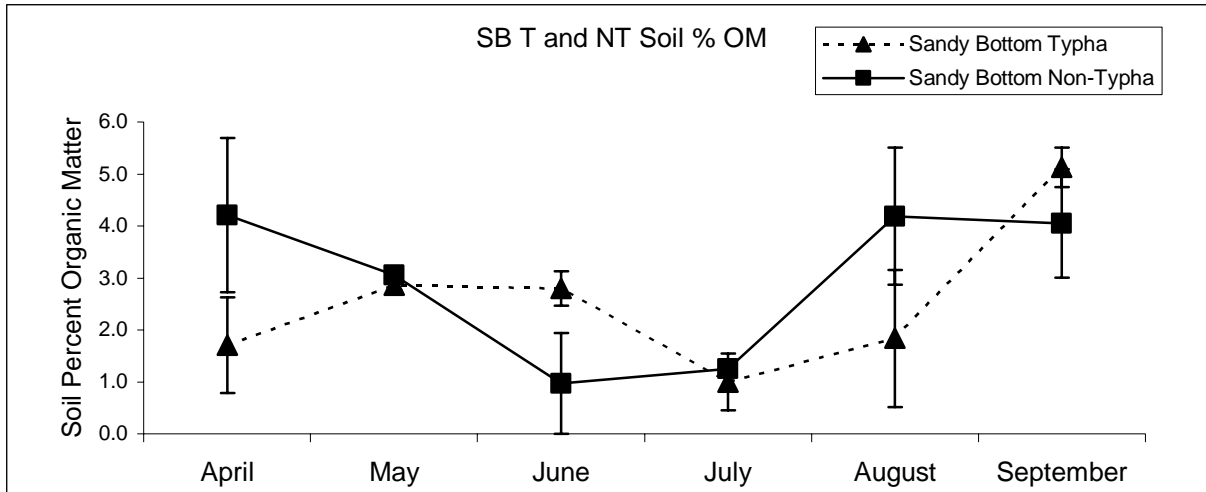


Figure 9d. Mean (± 1 SE) percent soil organic matter in Typha and Non-Typha associations, Sandy Bottom Sites, 2007 growing season (April to Sept.).

Total Carbon

There was no significant difference in total carbon between Typha and Non-Typha associations at Suffolk Bypass or Courtland East in 2006 (Figures 10a-c). However, total carbon was significantly higher in Non-Typha associations in Courtland West (note: the Sandy Bottom site was not measured in 2006). There was a significant difference between soil total carbon and the site's percent OM. Suffolk Bypass site had a significantly higher amount of total carbon. In 2007, total carbon was significantly higher in Non-Typha associations at both Suffolk Bypass and Courtland East, but we did not find any significant difference between association types at either Sandy Bottom or Courtland West (Figures 11a-d). As in 2006, the total carbon at Suffolk Bypass was significantly higher than at all other sites despite there being no significant difference in soil OM observed that year.

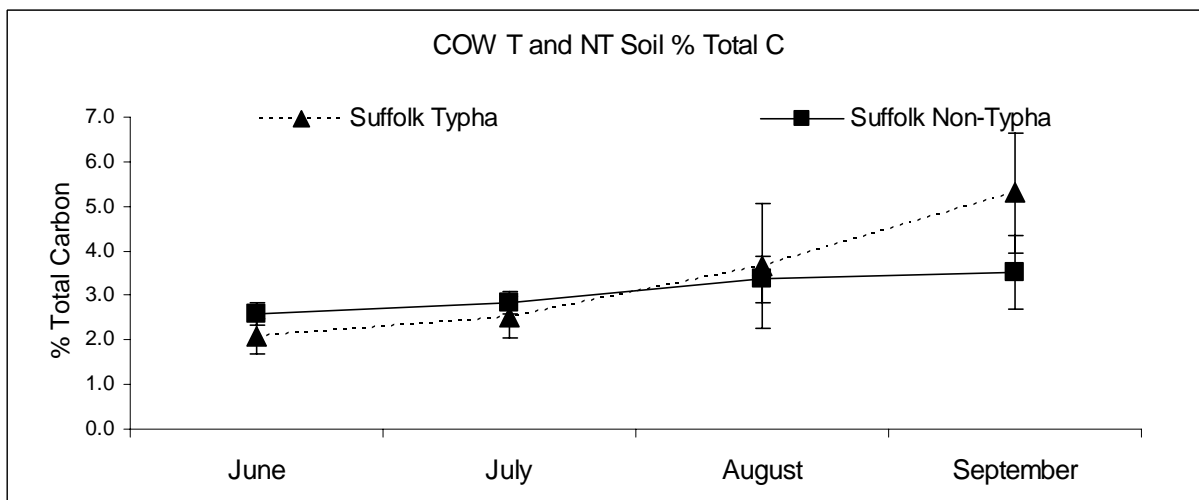


Figure 10a. Mean (± 1 SE) soil total carbon in Typha and Non-Typha associations, Suffolk Bypass Site, 2006 growing season (June to Sept.).

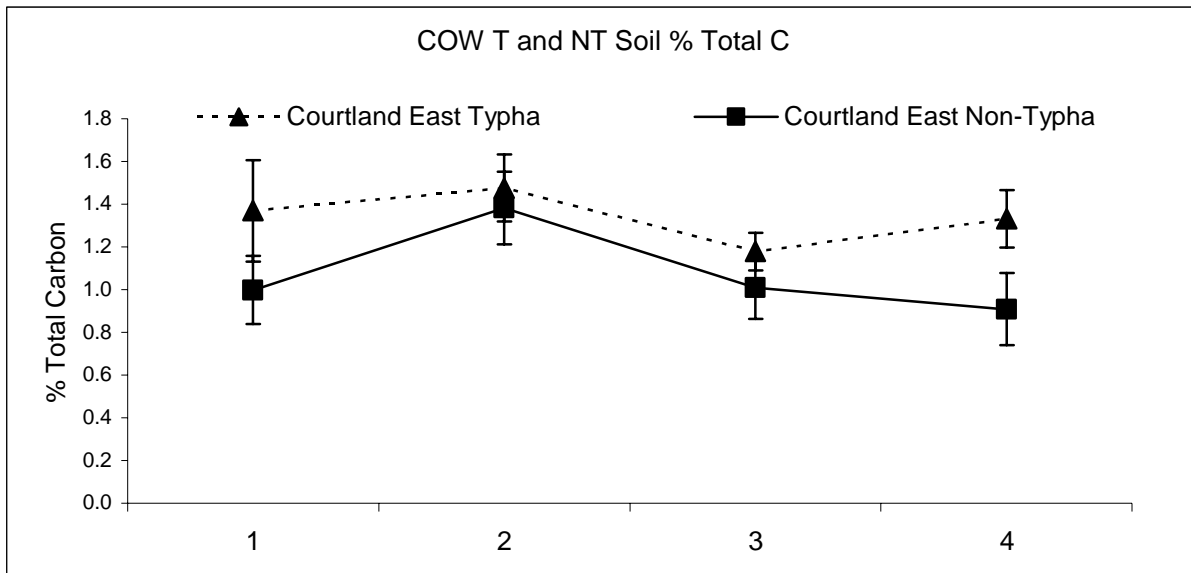


Figure 10b. Mean (± 1 SE) soil total carbon in Typha and Non-Typha associations, Courtland East Site, 2006 growing season (June to Sept.).

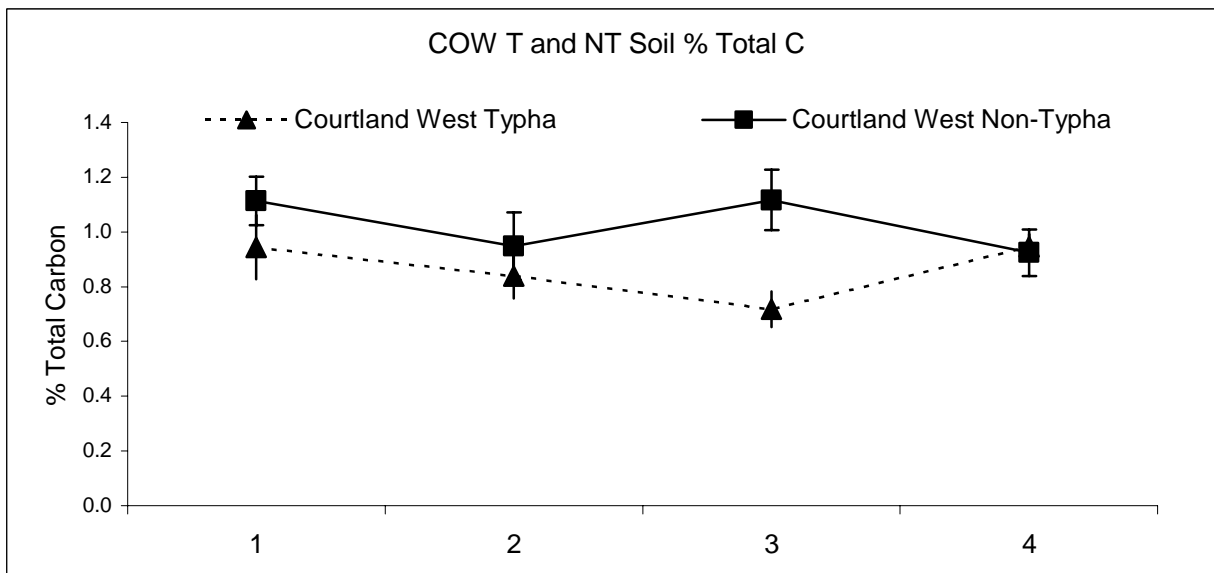


Figure 10c. Mean (± 1 SE) soil total carbon in Typha and Non-Typha associations, Courtland West Site, 2006 growing season (June to Sept.).

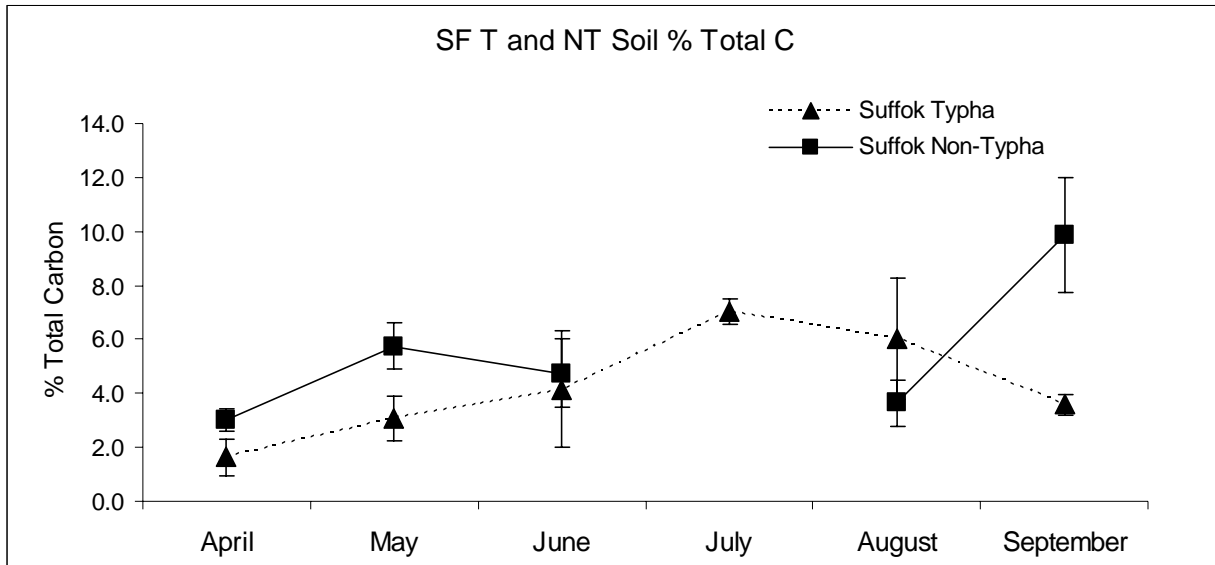


Figure 11a. Mean (± 1 SE) soil total carbon in Typha and Non-Typha associations, Suffolk Bypass Site, 2007 growing season (April to Sept.).

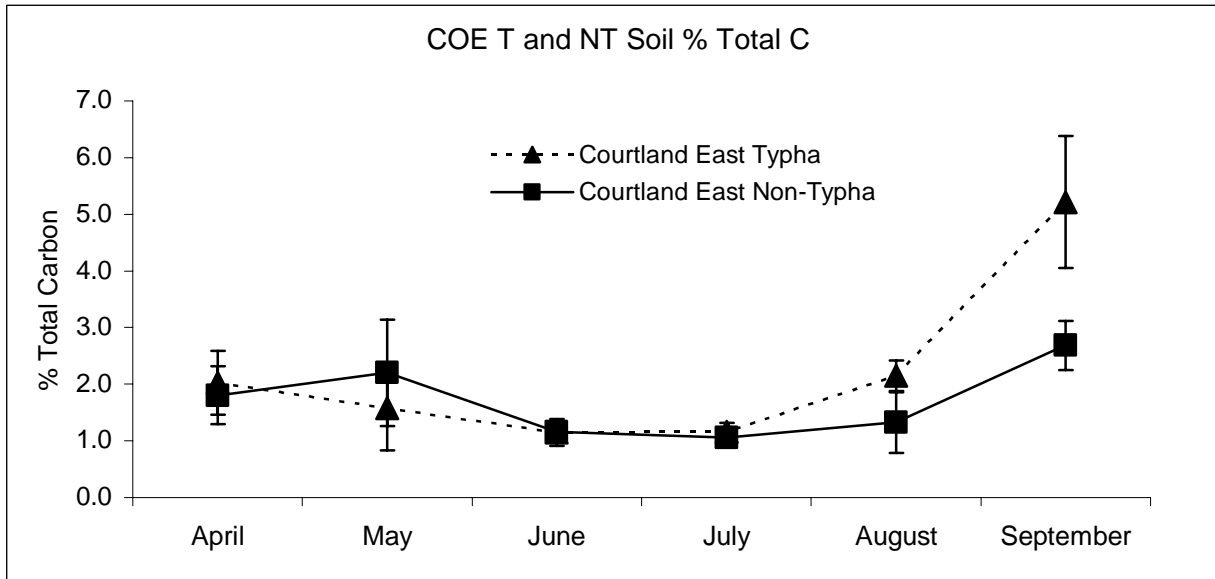


Figure 11b. Mean (± 1 SE) soil total carbon in Typha and Non-Typha associations, Courtland East Site, 2007 growing season (April to Sept.).

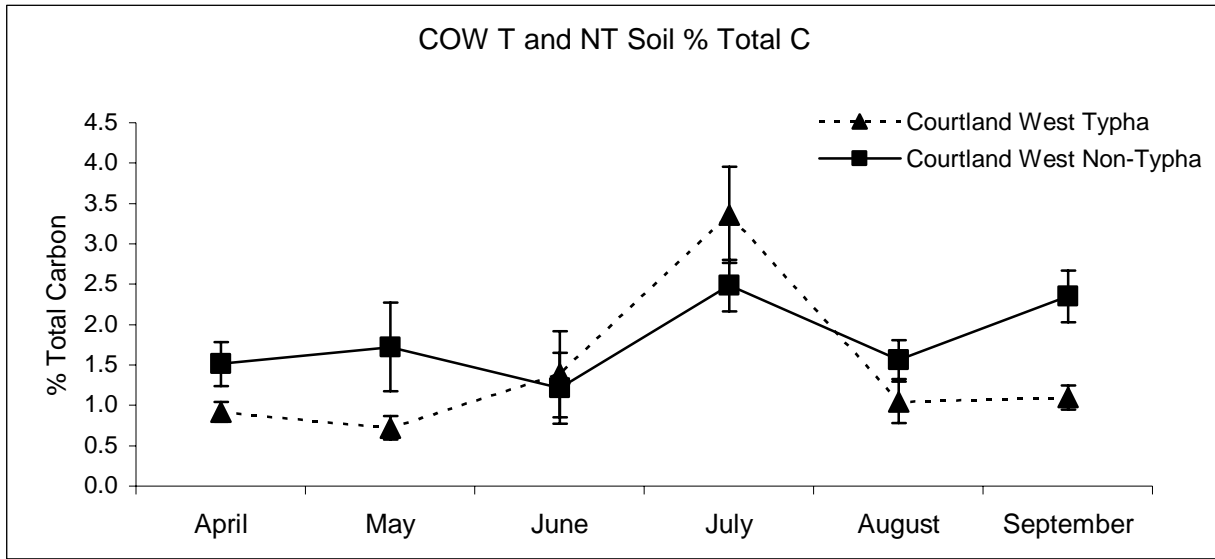


Figure 11c. Mean (\pm 1 SE) soil total carbon in Typha and Non-Typha associations, Courtland West Sites, 2007 growing season (April to Sept.).

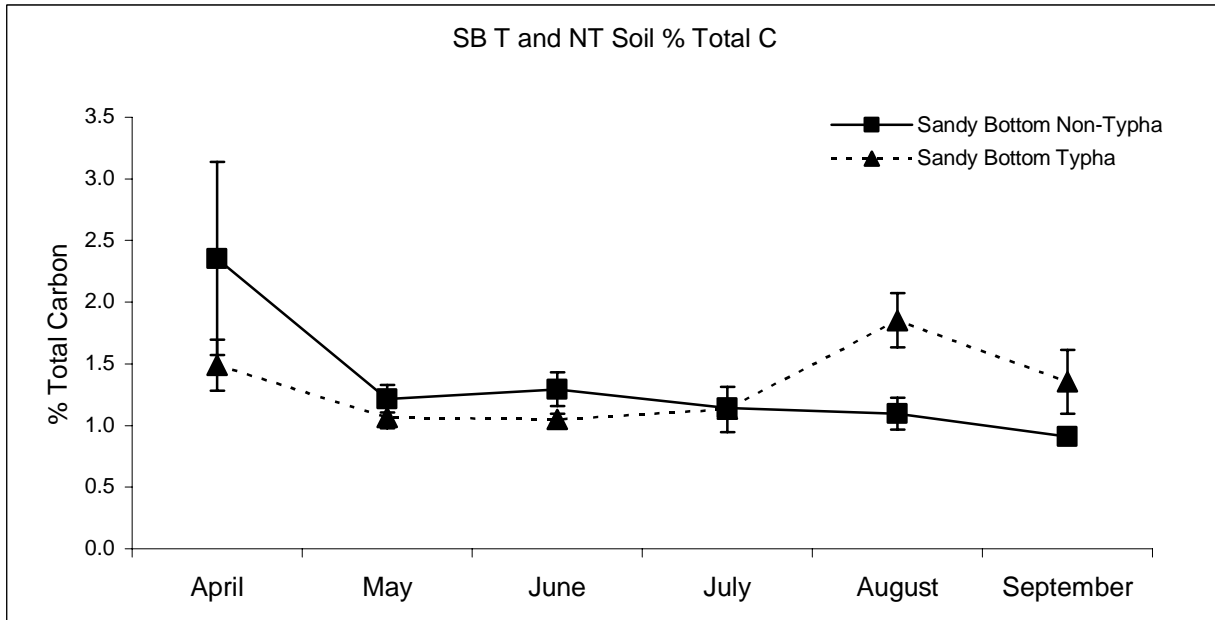


Figure 11d. Mean (\pm 1 SE) soil total carbon in Typha and Non-Typha associations, Sandy Bottom Site, 2007 growing season (April to Sept.).

Total Nitrogen

Total soil nitrogen in 2006 was significantly higher in the Typha association at Courtland West and in the Non-Typha association at Courtland East. No significant differences in total nitrogen were observed in the soil at Suffolk Bypass; this variable was not measured at Sandy

Bottom in 2006. Suffolk Bypass also had significantly higher total nitrogen in both Typha and Non-Typha associations as compared to the Courtland sites. In 2007, there was no significant difference in total nitrogen between stands at three of the sites; in Courtland West, total nitrogen was significantly higher in the Non-Typha association. Again in 2007 we observed that Suffolk Bypass had significantly higher total nitrogen compared to the other 3 created wetlands (Figures 12a-c, 13a-d).

We noted that at Suffolk Bypass, the percent OM, total carbon, and total nitrogen all increased throughout the growing season in 2006, returned to lower levels the following spring, and increased again throughout the 2007 growing season.

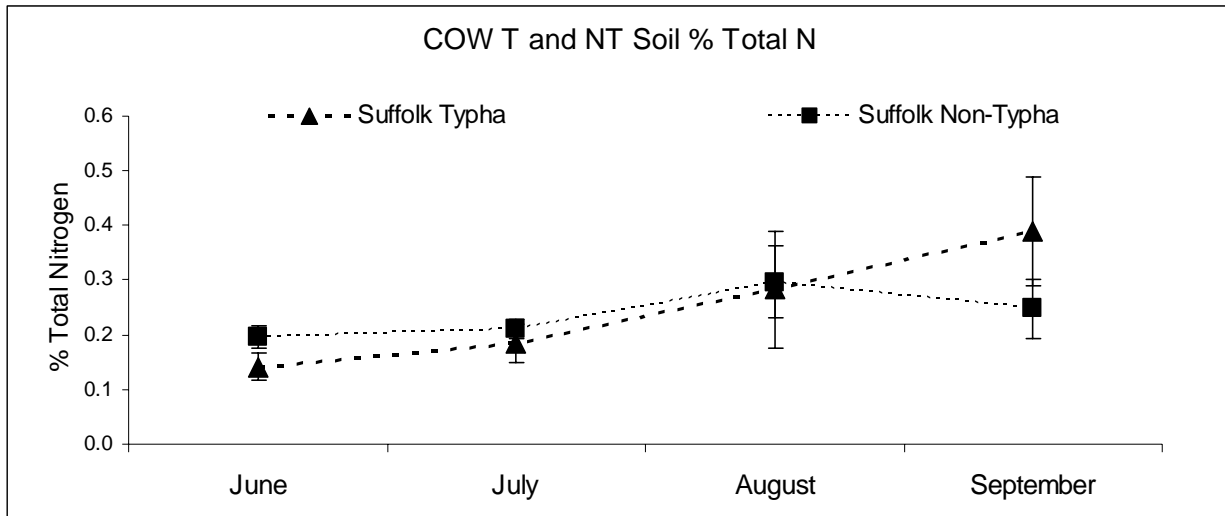


Figure 12a. Mean (± 1 SE) % soil total nitrogen in Typha and Non-Typha associations, Suffolk Bypass Site, 2006 growing season (June to Sept.).

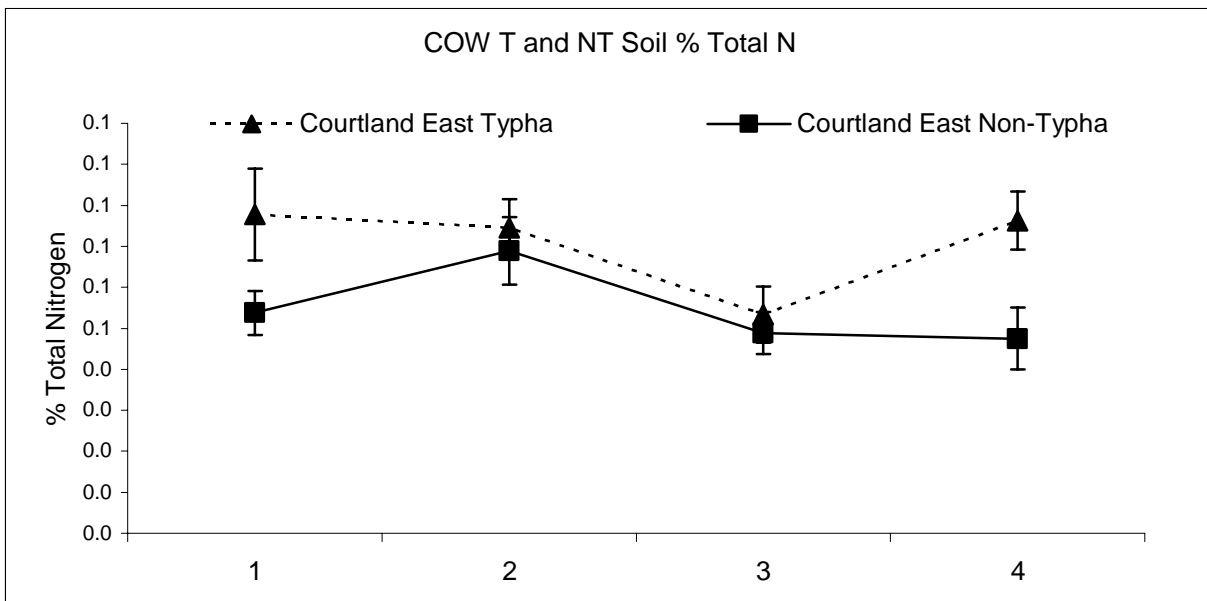


Figure 12b. Mean (± 1 SE) % soil total nitrogen in Typha and Non-Typha associations, Courtland West Site, 2006 growing season (June to Sept.).

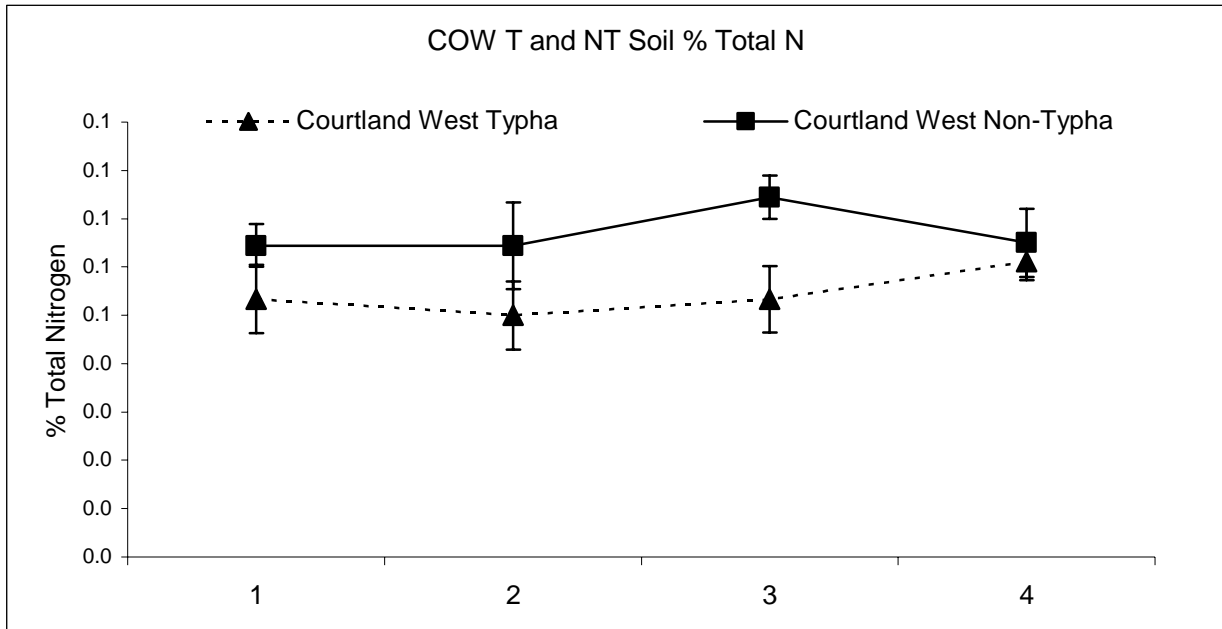


Figure 12c. Mean (± 1 SE) % soil total nitrogen in Typha and Non-Typha associations, Courtland West, 2006 growing season (June to Sept.).

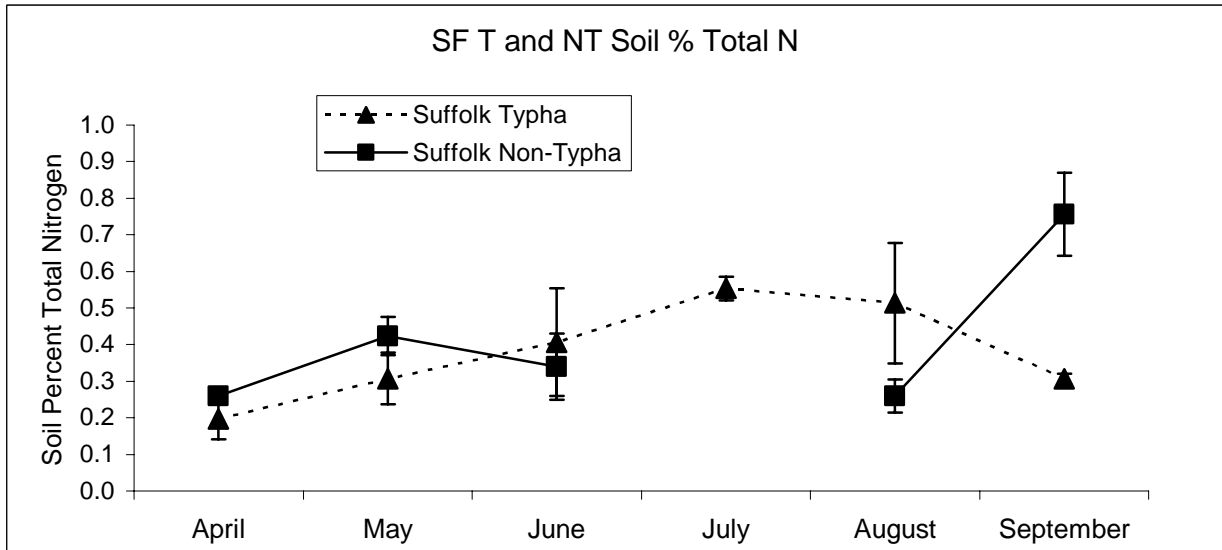


Figure 13a. Mean (± 1 SE) soil total nitrogen in Typha and Non-Typha associations, Suffolk Bypass Site, 2007 growing season (April to Sept.).

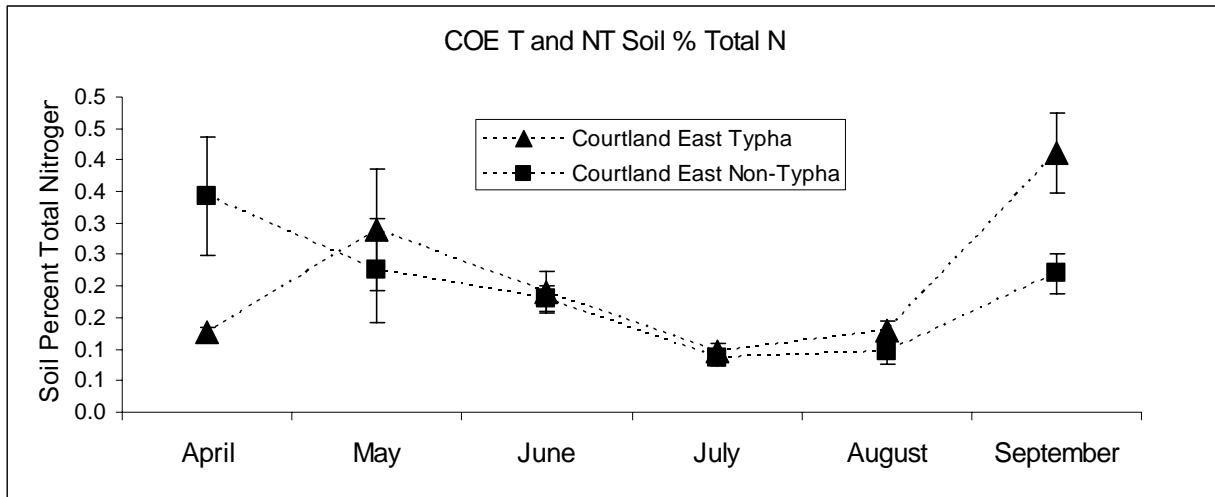


Figure 13b. Mean (± 1 SE) soil total nitrogen in Typha and Non-Typha associations, Courtland East Site, 2007 growing season (April to Sept.).

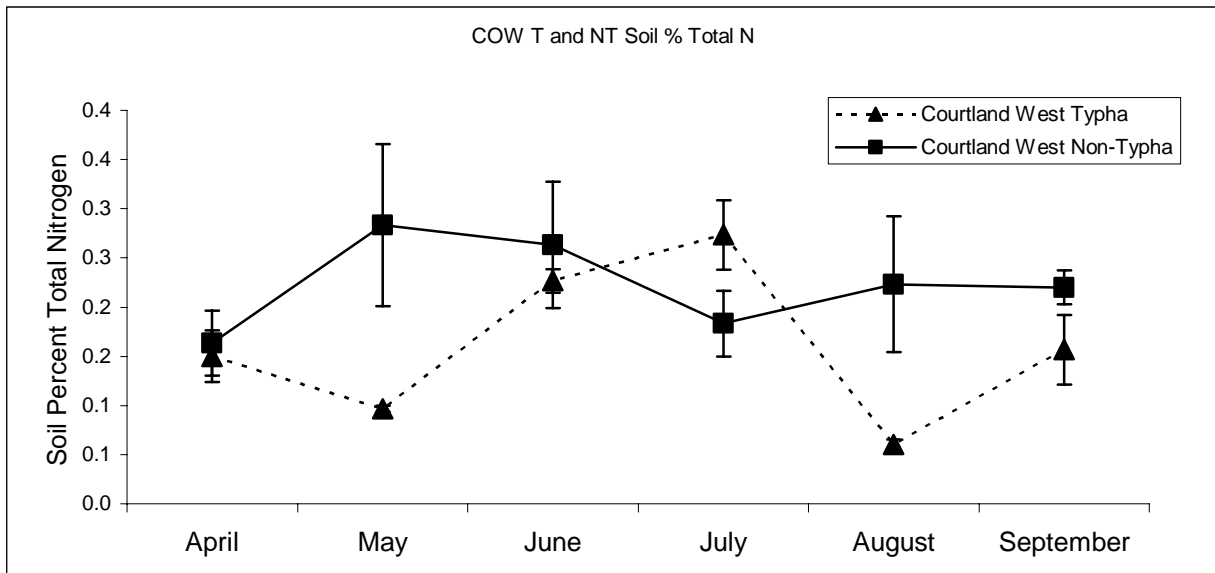


Figure 13c. Mean (± 1 SE) soil total nitrogen in Typha and Non-Typha associations, Courtland West Site, 2007 growing season (April to Sept.).

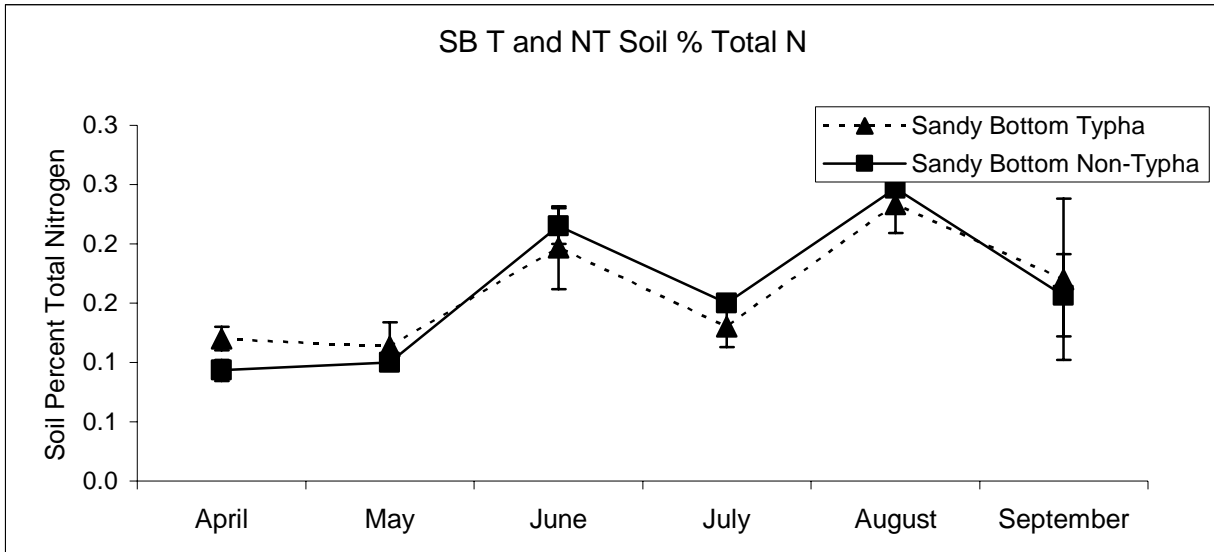


Figure 13d. Mean (± 1 SE) soil total nitrogen in Typha and Non-Typha associations, Sandy Bottom Site, 2007 growing season (April to Sept.).

Carbon:Nitrogen Ratio

There was no significant difference in the carbon:nitrogen ratio (C:N) between Typha and Non-Typha plant associations within each site in either 2006 or 2007 (Figures 14a-c, 15a-d). Significant differences existed between sites in 2006, but not in 2007. Linear regression showed that the percent total carbon and percent total nitrogen in soils was positively correlated ($R^2=0.8027$); this was expected since most soil nitrogen is stored as organic matter.

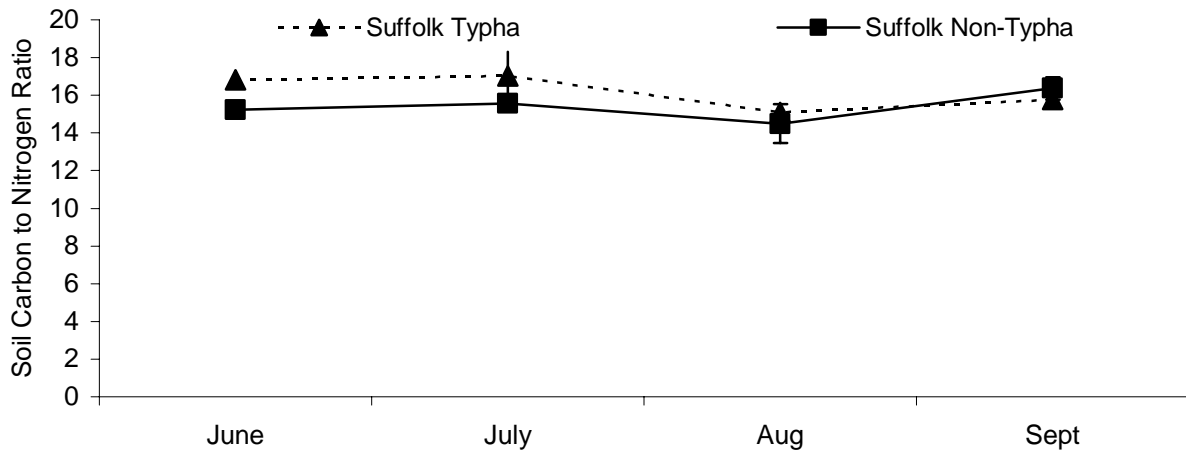


Figure 14a. Mean (± 1 SE) soil carbon to nitrogen ratio in Typha and Non-Typha associations, Suffolk Bypass Site, 2006 growing season (June to Sept.).

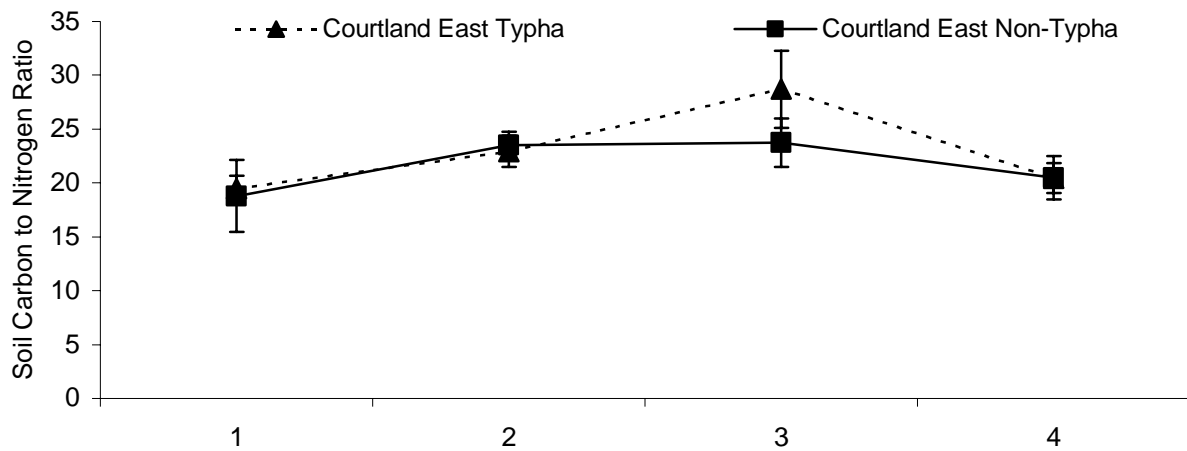


Figure 14b. Mean (± 1 SE) soil carbon to nitrogen ratio in Typha and Non-Typha associations, Courtland East Site, 2006 growing season (June to Sept.).

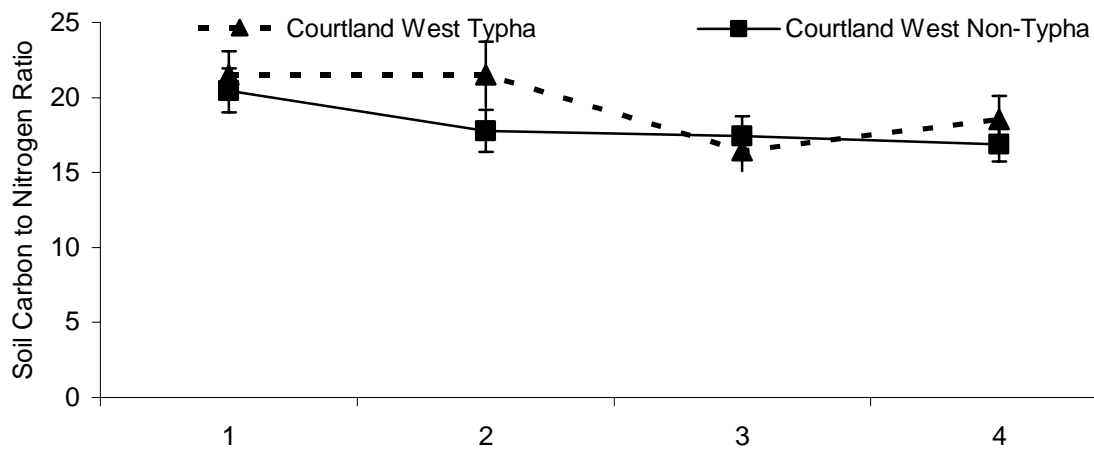


Figure 14c. Mean (± 1 SE) soil carbon to nitrogen ratio in Typha and Non-Typha associations, Courtland West Site, 2006 growing season (June to Sept.).

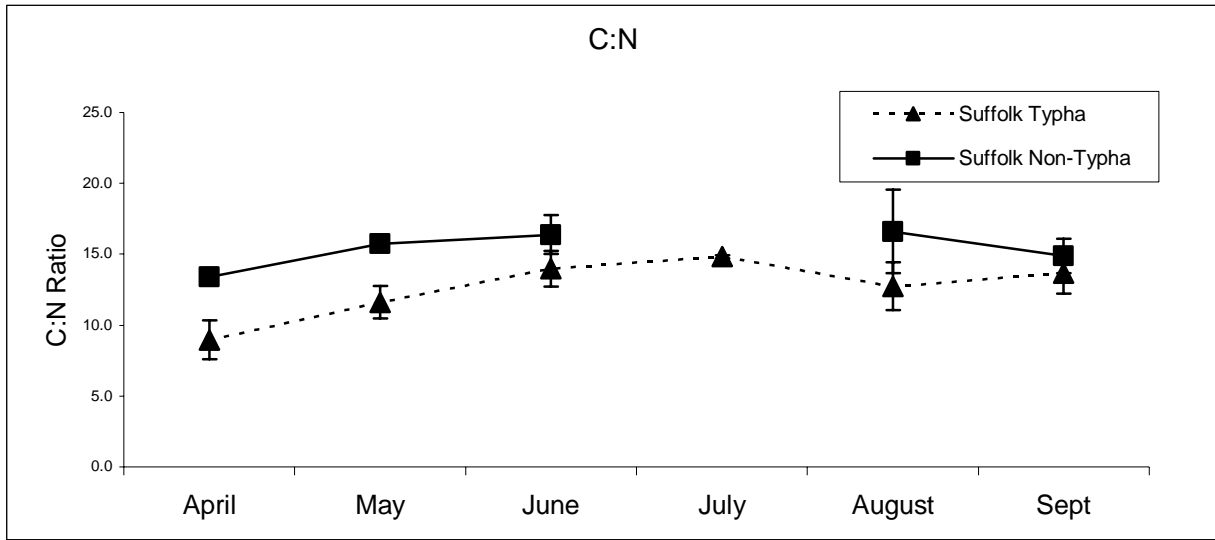


Figure 15a. Mean (± 1 SE) carbon to nitrogen ratio in Typha and Non-Typha associations, Suffolk Bypass Site, 2007 growing season (April to Sept.).

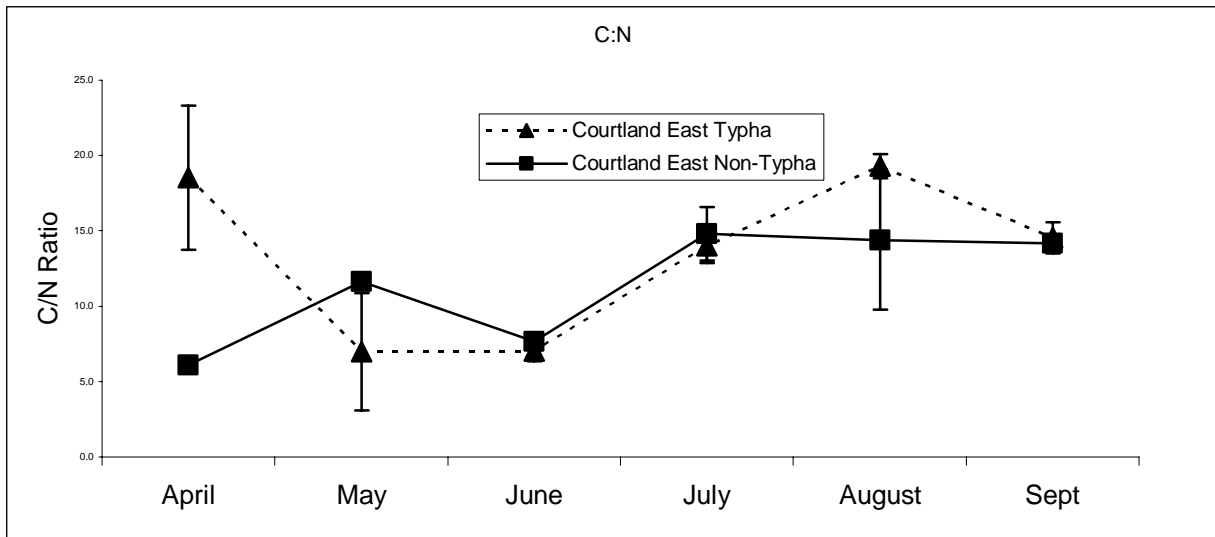


Figure 15b. Mean (± 1 SE) carbon to nitrogen ratio in Typha and Non-Typha associations, Courtland East Site, 2007 growing season (April to Sept.).

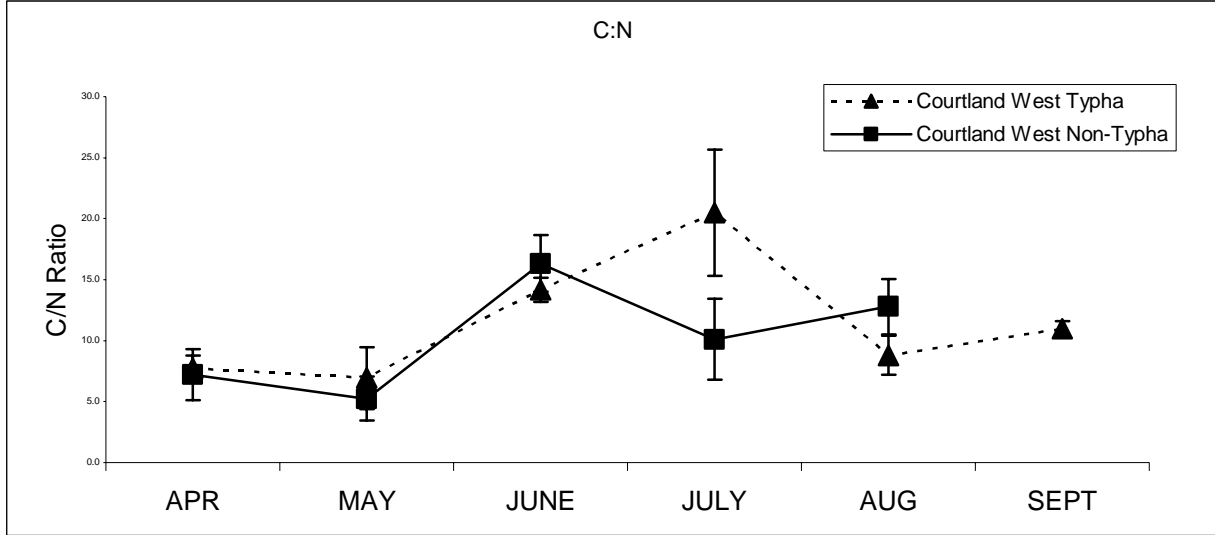


Figure 15c. Mean (± 1 SE) carbon to nitrogen ratio in Typha and Non-Typha associations, Courtland West Site, 2007 growing season (April to Sept.).

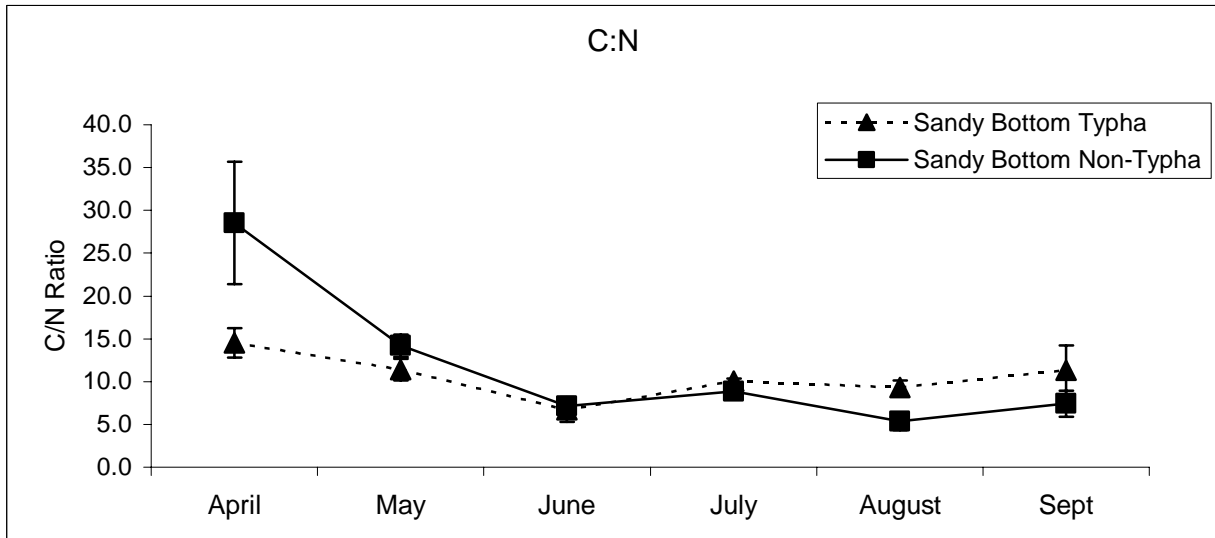


Figure 15d. Mean (± 1 SE) carbon to nitrogen ratio in Typha and Non-Typha associations, Site, 2007 growing season (April to Sept.).

Total Phosphorus

None of the sites exhibited a significant difference in soil total phosphorus between Typha and Non-Typha associations in 2006. However, total phosphorus in 2007 was significantly higher in the Non-Typha association at Courtland West. No significant difference was observed at the other three sites (Figures 16a-c, 17a-d). In both years, Suffolk Bypass had significantly higher total phosphorus when compared to the other sites. However, we observed an extremely large shift in the baseline of total phosphorus between 2006 and 2007 (Figures 16-

17). The latter may be due to differences in moisture during the growing season where more evenly spaced rain patterns in 2006, compared to dry growing season in 2007, would enhance phosphorus uptake in 2006.

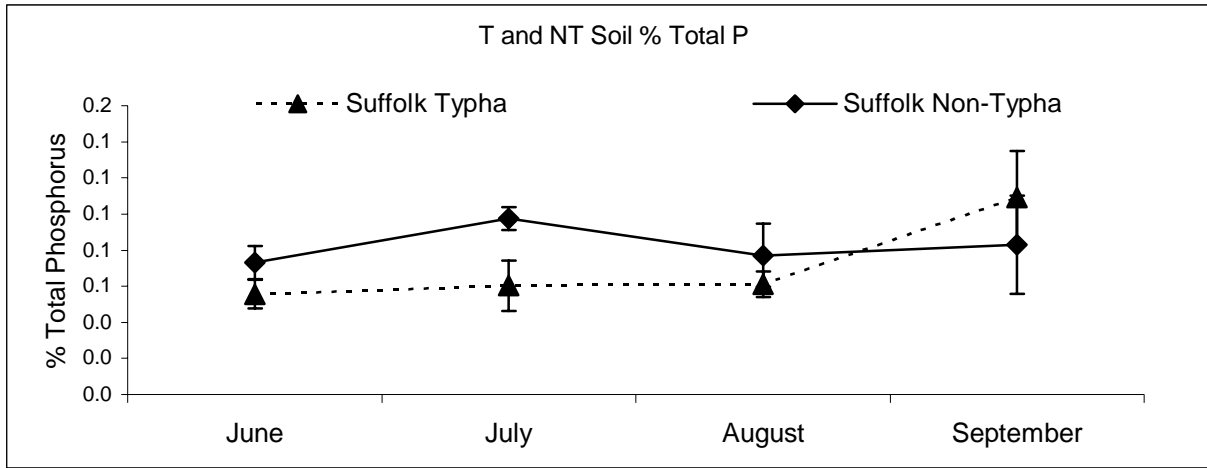


Figure 16a. Mean (± 1 SE) soil percent total phosphorus in Typha and Non-Typha associations, Suffolk Bypass Site, 2006 growing season (June to Sept.).

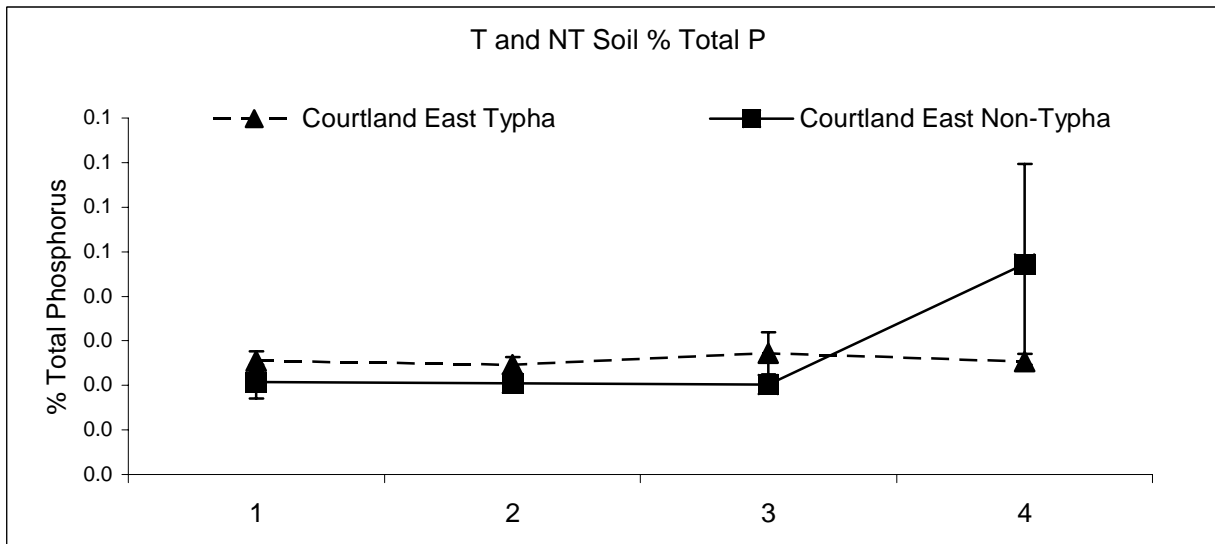


Figure 16b. Mean (± 1 SE) soil percent total phosphorus in Typha and Non-Typha associations, Courtland East Site, 2006 growing season (June to Sept.).

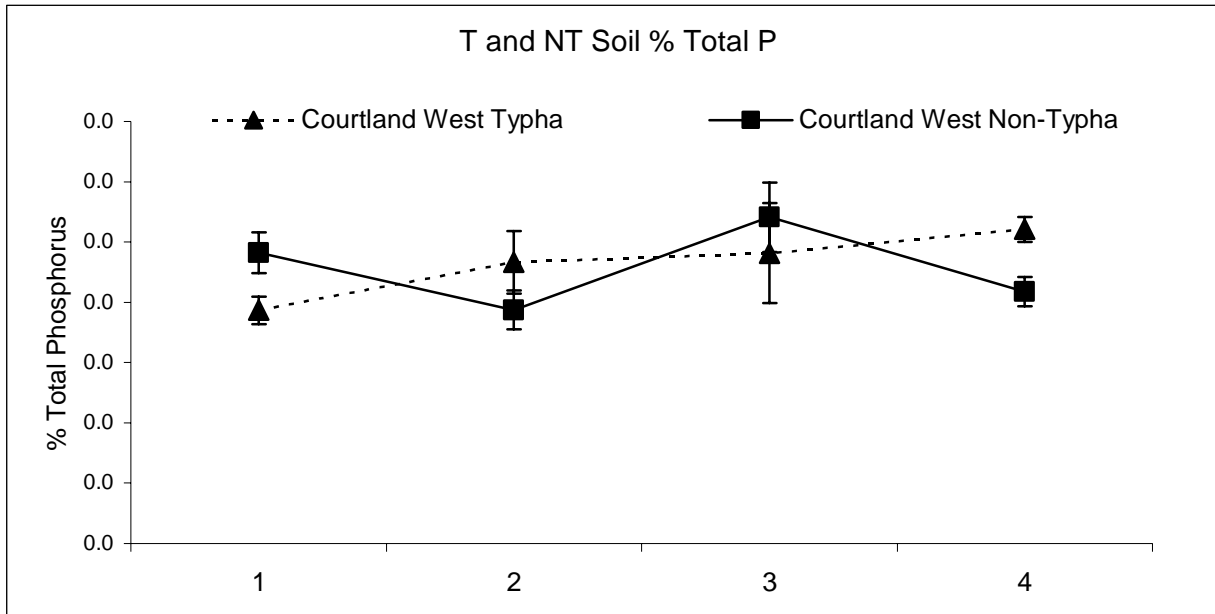


Figure 16c. Mean (± 1 SE) soil percent total phosphorus in Typha and Non-Typha associations, Courtland West Site, 2006 growing season (June to Sept.).

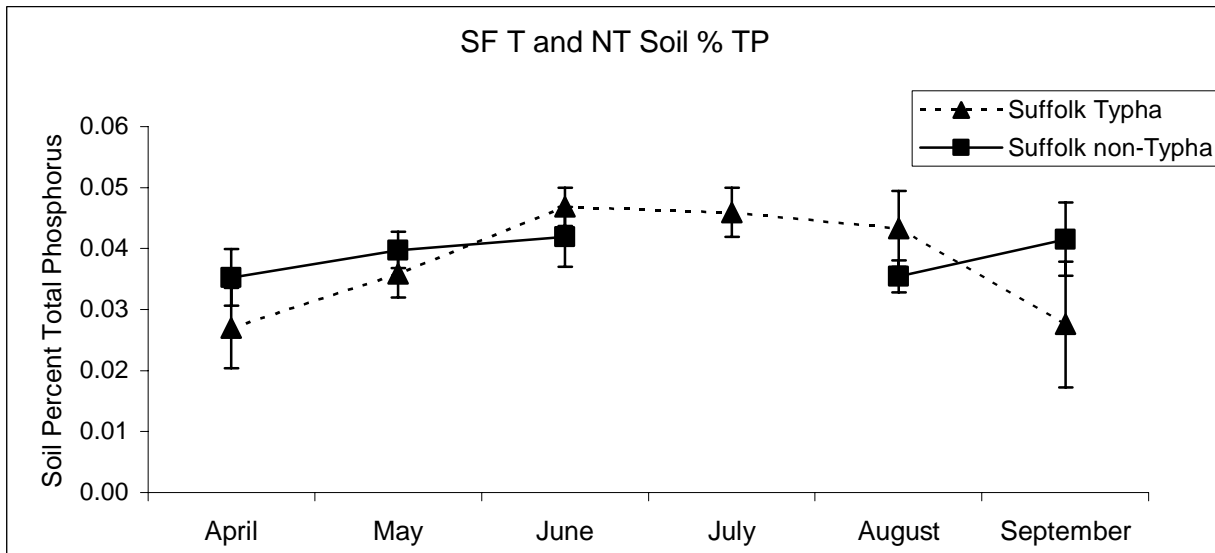


Figure 17a. Mean (± 1 SE) soil percent total phosphorus in Typha and Non-Typha associations, Suffolk Bypass Site, 2007 growing season (April to Sept.).

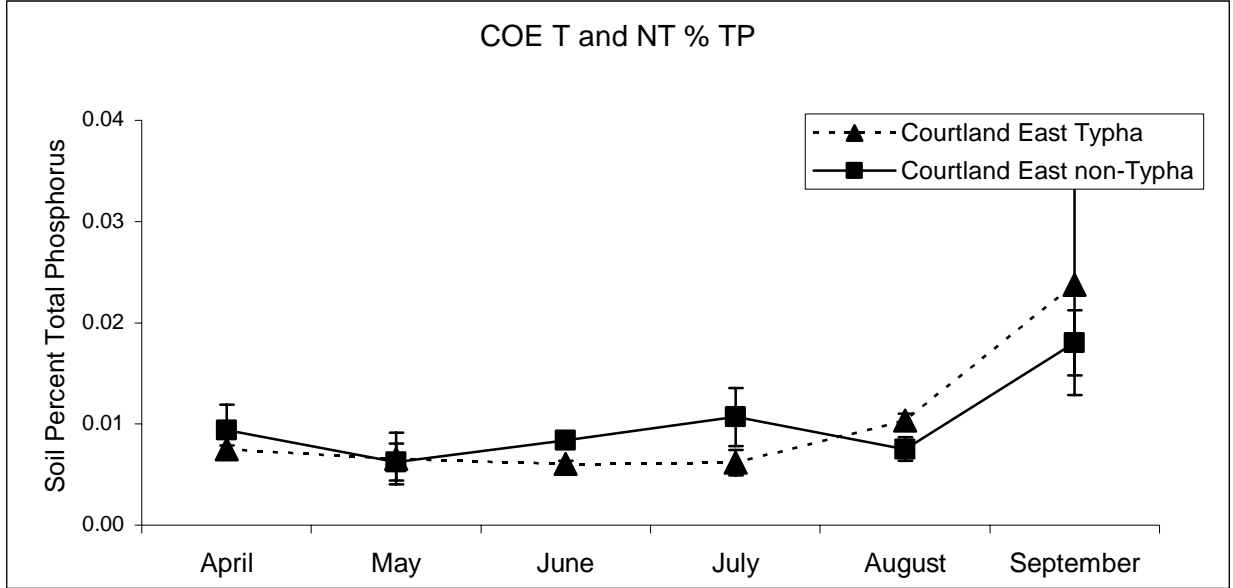


Figure 17b. Mean (± 1 SE) soil percent total phosphorus in Typha and Non-Typha associations, Courtland East Site, 2007 growing season (April to Sept.).

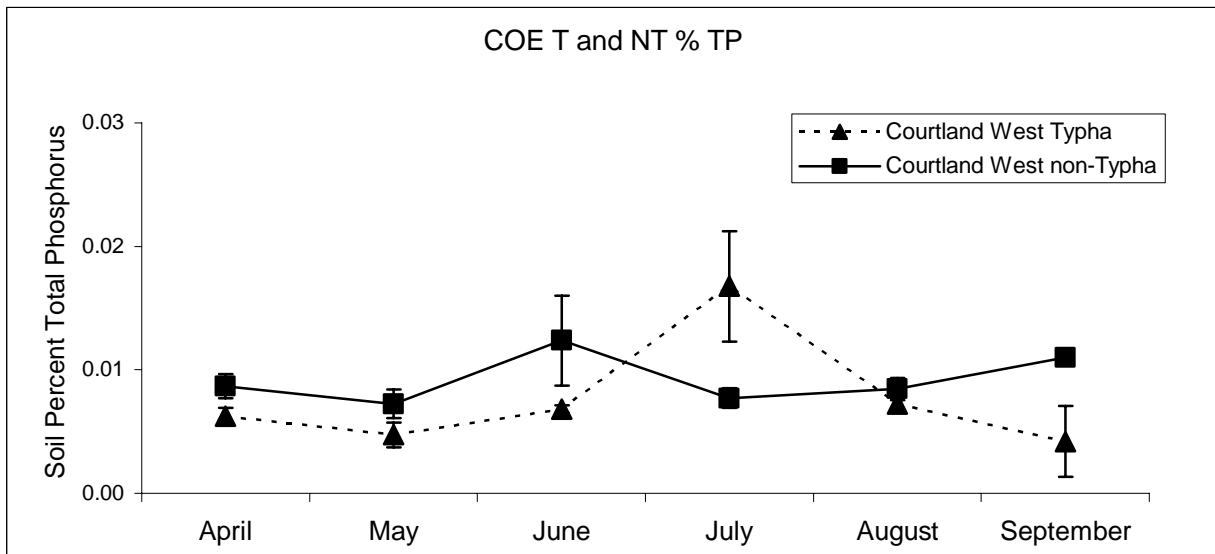


Figure 17c. Mean (± 1 SE) soil percent total phosphorus in Typha and Non-Typha associations, Courtland West Site, 2007 growing season (April to Sept.).

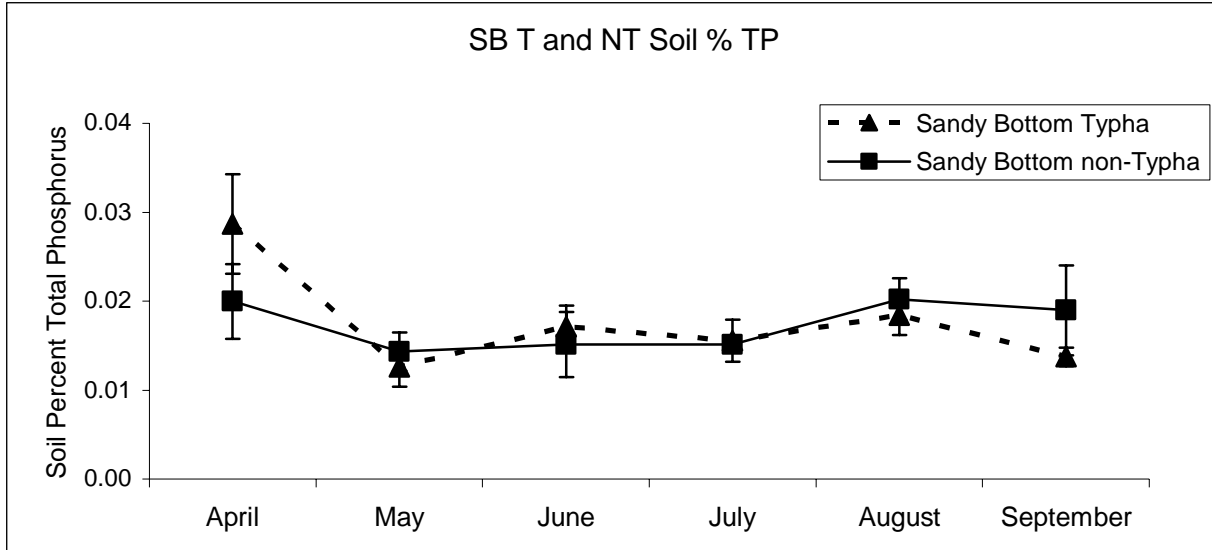


Figure 17d. Mean (± 1 SE) soil percent total phosphorus in Typha and Non-Typha associations, Sandy Bottom Site, 2007 growing season (April to Sept.).

Acid Extractable Phosphorus

No significant differences were found in acid extractable phosphorus between Typha and Non-Typha associations in 2006. In 2007, we observed a significant difference in acid extractable phosphorus only at Courtland East. In both years, Suffolk Bypass had significantly higher soil acid extractable phosphorus than the three other study sites (Figures 18a-c, 19a-d). Acid extractable phosphorus follows a similar trend as total phosphorus, as the majority of total phosphorus measured is in the form of acid extractable phosphorus.

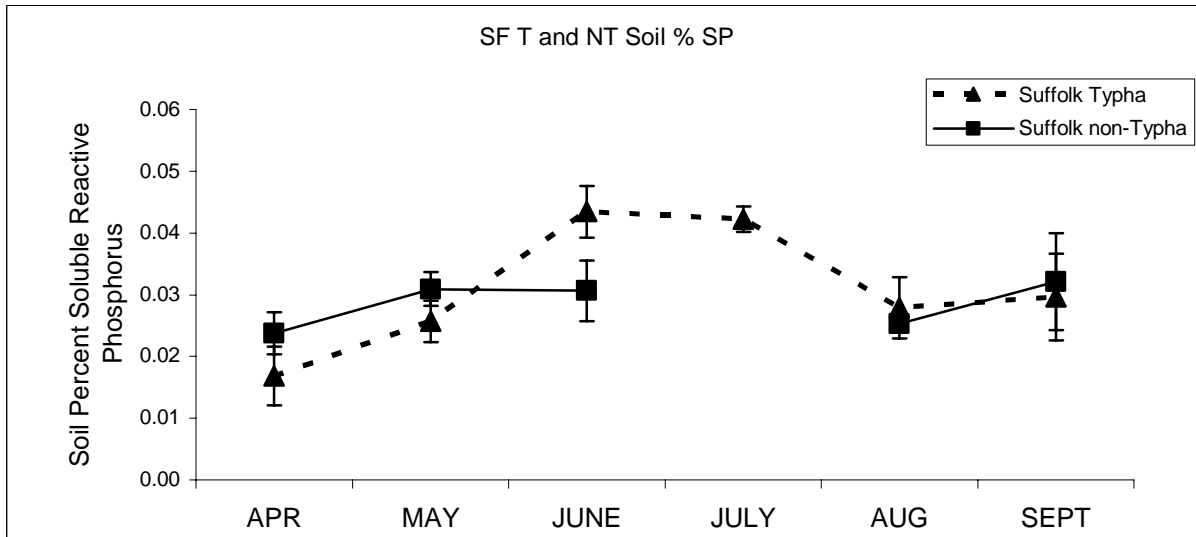


Figure 18a. Mean (± 1 SE) percent acid extractable soil phosphorus in Typha and Non-Typha associations, Suffolk Bypass Site, 2006 growing season (June to Sept.).

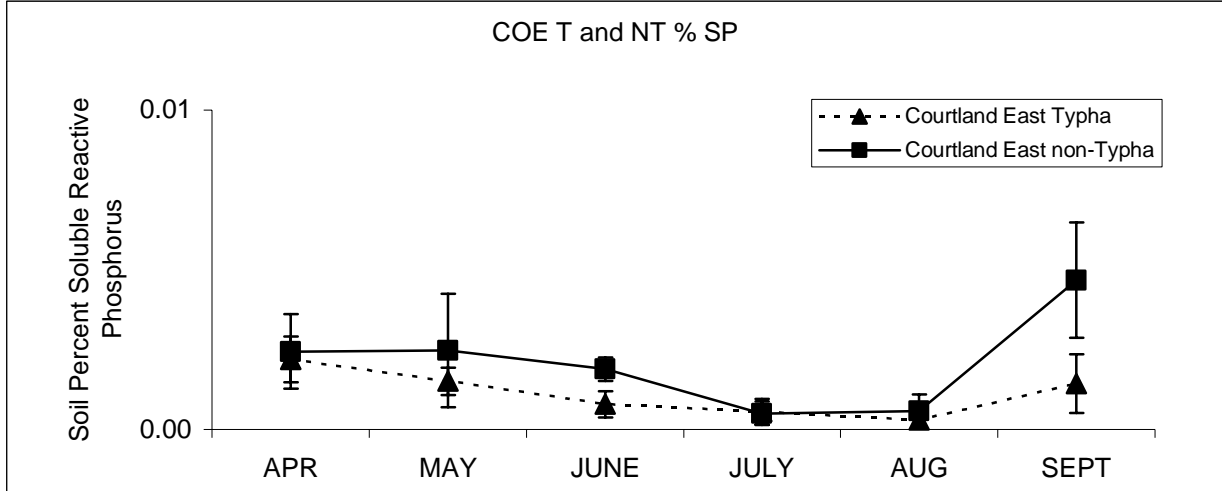


Figure 18b. Mean (± 1 SE) percent acid extractable soil phosphorus in Typha and Non-Typha associations, Courtland East Site, 2006 growing season (June to Sept.).

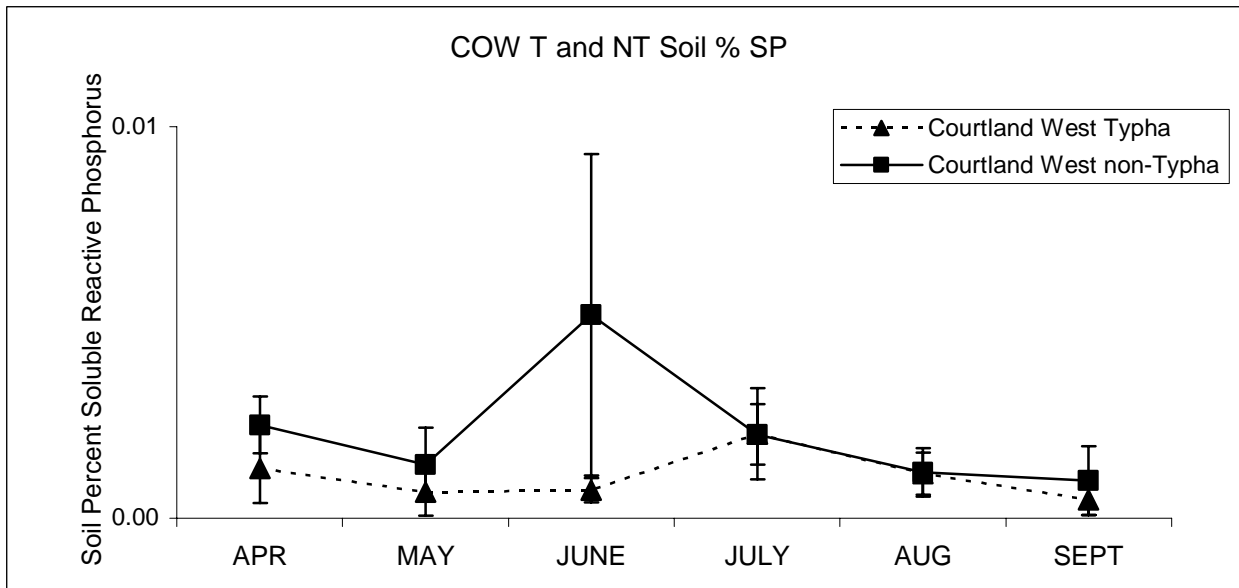


Figure 18c. Mean (± 1 SE) percent acid extractable soil phosphorus in Typha and Non-Typha associations, Courtland West Site, 2006 growing season (June to Sept.).

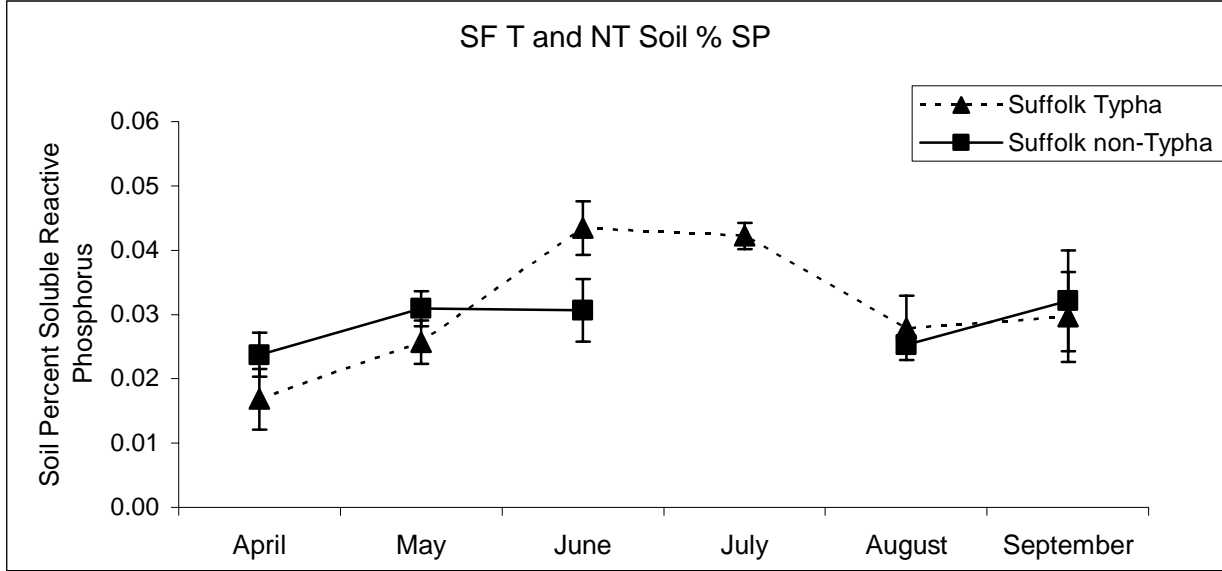


Figure 19a. Mean (± 1 SE) percent acid extractable soil phosphorus in Typha and Non-Typha associations, Suffolk Bypass Site, 2007 growing season (April to Sept.).

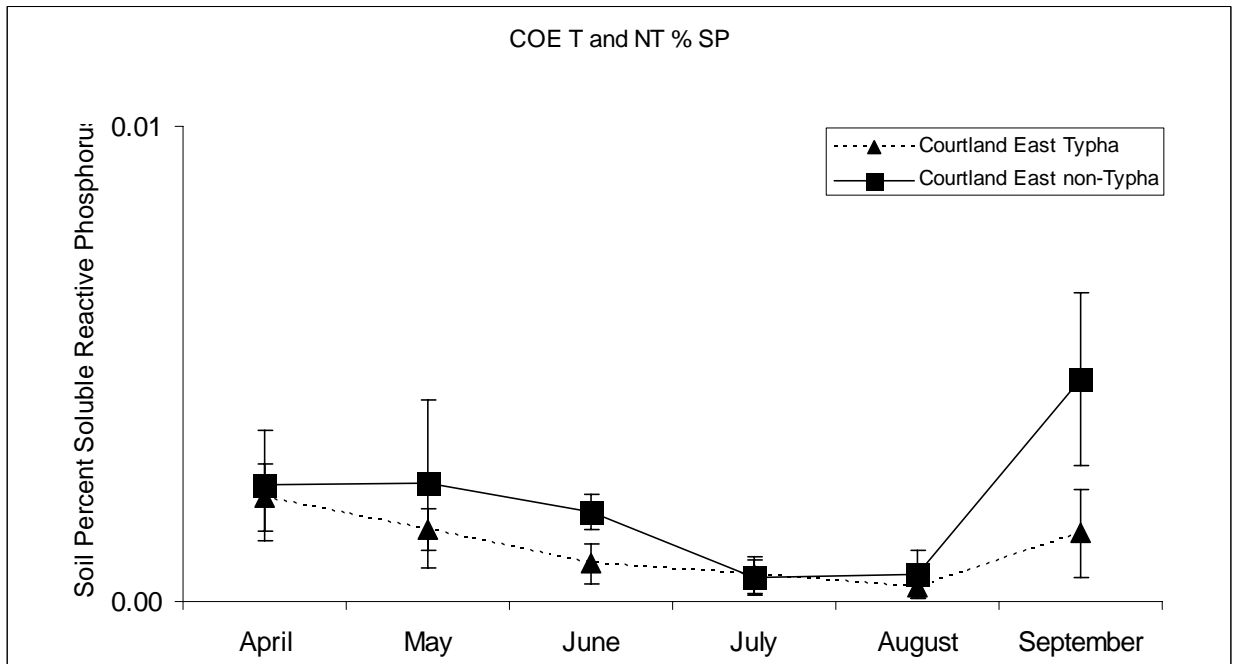


Figure 19b. Mean (± 1 SE) percent acid extractable soil phosphorus in Typha and Non-Typha associations, Courtland East, 2007 growing season (April to Sept.).

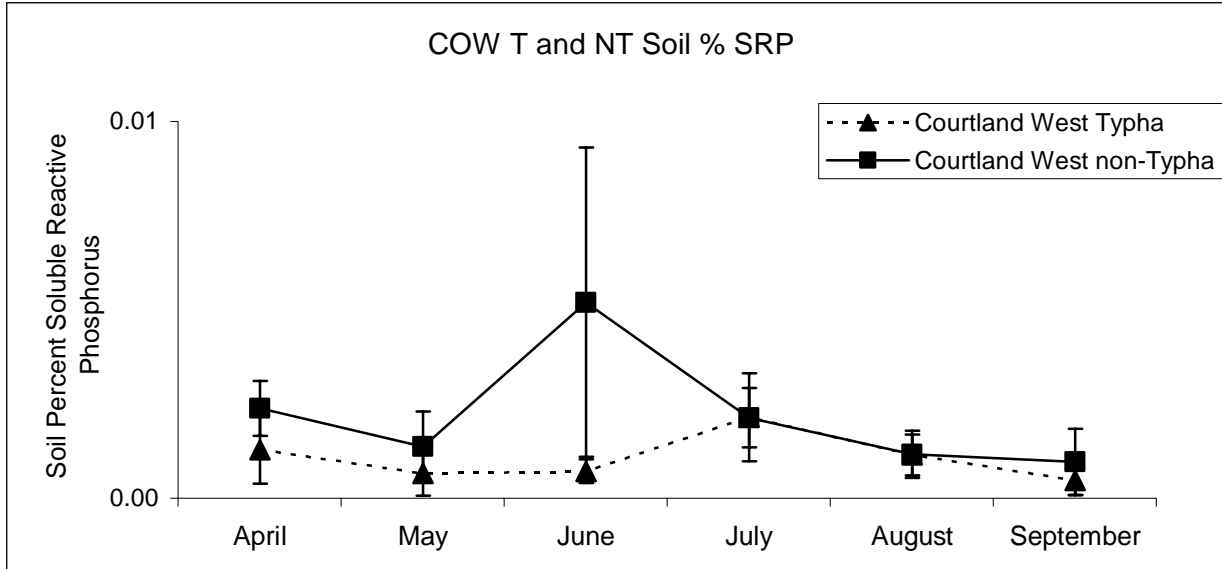


Figure 19c. Mean (± 1 SE) percent acid extractable soil phosphorus in Typha and Non-Typha associations, Courtland West Site, 2007 growing season (April to Sept.).

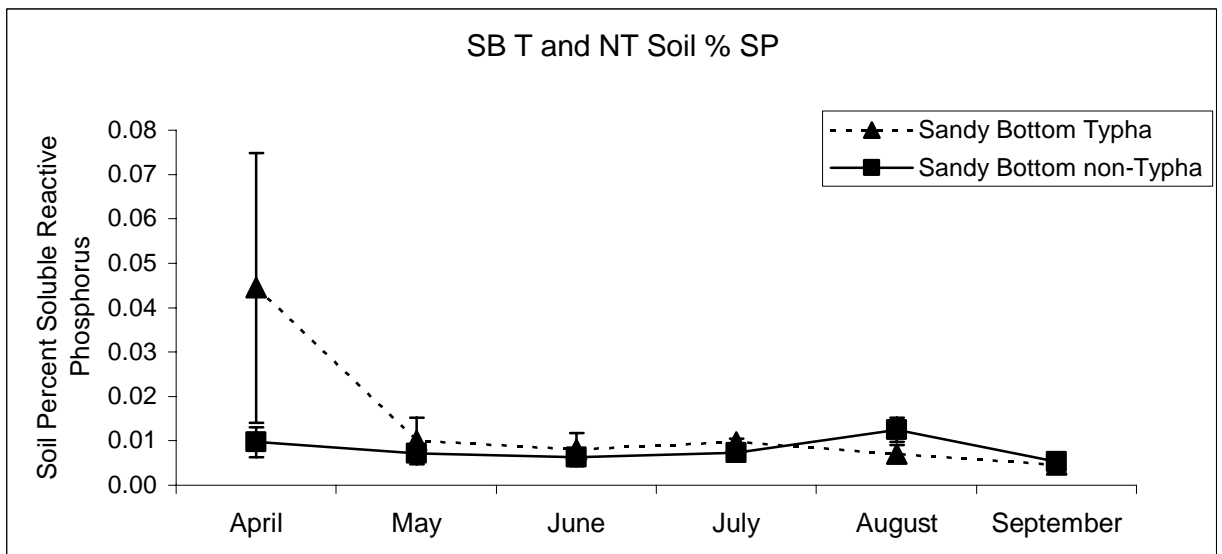


Figure 19d. Mean (± 1 SE) percent acid extractable soil phosphorus in Typha and Non-Typha associations, Sandy Bottom Site, 2007 growing season (April to Sept.).

Soil Organic Phosphorus

There was no significant difference in percent organic phosphorus between Typha and Non-Typha associations at any sites in either 2006 or 2007; there was also no significant difference between sites (Figures 20a-c, 21a-d). We did observe a trend of higher percent organic phosphorus at Suffolk Bypass in 2006. Although we did not observe any significant differences, we did measure large changes in soil percent organic phosphorus between 2006 and 2007.

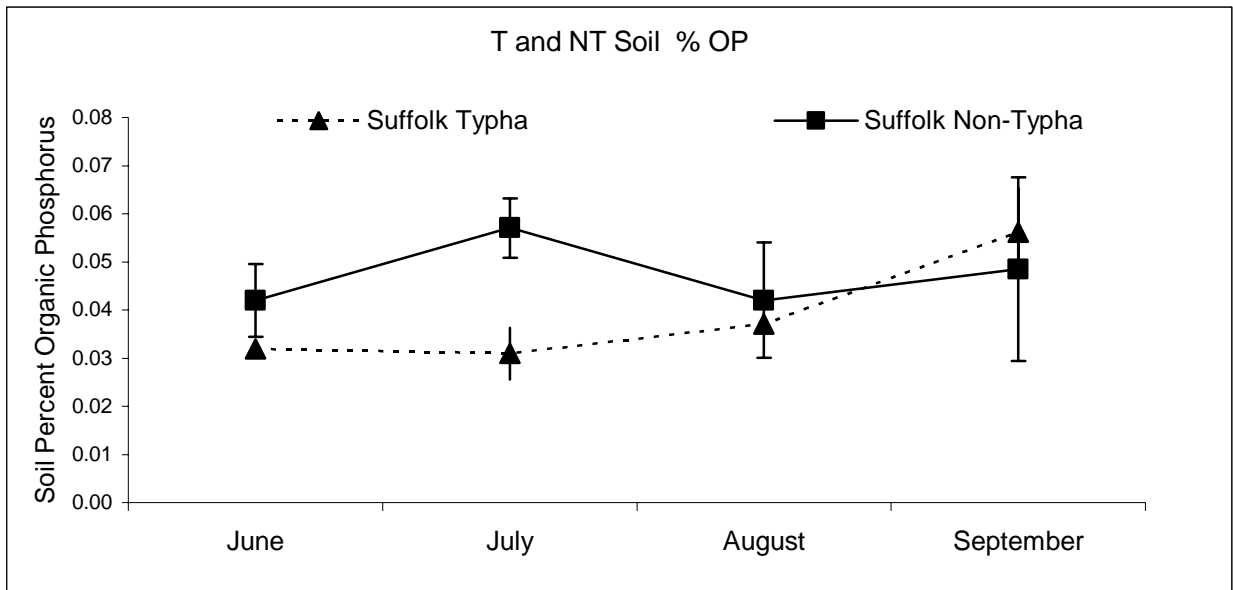


Figure 20a. Mean (± 1 SE) percent soil organic phosphorus in Typha and Non-Typha associations, Suffolk Bypass Site, 2006 growing season (June to Sept.).

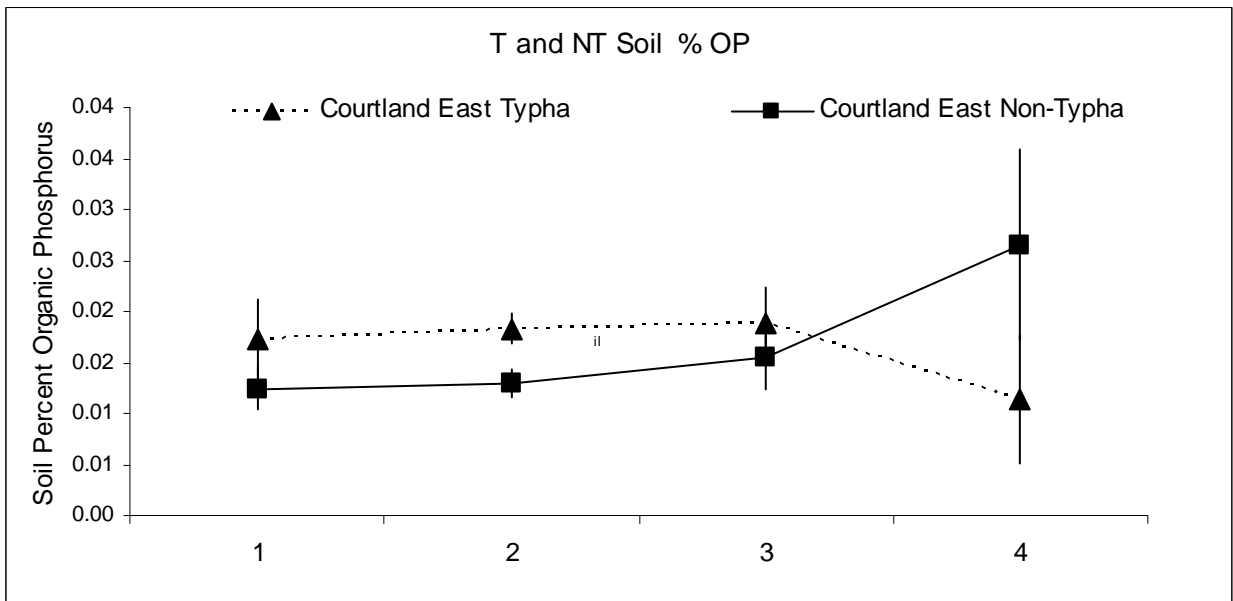


Figure 20b. Mean (± 1 SE) percent soil organic phosphorus in Typha and Non-Typha associations, Courtland East Site, 2006 growing season (June to Sept.).

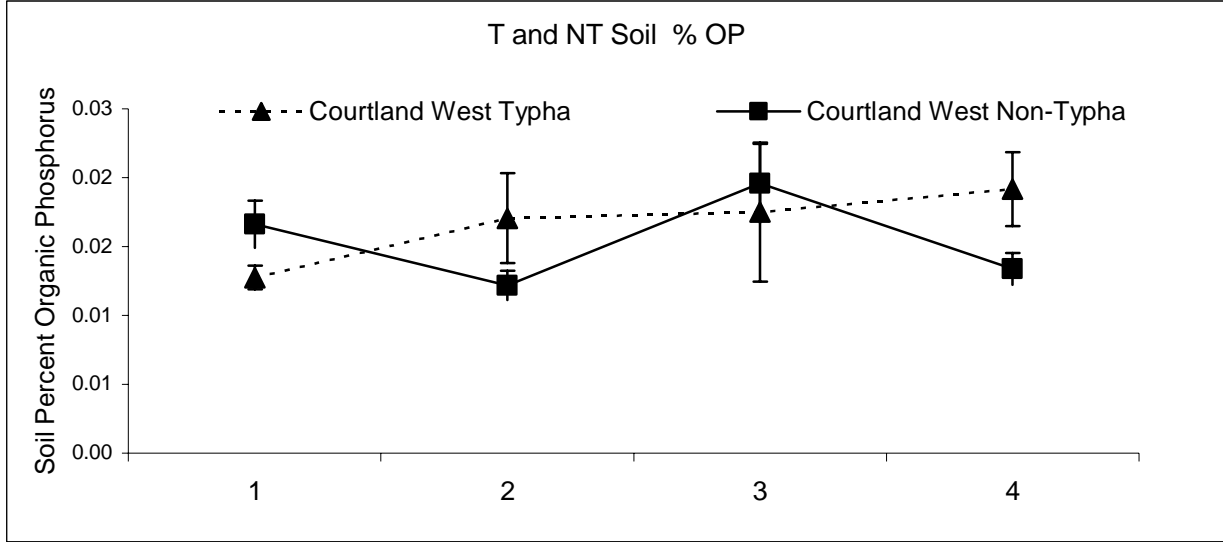


Figure 20c. Mean (± 1 SE) percent soil organic phosphorus in Typha and Non-Typha associations, Courtland West Site, 2006 growing season (June to Sept.).

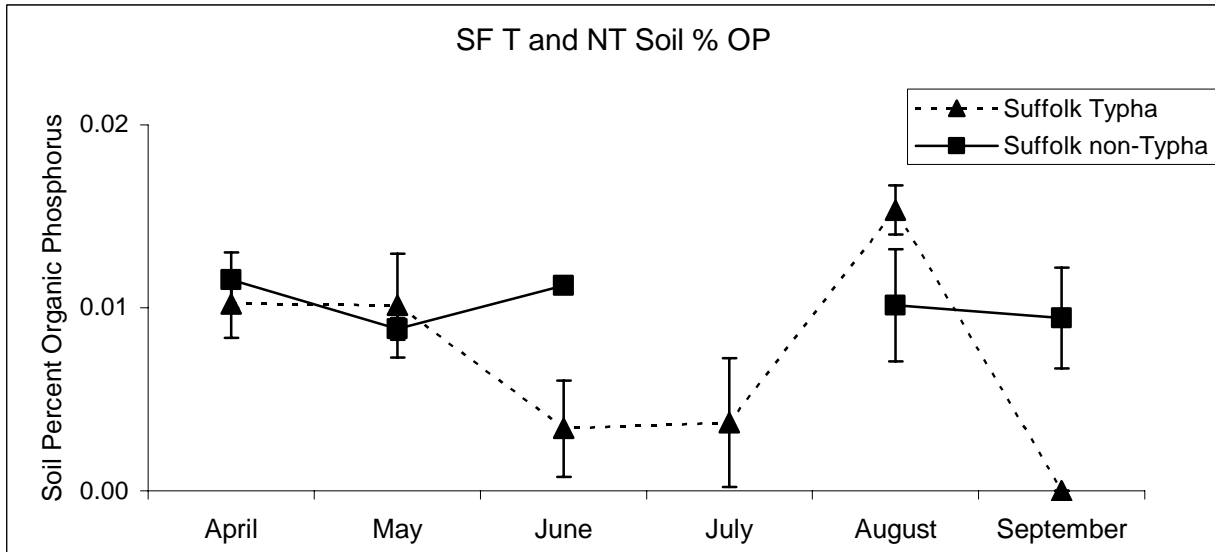


Figure 21a. Mean (± 1 SE) percent organic soil phosphorus in Typha and Non-Typha associations, Suffolk Bypass Site, 2007 growing season (April to Sept.).

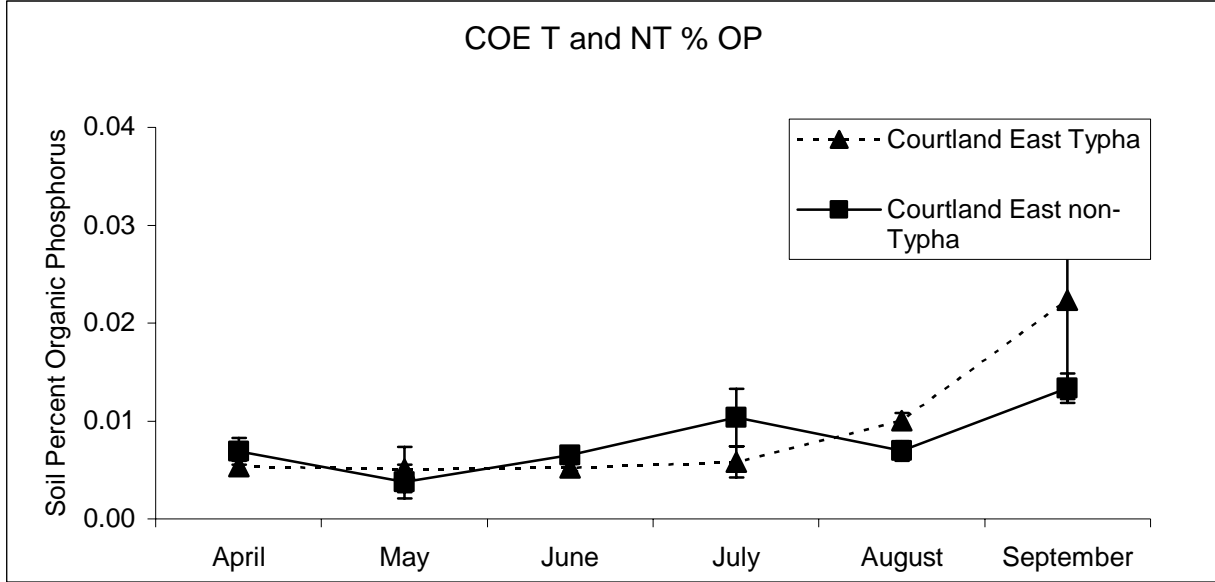


Figure 21b. Mean (± 1 SE) percent organic soil phosphorus in Typha and Non-Typha associations, Courtland East Site, 2007 growing season (April to Sept.).

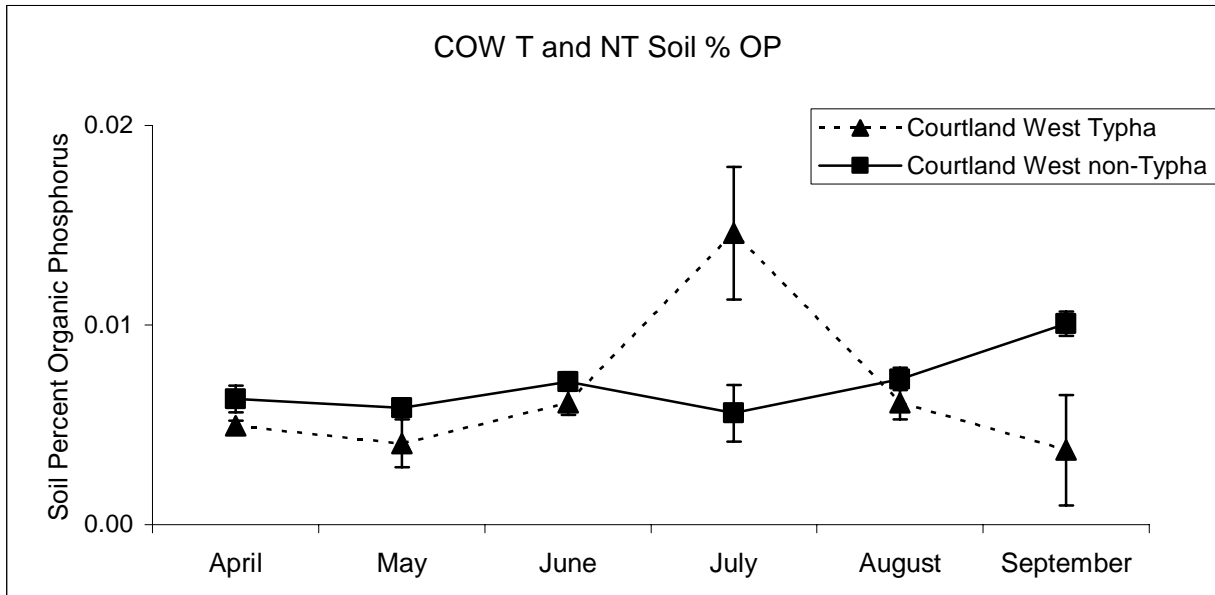


Figure 21c. Mean (± 1 SE) percent organic soil phosphorus in Typha and Non-Typha associations, Courtland West Site, 2007 growing season (April to Sept.).

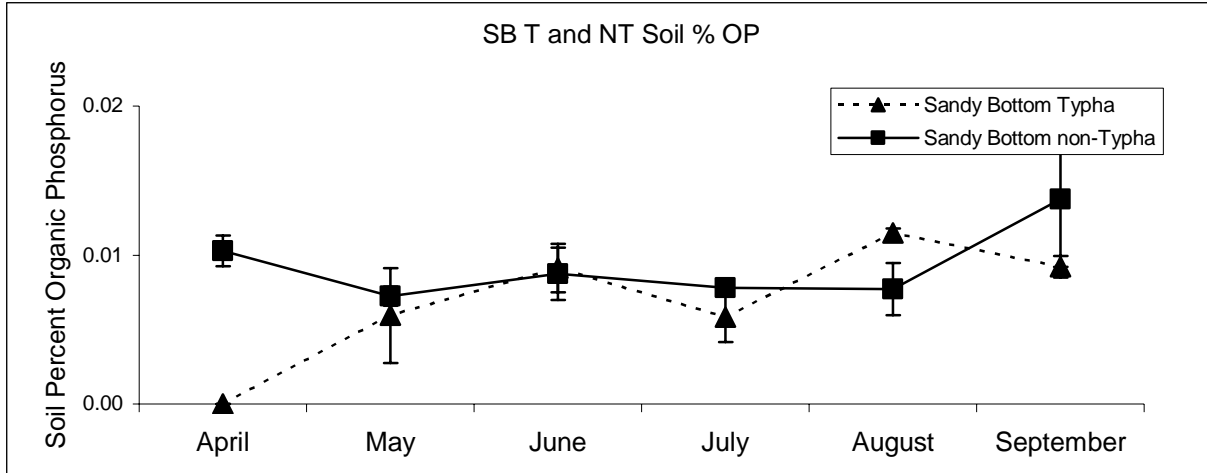


Figure 21d. Mean (± 1 SE) percent organic soil phosphorus in Typha and Non-Typha associations, Sandy Bottom Site, 2007 growing season (April to Sept.).

Nitrogen:Phosphorus Ratio

Repeated measures ANOVA showed that the average nitrogen:phosphorus ratio (N:P) was higher in Non-Typha associations at the two Courtland sites in 2006. No significant difference was observed between stand types at Suffolk Bypass, and no data was collected at Sandy Bottom that year. Significant differences in soil N:P also existed between the three sites. In 2007, we did not observe any significant differences in soil N:P between stand types at any of the four sites. Again, there was a significant difference in N:P between sites, with Suffolk Bypass and Sandy Bottom exhibiting much lower N:P ratios particularly in the first three months of the growing season (Figures 22a-c, 23a-d). The N:P ratios were generally much larger in 2007 due to an increase in total nitrogen and a large decrease in total phosphorus; this change was particularly apparent at Courtland West and Suffolk Bypass.

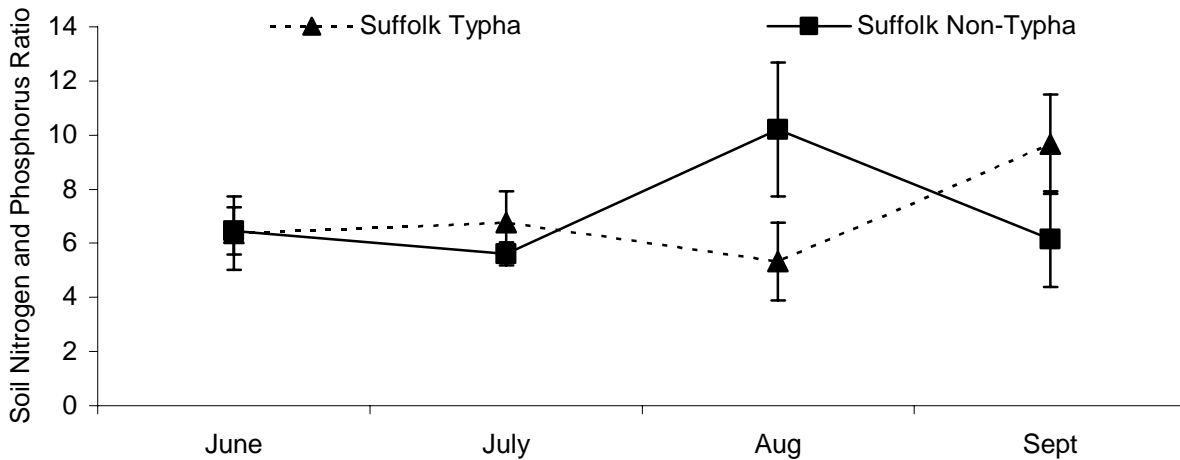


Figure 22a. Mean (± 1 SE) soil nitrogen to phosphorus ratio in Typha and Non-Typha associations, Suffolk Site, 2006 growing season (June to Sept.).

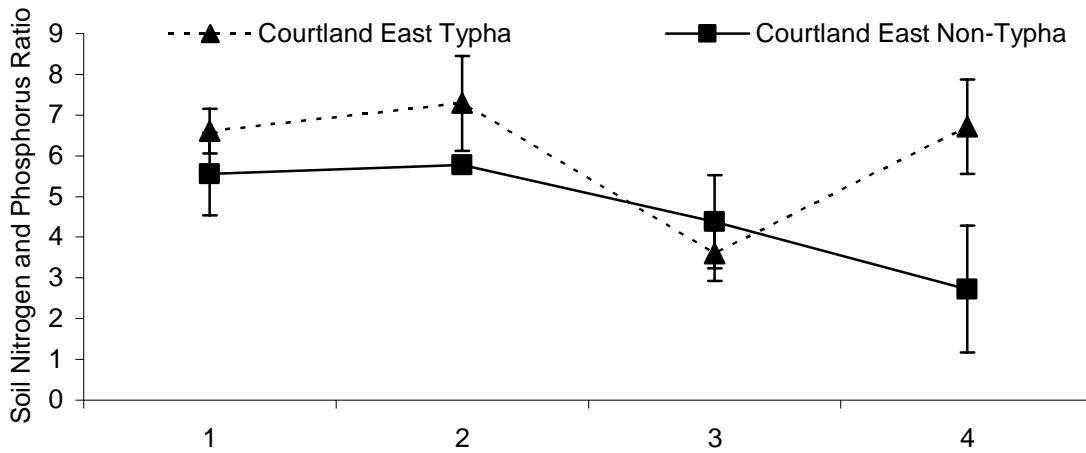


Figure 22b. Mean (± 1 SE) soil nitrogen to phosphorus ratio in Typha and Non-Typha associations, Courtland East Site, 2006 growing season (June to Sept.).

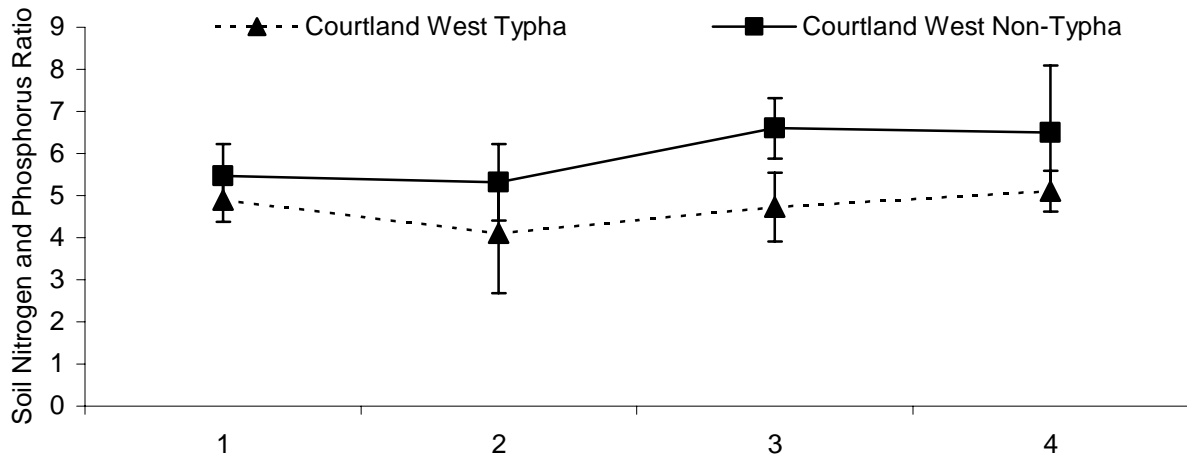


Figure 22c. Mean (± 1 SE) soil nitrogen to phosphorus ratio in Typha and Non-Typha associations, Courtland West Site, 2006 growing season (June to Sept.).

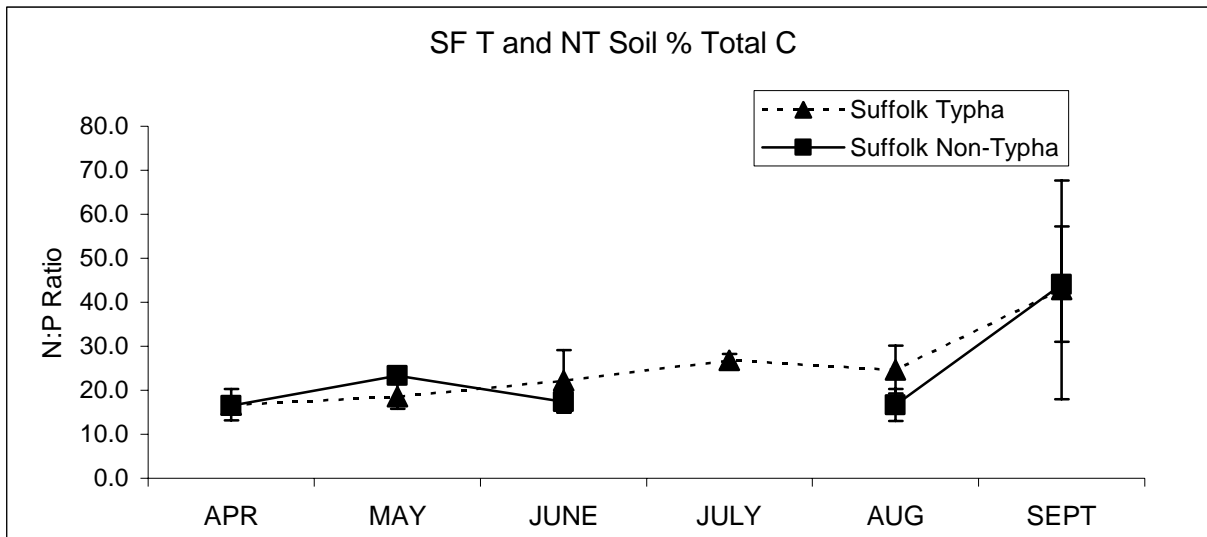


Figure 23a. Mean (± 1 SE) nitrogen to phosphorus ratio in Typha and Non-Typha associations, Suffolk Bypass Site, 2007 growing season (April to Sept.).

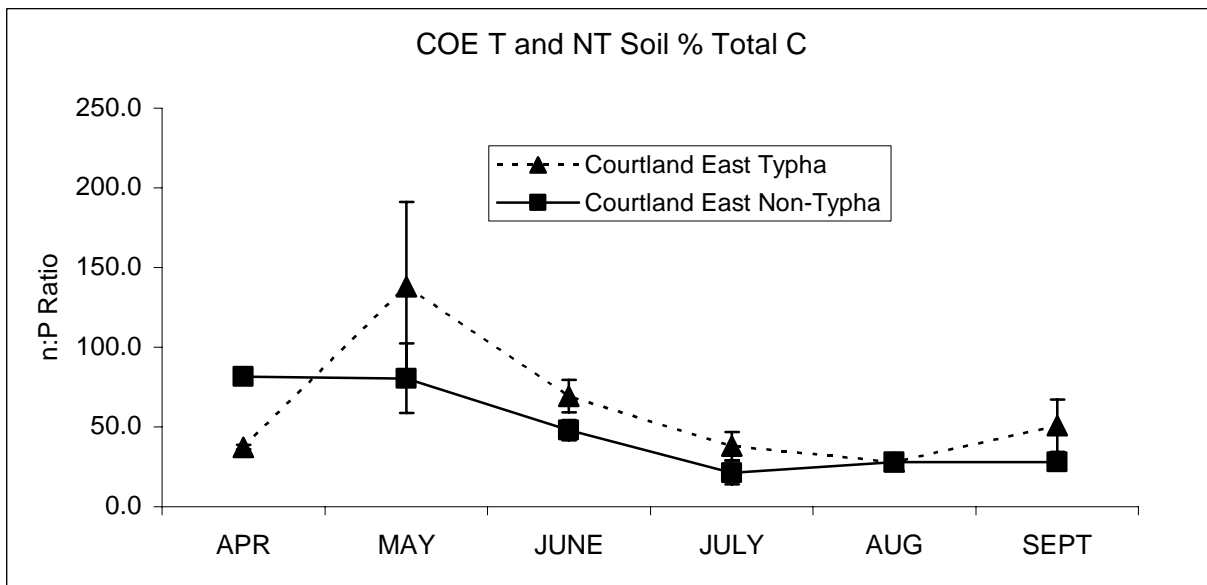


Figure 23b. Mean (± 1 SE) nitrogen to phosphorus ratio in Typha and Non-Typha associations, Courtland East Site, 2007 growing season (April to Sept.).

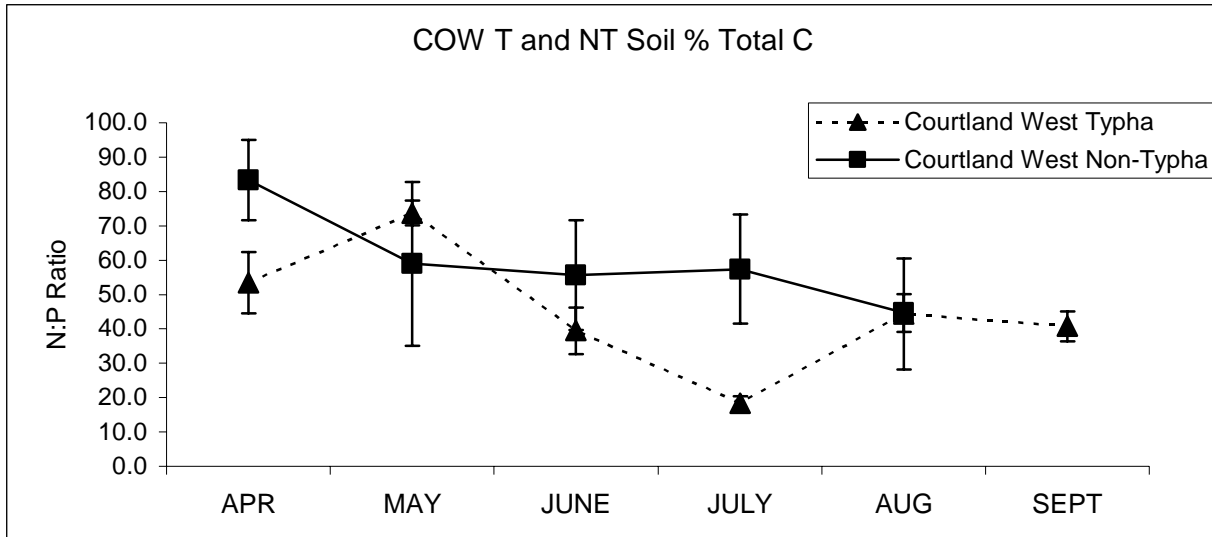


Figure 23c. Mean (± 1 SE) nitrogen to phosphorus ratio in Typha and Non-Typha associations, Courtland West Site, 2007 growing season (April to Sept.).

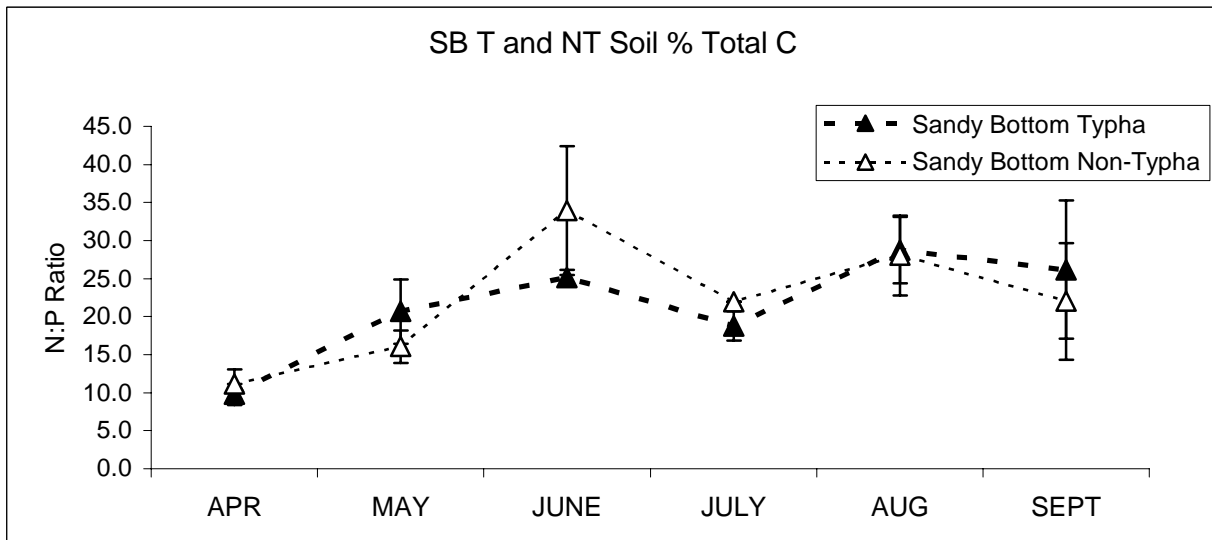


Figure 23d. Mean (± 1 SE) nitrogen to phosphorus ratio in Typha and Non-Typha associations, Sandy Bottom Site, 2007 growing season (April to Sept.).

Water Quality – Porewater Analysis

While we observed some variability in the overall porewater nutrient concentration over the 20 cm sampling interval, there were no significant differences. Analysis of depth profiles indicated that there were no consistent trends in nutrients associated with depth. Therefore, we used the average values for the top 20 cm of soil for statistical comparisons of nutrients between sites. Depth profiles showed the same trends in parameters throughout the seasons as those described by the porewater averages.

Total Dissolved Phosphorus

There were significant differences in total dissolved phosphorus between Typha and Non-Typha associations at Courtland West only. Suffolk Bypass had significantly higher total dissolved phosphorus than the other three study sites, likely due to the high total dissolved phosphorus measured in the Non-Typha association in April. In July and August, porewater dissolved organic and inorganic phosphorus decreased (Figures 24a-d).

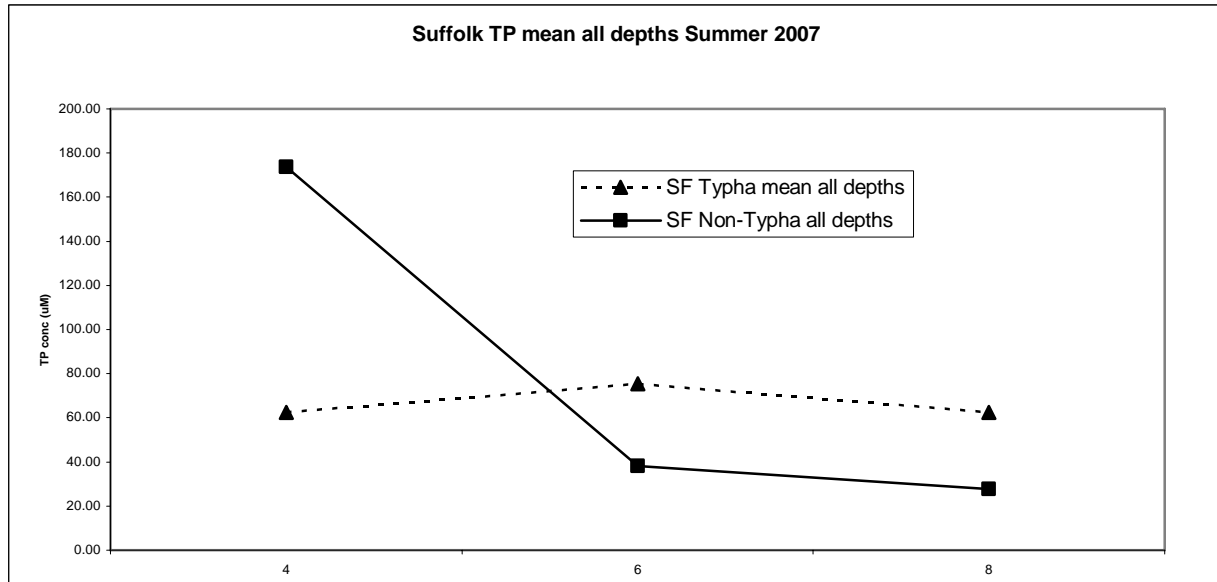


Figure 24a. Mean (± 1 SE) bimonthly porewater total dissolved phosphorus in Typha and Non-Typha associations, values are mean of top 20 cm of soil, Suffolk Bypass Site, 2007 growing season (April to August).

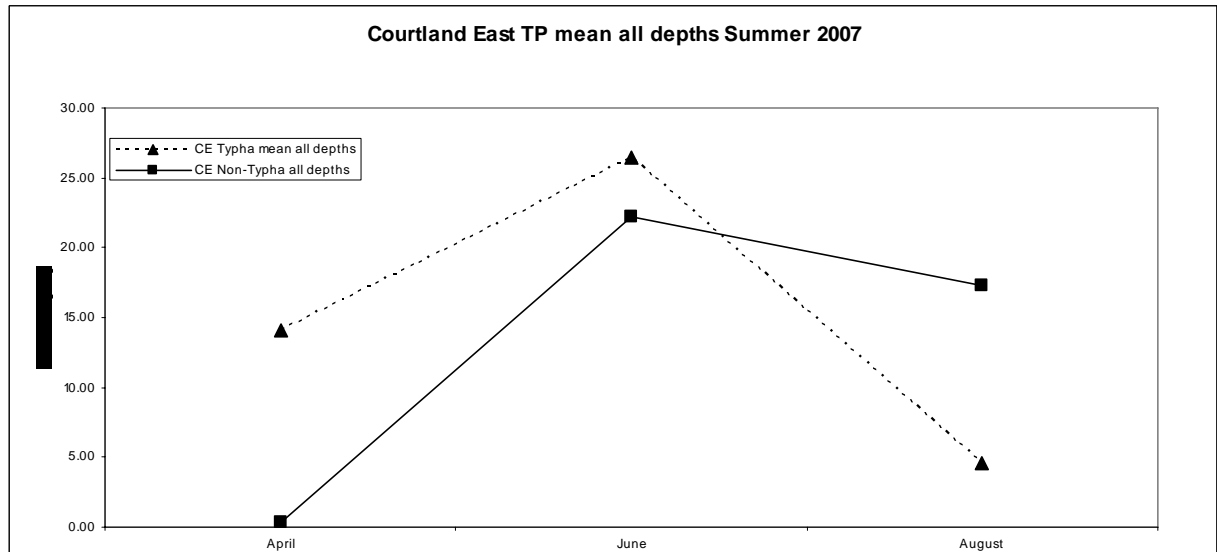


Figure 24b. Mean (± 1 SE) bimonthly porewater total dissolved phosphorus in Typha and Non-Typha associations, values are mean of top 20 cm of soil, Courtland East Site, 2007 growing season (April to August).

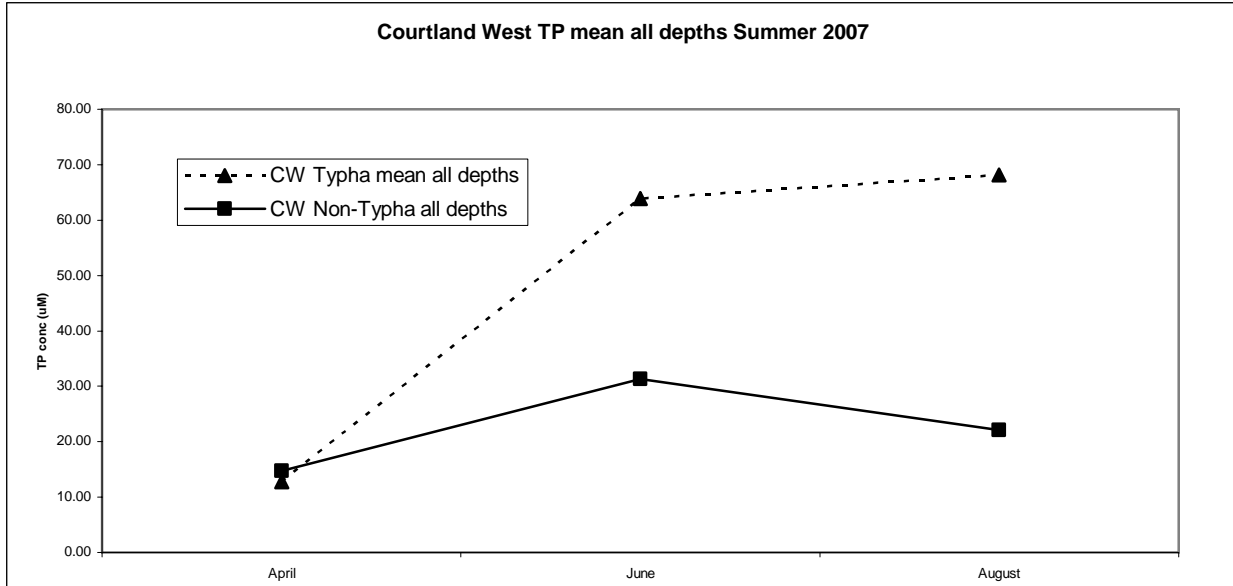


Figure 24c. Mean (± 1 SE) bimonthly porewater total dissolved phosphorus in Typha and Non-Typha associations, values are mean of top 20 cm of soil, Courtland West Site, 2007 growing season (April to August).

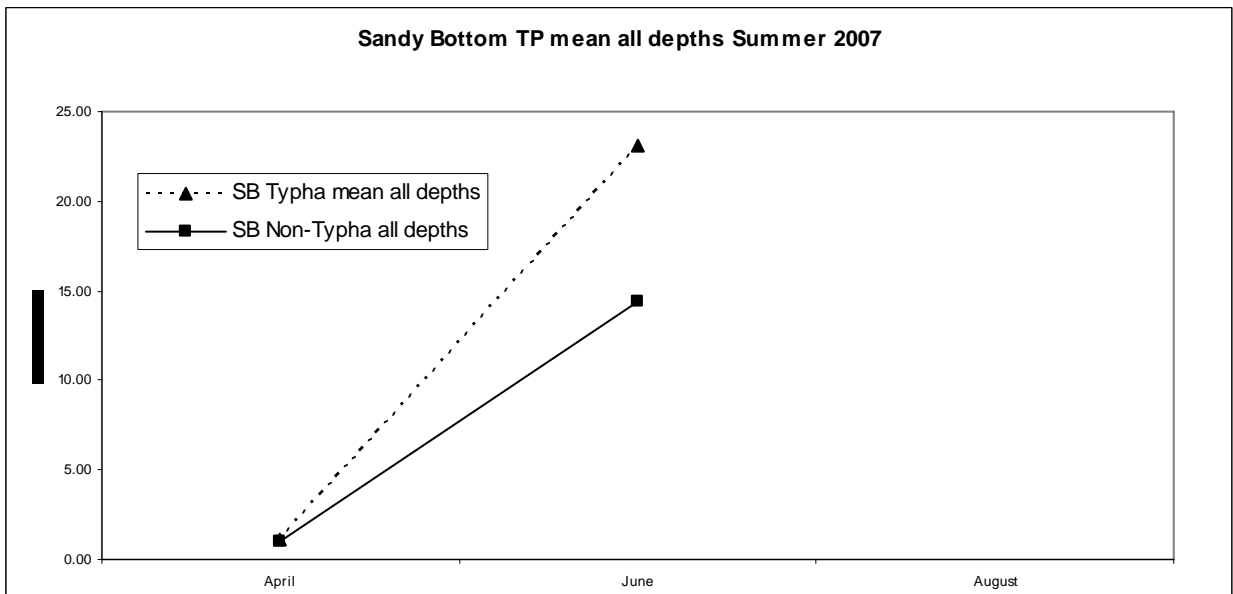


Figure 24d. Mean (± 1 SE) bimonthly porewater total dissolved phosphorus in Typha and Non-Typha associations, values are mean of top 20 cm of soil, Sandy Bottom Site, 2007 growing season (April to August).

Dissolved Inorganic Phosphorus

There was a significant difference in dissolved inorganic phosphorus between Typha and Non-Typha associations at Suffolk Bypass and Courtland West, but not at the other two study sites (Figures 25a-d). Suffolk Bypass had a significantly higher amount of dissolved inorganic phosphorus when compared with the other three sites. Dissolved inorganic phosphorus accounts for the majority of total dissolved phosphorus.

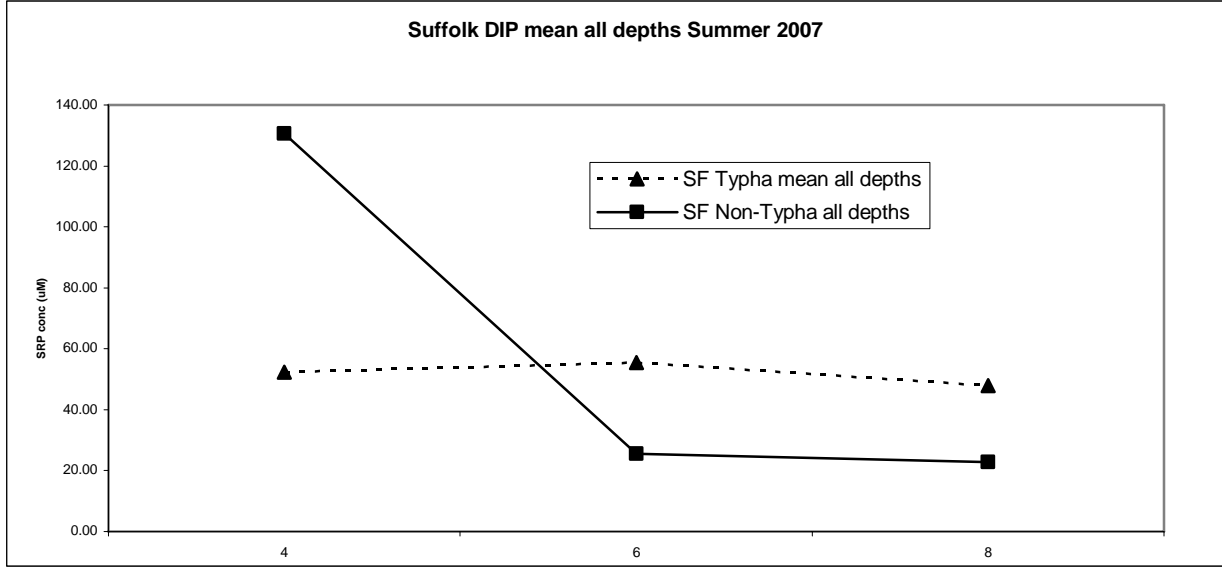


Figure 25a. Mean (± 1 SE) bimonthly porewater dissolved inorganic phosphorus in Typha associations, values are mean of top 20 cm of soil, Suffolk Bypass Site, 2007 growing season (April to August).

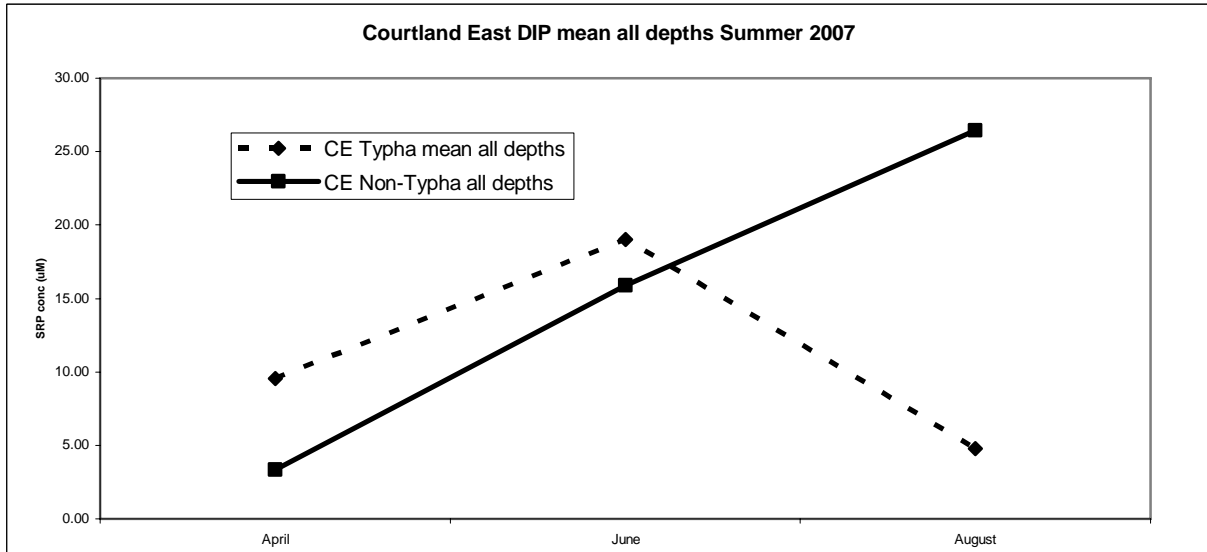


Figure 25b. Mean (± 1 SE) bimonthly porewater dissolved inorganic phosphorus in Typha associations, values are mean of top 20 cm of soil, Courtland East Site, 2007 growing season (April to August).

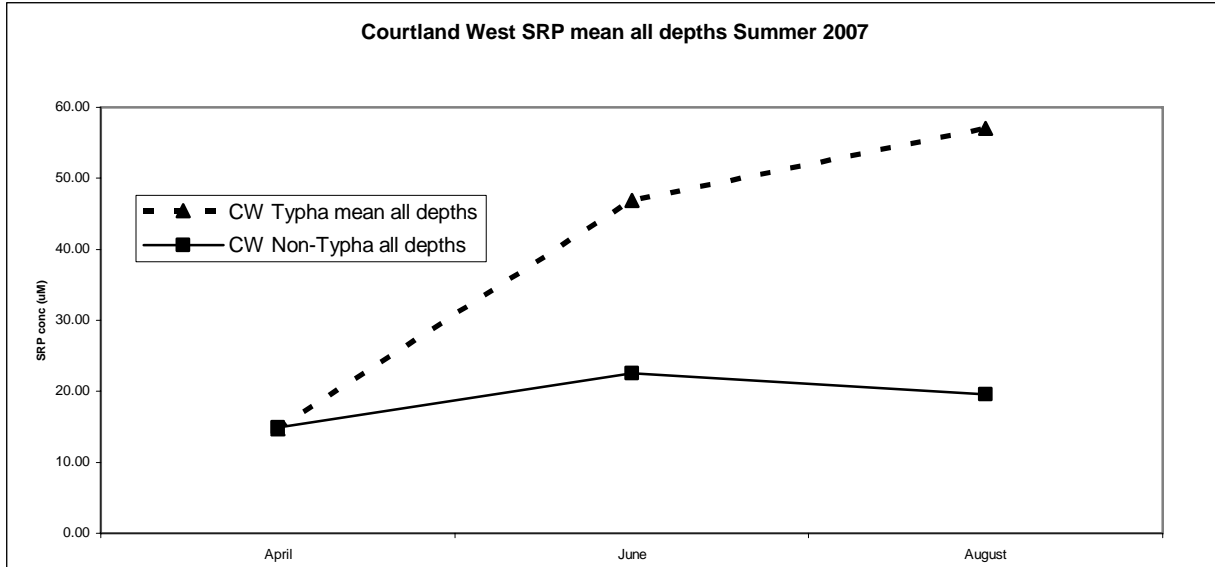


Figure 25c. Mean (± 1 SE) bimonthly porewater dissolved inorganic phosphorus in Typha and Non-Typha association, values are mean of top 20 cm of soil, Courtland West Site, 2007 growing season (April to August).

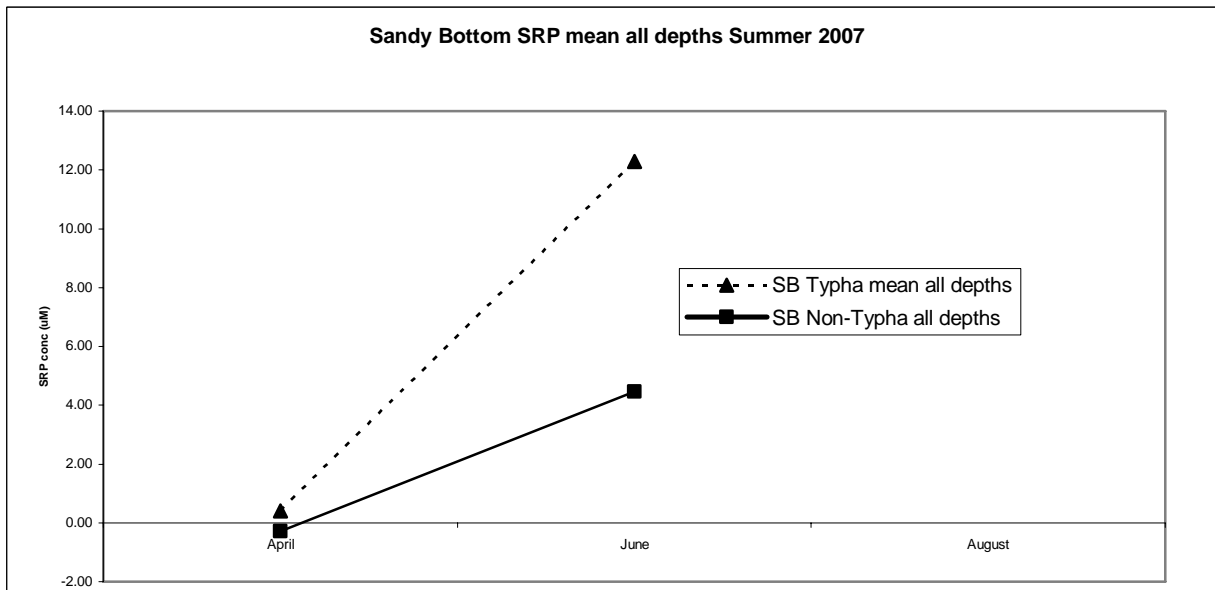


Figure 25d. Mean (± 1 SE) bimonthly porewater dissolved inorganic phosphorus in Non-Typha associations, values are mean of top 20 cm of soil, Sandy Bottom Site, 2007 growing season (April to August).

Dissolved Organic Phosphorus

Three of our study sites had significantly higher dissolved organic phosphorus in Typha associations compared to Non-Typha associations; Suffolk Bypass demonstrated no significant difference between stand types (Figures 26a-d). However, the amount of dissolved organic phosphorus present at Suffolk Bypass was higher than at all the other sites (twice the value of the next highest site).

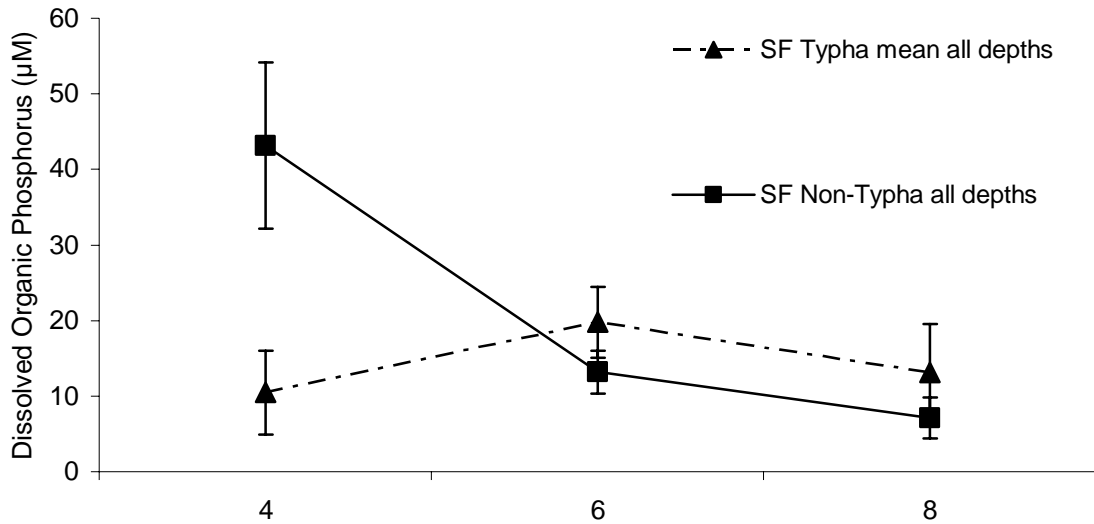


Figure 26a. Mean (± 1 SE) bimonthly porewater dissolved organic phosphorus in Typha and Non-Typha associations, values are mean of top 20 cm of soil, Suffolk Bypass Site, 2007 growing season (April to August).

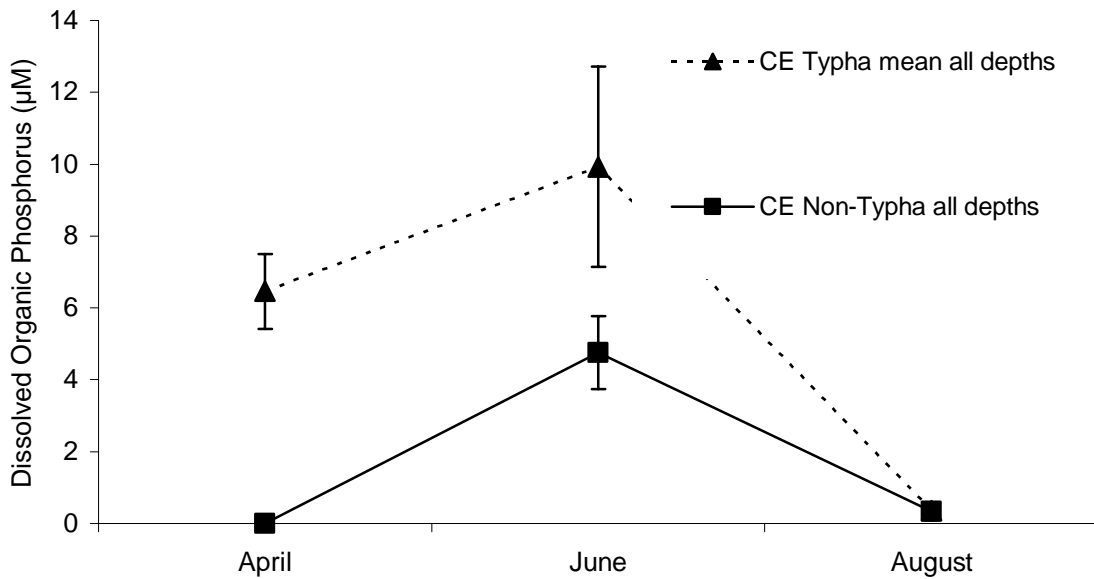


Figure 26b. Mean (± 1 SE) bimonthly porewater dissolved organic phosphorus in Typha and Non-Typha associations, values are mean of top 20 cm of soil, Courtland East Site, 2007 growing season (April to August).

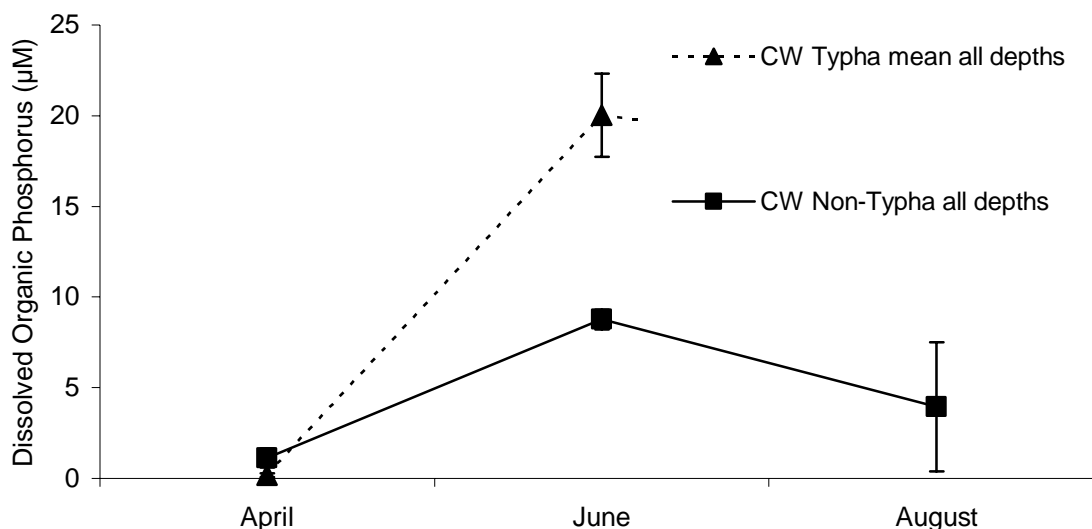


Figure 26c. Mean (± 1 SE) bimonthly porewater dissolved organic phosphorus in Typha and Non-Typha associations, values are mean of top 20 cm of soil, Courtland West Site, 2007 growing season (April to August).

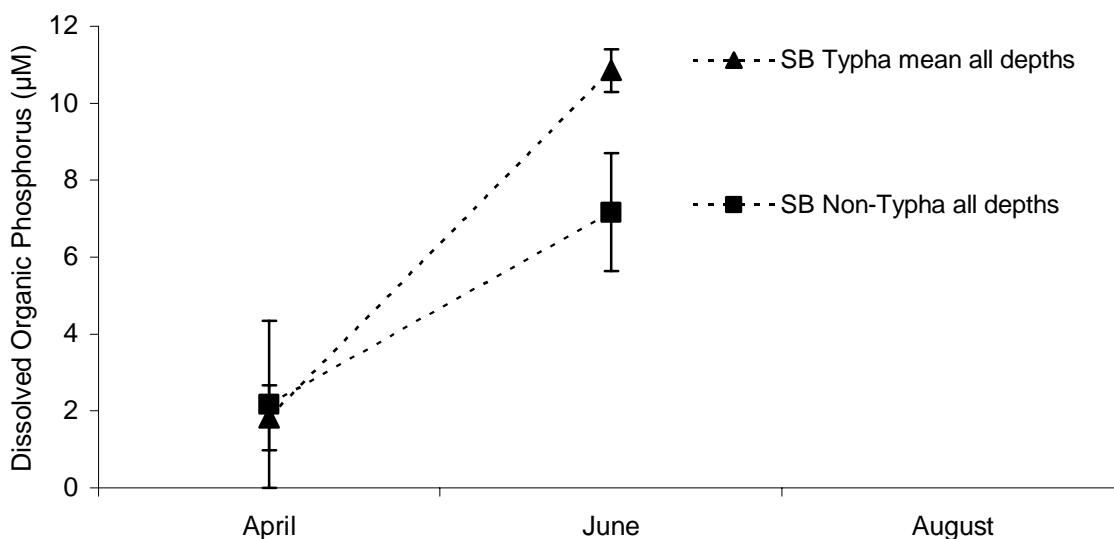


Figure 26d. Mean (± 1 SE) bimonthly porewater dissolved organic phosphorus in Typha and Non-Typha associations, values are mean of top 20 cm of soil, Sandy Bottom Site, 2007 growing season (April to August).

Ammonium

There was a significant difference in ammonium concentration between Typha and Non-Typha associations at Sandy Bottom, however, there was no difference within the three other research sites (Figures 27a-d). This was the opposite trend that we saw in the other forms of phosphorus measured.

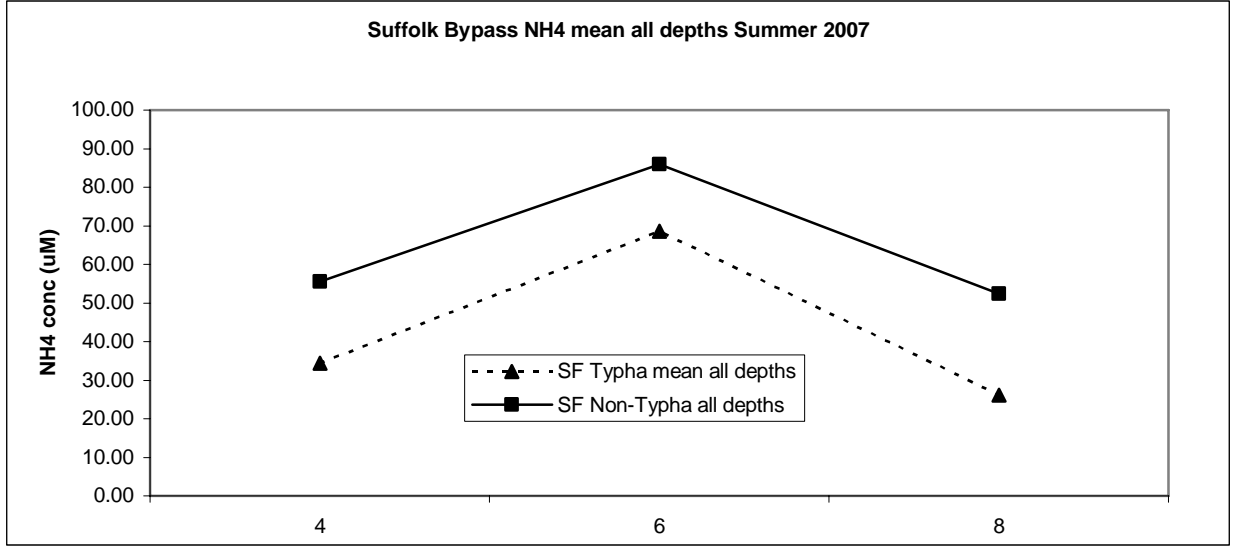


Figure 27a. Mean (± 1 SE) bimonthly porewater ammonium in Typha and Non-Typha associations, values are mean of top 20 cm of soil, Suffolk Bypass Site, 2007 growing season (April to August).

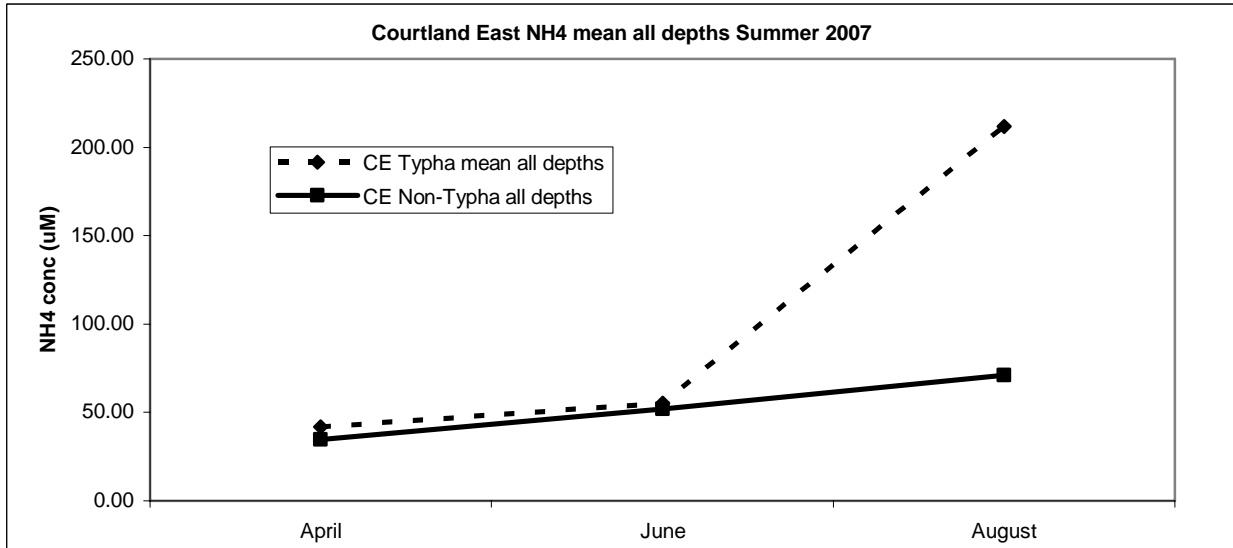


Figure 27b. Mean (± 1 SE) bimonthly porewater ammonium in Typha and Non-Typha associations, values are mean of top 20 cm of soil, Courtland East Site, 2007 growing season (April to August).

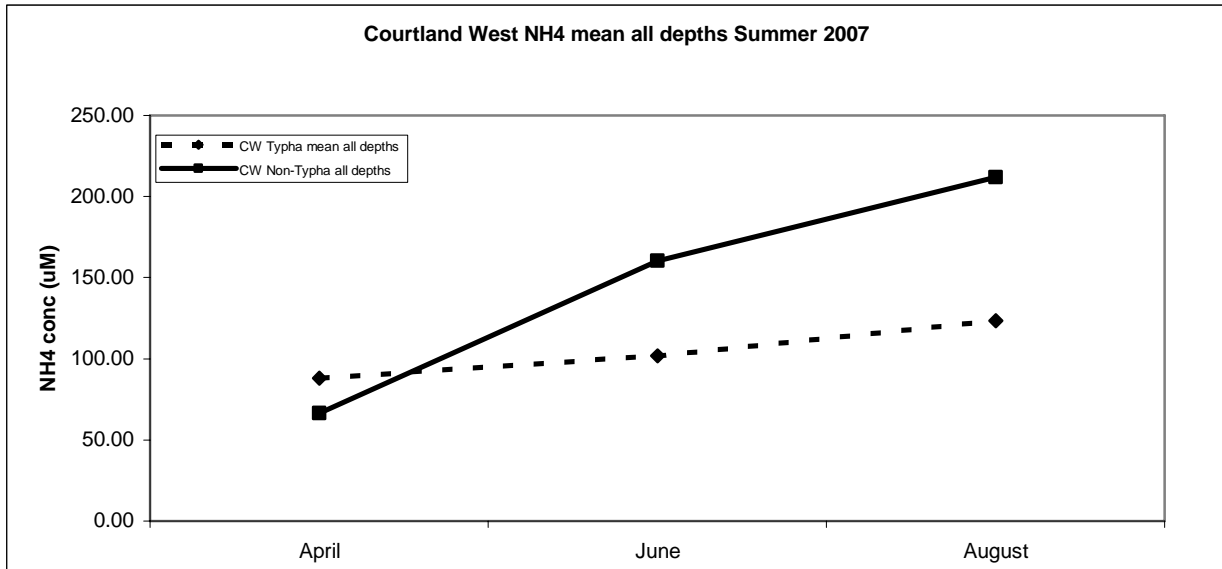


Figure 27c. Mean (± 1 SE) bimonthly porewater ammonium in Typha and Non-Typha associations, values are mean of top 20 cm of soil, Courtland West Site, 2007 growing season (April to August).

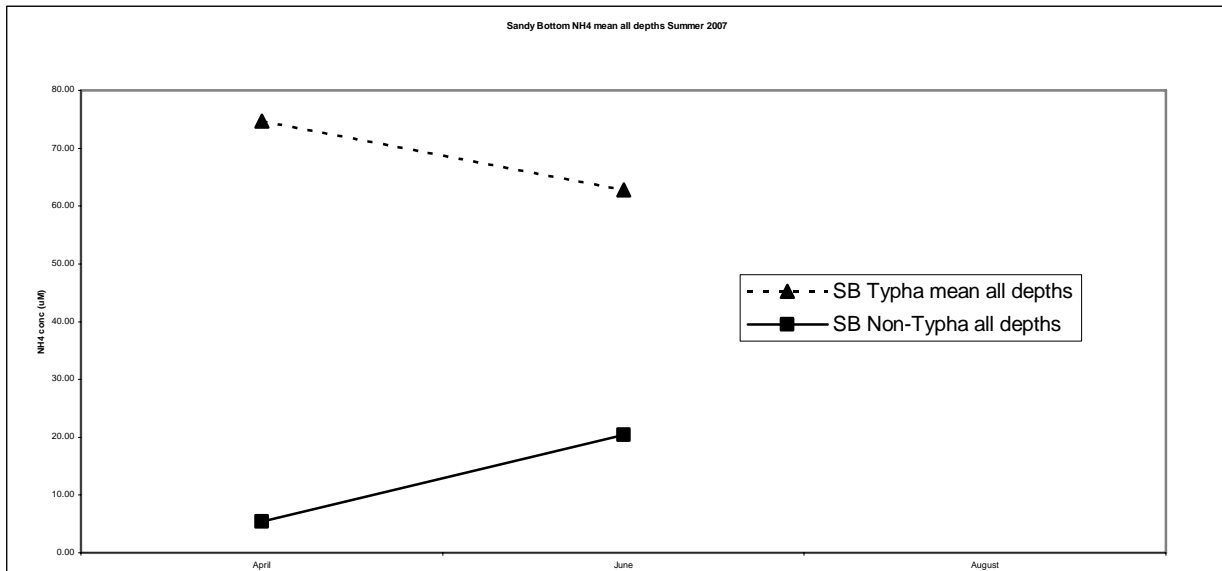


Figure 27d. Mean (± 1 SE) bimonthly porewater ammonium in Typha and Non-Typha associations, values are mean of top 20 cm of soil, Sandy Bottom Site, 2007 growing season (April to August).

DISCUSSION

Vegetation

Working on 15 of the 20 sites, DeBerry and Perry (in press) found that the overall average species richness was a respectable 29.1 species per site. The average species richness within site age classes (i.e., sites classified as 1-2, 3-5, 6-10, and 11-15 year age classes) ranged from 24.5 to 33.3, with highest values in the youngest and oldest age classes (33.3, 24.5, 27.5, and 31.7, respectively). They noted that the variance (as approximated by standard error) for species richness and diversity values decreased with increasing site age. They also noted a shift from a perennial herbaceous dominated wetland to a woody dominated one in a 10 to 15 year time span. While no initial data was present for the older sites, cattails were present in all of the young sites. It is more than likely that cattails were present early in the development of the older sites (small amounts could be found in nearby ditches); however, their lack of occurrence in older sites may be due to the overstory link (i.e., woody canopy cover inhibits herbaceous growth) to wetland maturation (see Gilliam 2007). Combined with our preliminary findings of the effect of cattails on bald cypress, it therefore appears that the composition of the herbaceous species present in a young site does not seem to matter. While they may compete initially with planted woody species for open resources, the woody species will eventually develop the ability to enclose the resources and gain control.

Our data also showed that nutrient loads, which others have found tend to affect which cattail may dominate an area (Woo and Zedler 2002), did not increase cattail occurrence. Since many of the cattails found in our study sites were hybrids, it is possible that competition between cattail species has, unfortunately, become unimportant.

DeBerry and Perry (in press) conclude that since development of a woody canopy in forested wetland creation is a logical goal, many sites are often planted with late successional species in an attempt to “jump start” succession (U.S. Army Corps of Engineers 2002). This practice, however, has met with little success due to high mortality of such species under the stressful site conditions of early-created wetland development (McLeod et al. 2001). The planting specifications on the sites used in our study show that a diversity of species were selected for planting over the years. Although our study was not designed to assess survivorship of planted species, one general observation that we can make is the lack of certain late successional groups on older sites (e.g., *Quercus* spp.). Furthermore, DeBerry and Perry (in press) indicated that a shift in dominance from planted to naturally colonizing volunteer trees and shrubs occurs along the chronosequence of VDOT sites, resulting in a stand of pioneer species (e.g., *Salix nigra*) similar to observations made by Spencer et al. (2001) in regenerating hardwood swamp chronosequence in southeastern Virginia. Such dominance shifts may be inevitable if wetland practitioners continue to plant late successional species on newly created wetland sites. Alternative planting strategies, like incorporating nurse crops such as *Salix nigra* early in the planting process, may be beneficial practices that have the potential to increase structural complexity and species richness over time (McLeod et al. 2001).

Vegetation – Specific Sites

Diversity Indices and Species Richness

While it was hypothesized that *Typha* would be the dominant species in *Typha* Associations, it was shown that in three of the sites (CW, CE, and SF) other species were co-dominant with *Typha*. This is a strong indication that the occurrence of *Typha* does not limit the growth of other vegetation and that *Typha* Associations are not monocultures. Overall diversity and species richness values also indicate that *Typha* dominance did not cause a consistent negative effect on richness or diversity at any of the sites. Other studies have reported *Typha* invasion and subsequent lowering of species diversity in many types of disturbed wetlands (Newman et al. 1994, Green and Galatowitsch 2002, Woo and Zedler 2002, Childers et al. 2003). However, in this study, no consistent negative effect (decrease in SR or H') was associated with vegetation community dominance by *Typha*.

Community Composition Differences Related to Succession

The standing crop biomass observed in *Typha* Associations was within the range described by Mitsch and Gosselink (2000) for natural inland freshwater wetlands (500-5500 g m⁻²). While the upper portion of the standing crop biomass range for Non-*Typha* Associations also fell within Mitsch and Gosselink's description, the lower end did not. High standing crop biomass in *Typha* Associations is most likely a factor of the large size of *Typha* aboveground plant material.

Models proposed by van der Valk (1981) and Noon (1996) predict that the proportion of annuals will be high in the first few seasons of primary succession, and then decrease from the time of initial colonization of the site, eventually giving way to a community dominated by perennials. DeBerry and Perry (in press) as part of this study found that perennials were more important than annuals in created forested wetlands in the piedmont and coastal plain of Virginia. We also found that the annuals in the four study sites were much lower than predicted by van der Valk and Noon's models, but were consistent with what DeBerry and Perry (2004, 2007, in press) found in other southeastern Virginia created wetlands.

Comparing the four sites in the context of Noon's (1996) model, Sandy Bottom and Suffolk Bypass can be considered to be in what Noon defined as the Arrival and Establishment Phase (1-4 years since construction). These types of sites would be expected to be dominated by highly competitive quickly reproducing species, generally annuals and prolifically reproducing perennials that utilize "annual-like" strategies (DeBerry and Perry 2005). These species are able to take advantage of large amounts of open soil in newly constructed sites and expand throughout the entire initial growing season via rhizomatous growth, not just when seeds are dispersed. While in Noon's model the very early successional communities exhibited high species richness because of recruitment of a wide variety of species, this was not observed at Sandy Bottom and Suffolk Bypass. This is possibly due to the lack of adjacent herbaceous wetlands to serve as propagule sources. Because these sites are not hydrologically connected to other wetlands via surface water, the only opportunity for seed introduction is through wind-dispersal. Since the majority of wetlands near these sites are mature forested wetlands, the

variety of herbaceous wetland propagules is likely lower than if there were adjacent herbaceous wetlands. Therefore, the seeds that do make it into the site are often from the weedy cosmopolitan species, with prolific wind-dispersed propagules, that can be found in ditches and other small confined wet areas. These species include *Typha* spp., *P. australis*, *S. cyperinus*, and *J. effusus*. These highly competitive species have the ability to outcompete other vegetation; combined with a low diversity in introduced propagules, they are quickly able to take over early successional sites. The lower recruitment diversity associated with the created wetlands in this study may be a strong control on the successional development of the vegetation community as the sites age.

Noon's model goes on to predict that as herbaceous percent cover increases to 100% or greater, the community shifts from one that is dominated by grass-like species to one dominated by forbs. While the percent cover was greater in the older study sites, many of the sites were still dominated by graminoid species such as *Typha* spp., *J. effusus*, and *S. cyperinus*. It is likely that these grass, rush, and sedge dominated communities will persist until woody species such as *Taxodium distichum* (planted) and *Salix nigra* (a volunteer) become mature and shade out the herbaceous vegetation layer. Since these created sites were designed to replace the structure and function of palustrine forested wetlands and the mature forested vegetation community is the desired state of these sites, it seems that the successional change (or lack thereof) associated with the herbaceous vegetation may not be the most important aspect of the vegetation community development. Therefore, it is perhaps more important to better understand the effect of the entire herbaceous community on the development of woody saplings (Gilliam 2007).

While some inferences can be made about the vegetation community at these sites in the context of primary successional models, the lack of clear trends associated with newer and older sites indicates that all created mitigation wetlands do not easily fit into successional models and that inferences made about one wetland often do not translate to other sites of similar age.

Nutrient Dynamics

Differences Between *Typha* and Non-*Typha* Associations

Craft et al. (1995) and Craft and Richardson (1997) found that *Typha* populations expanded in response to phosphorus (P) enrichment. However, in this study we found that there were no significant differences or trends between the soil chemistry of *Typha* and Non-*Typha* Associations. In 2007, only total phosphorus was significantly higher in the Non-*Typha* Association at Courtland West, and acid extractable phosphorus was higher in the Non-*Typha* Association at Courtland East. While these are both the older, more mature created sites, the lack of a consistent trend in the data and the fact that only one form of phosphorus was different in each, does not allow for interpretation of differences based on site age or *Typha* or Non-*Typha* vegetation assemblage.

Porewater sampling via diffusion samplers was conducted because it allows sampling of the soil solution in the matrix pores, which are the areas where roots come into contact with porewater (Harvey et al. 1995, Winger et al. 1998). As was the case with soil nutrients, there were no consistent significant differences in porewater nutrient concentration between *Typha*

and Non-Typha Associations for any of the sites. This further confirms the conclusion that the soil and porewater nutrient availability was not different in areas of these sites that were dominated by *Typha* and areas that were not. Therefore, it can be concluded that the soil and porewater parameters investigated in this study were not a major control on the presence or density of *Typha* in created wetlands less than 15 years old; the differences in dominant vegetation type in these areas were due to other factors, such as propagule dispersal and inter-specific competition.

Differences Between Sites

Due to the lack of distinction between soil and porewater characteristics in Typha and Non-Typha Associations, the two Association types within each site were combined for all inter-site comparisons. The initial experimental design assumed a grouping of the sites by age. However, large nutrient availability differences observed between the two younger sites (Sandy Bottom and Suffolk Bypass) have made grouping these sites impractical. Sandy Bottom had different hydrology and soil characteristics than Suffolk Bypass, primarily due to epiaquic conditions that are a result of soil compaction that occurred during the wetland construction process. The impermeable clay pan in the soil profile has led to perching of surface water and has prevented discharge of groundwater, resulting in extremely dry conditions during much of the summer (Daniels et al. 2005, Fajardo 2006). The low OM measured at Sandy Bottom, a site where 4% OM topsoil was supposedly was disked into the soil to a depth of 20 cm (Daniels et al. 2005, Fajardo 2006), indicates that either this OM addition did not occur to the level required, or that it was very rapidly remineralized and lost from the system. Either way, the lack of OM in these the Sandy Bottom soils has resulted in a fundamental difference between Sandy Bottom and Suffolk Bypass. This difference is compounded by the fact that the Suffolk site had very high OM additions to the topsoil during construction, in the form of partially composted leaf litter. This resulted in initial percent soil OM between 2 and 5% in the surface layers (W.L. Daniels, personal communication). The OM additions at Suffolk Bypass have lead to the extreme differences observed between the Suffolk site and the other three sites in all soil parameters.

The results of the vegetation community analyses indicated that there were no trends in differences between the individual sites in species richness and Shannon diversity indices. This was not the case for the nutrient results, as there was a definite trend of significantly higher nutrient availability and OM at Suffolk Bypass. This site had consistently higher OM, total carbon, and total nitrogen than all other sites in 2006 and 2007. The older sites did not receive the same type of OM amendments and despite over 15 years of OM accumulation have not reached the same level of soil OM as Suffolk Bypass. Because of the very low level of OM at measured at Sandy Bottom, Courtland East, and Courtland West, the increase in OM of 1% of bulk soil content that is most likely not representative of the normal annual increase. Long-term sampling is needed to understand the incorporation of OM in created wetlands over long periods of time. The inability of created wetlands to accumulate OM to a level equivalent to natural wetlands has been identified by other researchers and has led to the practice of higher levels of OM incorporation during wetland construction (Stolt et al. 2000, Daniels et al. 2005).

Suffolk Bypass also had much higher porewater concentration of total dissolved phosphorus (TDP), dissolved inorganic phosphorus (DIP), and dissolved organic phosphorus (DOP), than the other sites. This is primarily due to very high concentration of all forms of phosphorus measured at Suffolk Bypass in April, which then dropped off and were similar to the concentrations measured at Courtland East and West. The differences in the higher 2006 and lower 2007 phosphate data were possibly due to a wet spring and dry summer in 2006 and normal rainfall pattern in 2007. The former would have slower inorganic uptake during dry (drought) conditions while the latter may enhance uptake (Mitsch and Gosselink 2007). Sandy Bottom had a consistently lower porewater concentration of all forms of phosphorus compared to the other sites (Figures 24-26). The different trend is seen in porewater ammonium (NH_4^+), with the older sites, Courtland East and West, having higher concentrations than both younger sites, Suffolk Bypass and Sandy Bottom (Figure 27). The difference may be attributed to higher (mature) root activity in the older sites (Mitsch and Gosselink 2007) that would enhance remineralization. However, Suffolk Bypass, with its large OM content acting as catalyst, would be expected to rapidly catch up to the older sites. On the other hand, the low OM in Sandy Bottom could cause it to lag behind.

***Typha* Leaf Tissue**

There were no significant differences in *Typha* aboveground tissue N:P ratio in any of the four study sites. The N:P ratio ranged from 20 to 30 in 2006 and from 15 to 35 in 2007. This wide range of variation was observed within all sites and seems to indicate that even for a single population, growing under similar conditions, the range of tissue molar N:P ratios can be very large. In 2006 and 2007, the majority of the sampling points were at or below the critical molar N:P ratio of 31, indicating N limitation according to Koerselman and Meuleman (1996). However, the month-to-month variation within a single site was often larger than 4.5, the range between the critical values for N and P limitation (Koerselman and Meuleman 1996). This seems to indicate that the range they identified may be too fine to account for all the variation that can occur within a population, and presumably between populations.

A study conducted by McJannet et al. (1995) measured a molar N:P ratio of 9.25, in *Typha x glauca* grown under nutrient enrichment, these results were much lower than the range we measured, and according to Koerselman and Meuleman (1996) indicated that these plants were also N limited. However, since N and P were both available in high quantities, in their experiment the excess P in the plant tissue may represent luxury uptake of P relative to N, which can occur during periods of very high P availability (McJannet et al. 1995). The lack of N or P uptake that was observed in *Typha* plants propagated from rhizomes in sterile sand mixtures, supports the conclusion that *Typha* have large stores of nutrients in belowground tissue, possibly from luxury uptake, that is utilized for growth under low nutrient conditions. Under very high nutrient enrichment, luxury uptake may also be expressed in aboveground tissue, as was the case in the study by McJannet et al. (1995). However, we did not observe leaf tissue N:P ratios less than 10, indicating that phosphorus is not available in high enough levels to elicit luxury uptake and storage in aboveground tissue.

Since the focus of this research was to determine if environmental factors had an effect on *Typha* dominance, it was the only species for which leaf tissue was analyzed. Therefore inferences about relationships between *Typha* N:P ratio and soil N:P ratio are only made for the *Typha* Associations in the sites. However, since the soil characteristics were not significantly different in *Typha* and Non-*Typha* Associations it is likely that the same soil processes were taking place across the entire sites, regardless of dominant vegetation species.

Since all sites had areas of *Typha* expansion, it can be assumed that these plants were not nutrient limited. Therefore, we assumed that 25-35 was an optimal range of N:P ratio in *Typha* tissue. The soil range of N:P ratios in 2006 (5 to 7) was very low compared to the optimal *Typha* N:P, which would indicate that the sites were N limited, this is also indicated by comparison to Koerselman and Meuleman (1996) critical values. However, in 2007 the soil N:P ratios were higher in all sites. The ratios, therefore, appear to uphold the hypothesis that the 2006 growing season was less than optimal. Suffolk Bypass and Sandy Bottom had N:P ratios (21-26) that were very similar to what was consistently seen in *Typha* leaf tissue, indicating no limitation. In 2007, the range of Courtland East and West soil N:P ratios were much higher (47-60) than the *Typha* leaf levels, which would indicate phosphorus limitation. The wide range in soil N:P ratio results in all of these sites between 2006 and 2007, may indicate that changes in soil N:P ratios do not have an immediate effect on aboveground tissue nutrient concentrations in *Typha*. Whether these changes are evident in belowground tissue or other vegetation types is not known, as these were not sampled in this study. However, the decrease in soil total phosphorus over time observed in these sites seems to indicate that it is being lost from the system, primarily to sequestration in perennial plant tissue.

Increasing Phosphorus Limitation with Site Age

Vitousek and Walker (1987) proposed a model for phosphorus dynamics in volcanic soil primary succession that may be useful in understanding phosphorus dynamics in created wetlands. In newly created volcanic soil, there is no OM and relatively high abundances of mineral phosphorus. This is very similar to initial soil conditions in created wetlands, where primary succession occurs on previously upland subsoils that are devoid of OM and have readily available inorganic phosphorus in the form of metal oxyhydroxides and clay complexes. The adsorbed and complexed inorganic phosphorus is released following inundation and lowering of redox potentials. This initial high phosphorus availability is rapidly taken up and stored in perennial plant tissue. A portion of the plant's organic phosphorus is restored to the soil as detritus and is remineralized by bacteria, releasing inorganic phosphorus, which is then rapidly taken up by plant growth. As the live aboveground and belowground biomass increases, especially in sites dominated by large perennial species, this process of uptake and storage of phosphorus in plant biomass, results in a decrease in the amount of soil total phosphorus as the site ages. This can lead to a "terminal steady state" of phosphorus deficiency in which organic phosphorus is the primary form of phosphorus in soil and very rapid uptake occurs upon remineralization (Walker and Syers 1976). The proposed conceptual model of changes in forms of phosphorus over time can be seen in Figure 28. The approximate locations on the time continuum of Suffolk Bypass and Courtland East and West can also be seen in Figure 28. These locations are based on the relative proportions of forms of soil phosphorus measured at these sites in 2007.

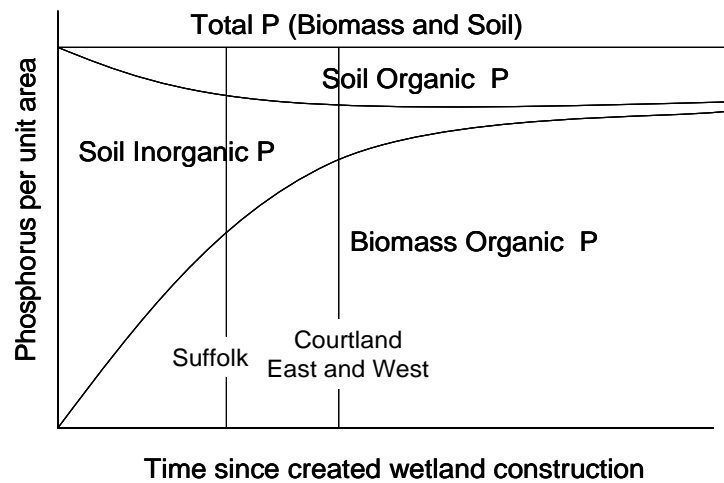


Figure 28. Conceptual model of proposed phosphorus dynamics in soil and plant biomass in created wetlands over time. Includes locations of Suffolk and Courtland East and West study sites on the trajectory of soil primary succession, based on soil phosphorus measurements in 2007.

In the created wetlands used in this study, the primary sources of nitrogen were surface runoff, incorporation of detrital OM, and atmospheric deposition. The major sources of nitrogen loss are sequestration in perennial biomass and denitrification or lost through outflow of surface water from these sites. It can be concluded that the rate of nitrogen addition was greater than the rate of nitrogen loss from these systems due to the observed increase in soil total nitrogen that was measured between 2006 and 2007. If this is a consistent trend, it may indicate an increase in nitrogen availability in created wetlands as they age. This would hasten the increase in soil N:P ratio as the site ages.

Typha may be able to capitalize on the high availability of phosphorus relative to nitrogen early in the site development, and expand rapidly. Bevington (2007) hypothesized that *Typha* may preferentially use nutrients stored in rhizomes for aboveground growth regardless of soil nutrient availabilities. This large supply of nutrients stored in rhizomes may allow *Typha* to maintain growth and expansion as nutrient supplies, particularly phosphorus, decrease in the surrounding soil. As phosphorus abundance decreases relative to nitrogen, *Typha* may be able to maintain itself from rhizomatous stores despite being unable to expand as readily. This is supported by the observation of rapid *Typha* expansion at Sandy Bottom, the site that had the lowest soil N:P in 2007. As created wetlands age the soil N:P increases. Once it is greater than 35 (the highest N:P measured in *Typha* tissue) the *Typha* population may become phosphorus limited. Because of large stores of nutrients in rhizomes, *Typha* may be able to continue to expand under this phosphorus limitation, but eventually this terminal steady state of phosphorus deficiency (Walker and Syers 1976) results in less expansion and dominance of the vegetation community by *Typha*. This is supported by anecdotal reports of decreases in *Typha* density and stand area in older created wetlands (S. Russell and L. Snead, personal communication).

More research is needed to test this hypothesis, and it would most likely require repeated annual sampling of soil nutrients and *Typha Association* area and density. Hopefully, the results of this research can be used as a starting point to continue to measure soil nutrient availability and *Typha Association* density in created wetlands, in order to better understand the successional dynamics of nutrient availability in these systems.

CONCLUSIONS

- *The results of the evaluation of a number of biological, chemical, and physical parameters studied (specifically, vegetation community structure, hydrology, and soil and porewater nutrient availability) within four created wetlands in the coastal plain of Virginia do not support the current rationale for Typha removal in created wetlands in Virginia; namely, that Typha dominance limits diversity within the vegetation community. Typha removal alone would more than likely not accomplish an increase in diversity.*
- *Although Typha Associations tended to occur in deeper water, there was no significant difference in water depth between Typha and Non-Typha Associations in this study. Therefore, although water depth may be a factor in Typha density, this work, backed by the literature, indicates that it may not be the main control on its prevalence within a vegetation community. Instead, it may be that deeper water inhibits other species from colonizing, therefore allowing the more anaerobic-tolerant rhizomes of Typha spp. to vegetatively colonize the deeper water.*
- *Neither soil parameters nor porewater nutrient concentrations were a major control on the presence or density of Typha. For most of these variables, no significant differences or trends between Typha and Non-Typha Associations occurred at any site. For those parameters that did exhibit significant differences, none did so consistently between sites or between sampling years; in other words, no trends emerged. Site construction and management may primarily account for observed differences in wetland soils.*
- *Based on growth measurements of 100 planted bald cypress (T. distichum) (50 trees in Typha dominated- and 50 in non-Typha dominated-understory) taken in a young created forested wetland. the occurrence of Typha did not significantly limit the growth of bald cypress saplings. Therefore, forested wetlands may develop at many mitigation sites without costly and potentially hazardous cattail control efforts. However, greater attention to inundation tolerance of saplings and hydrologic conditions in created wetlands may be needed.*
- *If the principle of obtaining “late succession early” is retained as a planting goal, the data in the study suggest that less effort should be expended on eradicating early perennial species such as cattails (except where hydrology is incorrect) and more on seeding and/or planting certain species, such as Betula nigra, Cephalanthus occidentalis, Fraxinus pennsylvanica, Quercus lyrata, Taxodium distichum, and Salix nigra, that may be more appropriate introductions to young wetland sites. Each of these woody species employs natural reproductive strategies characterized by germination during dry (drawdown) conditions, with sapling adaptations for survival when sites become re-flooded (Wallace et*

al. 1996; Deller and Baldassarre 1998; Keeland and Conner 1999; Cronk and Fennessey 2001). Thus, the typical management practice of “planting in the dry” (i.e., planting created sites prior to flooding), followed by re-introduction of surface water after planting, approximates the natural regeneration niche for such species, which is perhaps a factor in the putative survival rates of these species observed across all site age classes in our study (see DeBerry and Perry in press for complete discussion of appropriate woody plantings).

- *Cattail invasion at mitigation sites did not decrease growth of planted bald cypress.* Therefore, eradication of cattails at the four sites used in the Typha portion of the study may not be necessary. Further research is needed in order to assess the effect of cattails on woody vegetation long-term survival and to confirm these findings at additional sites. Forested wetlands may develop at many mitigation sites without costly and potentially hazardous cattail control efforts. However, greater attention to inundation tolerance of saplings and hydrologic conditions in created wetlands may be needed.
- *The sites studied did not fit easily into general successional models; there were no clear patterns in vegetation community structure associated with site age.* These findings suggest that it is important to consider created wetlands on an individual basis when setting management criteria and goals. Managers need to consider the structure (i.e., herbaceous, shrub, or tree) of the vegetation community that is ultimately desired when developing management practices; it may be unnecessary or even counterproductive to manage intermediate herbaceous succession in a wetland that is ultimately designed to replace a palustrine forested system.

RECOMMENDATIONS

1. *With the concurrence of the regulatory agencies, the National Resources Program of VDOT's Environmental Division should place additional emphasis on ensuring that hydrologic conditions are correct at VDOT constructed wetland sites as the results of this research effort appear to indicate that deeper water can inhibit colonization of other species, potentially resulting in Typha dominance.*
2. *With the concurrence of the regulatory agencies, the National Resources Program of VDOT's Environmental Division should emphasize nurse species as well as the planting and/or seeding of secondary succession species in the woody plantings they use at VDOT mitigation sites.*
3. *The National Resources Program of VDOT's Environmental Division should use heavy seeding of OBL and FACW plants at mitigation sites in order to establish a rapid cover of wetland herbaceous species to help to minimize invasion by less desirable species.*
4. *The wetland site managers in the National Resources Program of VDOT's Environmental Division should note that to replace mature, palustrine, forested wetlands (as in the study sites), woody saplings must grow large enough to shade out herbaceous layers before a*

community shift occurs. Therefore, it may be more productive to focus on the survival and growth of woody saplings than on the control of intermediate herbaceous community succession (e.g., removing *Typha*).

5. *Future work performed for the Environmental Division should investigate the effect of Typha spp. on other species that are commonly planted in created forested wetlands in southeast Virginia such as American sycamore (Platanus occidentalis), green ash (Fraxinus pennsylvanica), and hydrophytic oaks (e.g., Quercus falcata v. pagodafolia, Q. lyrata, Q. palustris).* However, because there are several diseases affecting green ash, including the Emerald ash borer, *Agrilus planipennis*, planting a large amount of green ash is of questionable value at this time.

BENEFITS AND IMPLEMENTATION PROSPECTS

Benefits

If the recommendations resulting from this research effort are accepted by the Corps of Engineers and the Virginia DEQ and followed by VDOT, it will result in a change in the way the department's wetland mitigation sites are managed. In general, this will result in fewer resources devoted to eradication and additional emphasis placed on ensuring hydrologic conditions are optimal for wetland herbaceous and woody species. More specifically, it will reduce the need to employ the mechanical and chemical eradication methods previously used. This new approach will ultimately result in more successful development of forested wetland sites. The potential for monetary savings with the amended approach will be dependent on the size, complexity, and species composition of the specific sites at which it is employed.

Implementation Steps

Implementation of the recommendations is dependent upon the permitting agencies. The following steps outline the proposed method for implementation:

1. Joint meeting with Corps and DEQ to discuss research findings and recommendations
2. Develop general guidance on management of site design and *Typha* populations
3. Develop site-specific adaptive management plans as needed

The implementation effort will be led by the Environmental Division's Natural Resource Program with support provided by the first author of this report and the Virginia Transportation Research Council.

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**APPENDIX
FORMULAS**

Formula 1: Relative Cover and Relative Frequency: Cover was estimated using a modified Braun-Blanquet cover scale(see Methods for description). Frequency was calculated as the presence/absence of cover values. Importance Value was calculated as the sum of the Relative Cover and Relative Frequency divided by two (2).

$$\text{Relative cover} = \frac{\text{Species coverage}}{\text{Sum of coverage values for all species}} \quad \times 100$$

$$\text{Relative frequency} = \frac{\text{Species frequency}}{\text{Sum of frequency values for all species}} \quad \times 100$$

Formula 2: Shannon Diversity Index (H') (Zar 1999) calculated using the relative IV data for each stand.

$$H' = -\sum_{i=1}^k p_i \log p_i$$

$$J' = \frac{H'}{H'_{\max}} \quad \text{where } H'_{\max} = \log k$$

where k is the number of species, p_i is the proportion of total IV for species i .

Formula 3: Ellenberg Community Coefficient Similarity Index (SI_E) (Mueller-Dombois and Ellenberg 1974).

$$SI_E = \frac{(M_c / 2)}{(M_a + M_b + M_c / 2)}$$

where M_a is the total IV for the species found only in site a , M_b is the total IV for species found only in site b , and M_c is the total IV for species found in both sites a and b

Formula 4: Weighted Averages were calculated as the product of the sum of per stand IV for each month and the indicator index of that species (Reed 1988). Indicator values ranged from 1 (OBL) to 5 (UPL), with intermediate indicators assigned in between (FACW+ = 1.67, FACW = 2, FACW- = 2.33, FAC+ = 2.67, FAC = 3, FAC- = 3.33, FACU+ = 3.67, FACU = 4, FACU- = 4.33) (Bailey 2007)

$$WA = \frac{(x_1 w_1 + x_2 w_2 + \dots + x_n w_n)}{\sum_{i=1}^n x_i}$$

where n is the number of species, x_1, x_2, \dots, x_n are the relative IV values for each species in the stand, and w_1, w_2, \dots, w_n are the indicator values of each species: