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Drivers of Sediment Accumulation and Nutrient Burial in Coastal South Carolina Residential Stormwater Detention Ponds

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Abstract

Stormwater detention ponds are widely utilized as control structures to manage runoff waters during storm events. These sediments also represent significant sites of organic carbon and nutrient burial. Here, carbon (C) and nutrient sources and burial rates were determined in 14 residential stormwater detention ponds throughout coastal counties of South Carolina. Bulk sediment accumulation was directly correlated with catchment impervious surface coverage ($R^2 = 0.90$) with sediment accumulation rates ranging from 0.06 to 0.50 cm y^{-1}. These rates of sediment accumulation and subsequent pond volume loss are lower than expected indicating that required maintenance dredging schedules be reassessed. Strong, positive correlations between the Terrestrial Aquatic Ratio (TAR_{HC}) biomarker index and sediment accumulation rate ($R^2 = 0.77$), in conjunction with high C:N ratios (16 – 33), suggests that terrestrial biomass drives this sediment accumulation, with relatively minimal contributions from algal derived material. Carbon and nutrient concentrations are consistent between ponds and differences in burial rates were therefore driven by rates of bulk sediment accumulation. Rates of C and nutrient burial (C: 8.7 – 161 g m^{-2} y^{-1}, N: 0.65 – 6.4 g m^{-2} y^{-1}, P: 0.238 – 4.13 g m^{-2} y^{-1}) are similar to those observed in natural lake systems, but lower than those observed in reservoirs or impoundments. Though individual ponds are small in area (930 – 41,000 m^2), they are regionally abundant and potentially capable of sequestering C and nutrients at environmentally significant rates.

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Chapter 1. Introduction

Global population growth has led to an expansion of urban and suburban landscapes (Stankowski 1972). One key parameter that characterizes urban land use is impervious surface coverage, which is thought to integrate the impacts of human development on a system (Holland *et al.,* 2004). Impervious surfaces, such as roads, parking lots, and buildings, increase the volume and velocity of runoff water during storm events, which can amplify flood risk, erosion, and pollutant transport (Corbett *et al.,* 1997; Grimm *et al.,* 2008; Jacobson 2011). To reduce these risks many urban and suburban communities incorporate engineered features that that intercept runoff water and mediate release to receiving waters (Verstraeten and Poesen 2000). These features often take to form of stormwater detention ponds. Though no limnologic distinction between ponds and lakes exists, stormwater ponds are generally smaller than 20,000 m^2 and are shallow, which allows for widespread light penetration to the benthos (Biggs *et al.,* 2005; Søndergaard *et al.,* 2005). Stormwater ponds further exhibit great morphometric diversity with variable surface areas, depth, and configuration (Chiandet and Xenopoulos 2011). In many regions ponds represent new wildlife habitats and are colonized by aquatic plants, fish, amphibians, and waterfowl (Bishop *et al.,* 2000). In the southeastern United States in particular, ponds have added aesthetic value, allowing adjacent properties to be marketed as waterfront homes (Bastien *et al.,* 2012).

The South Carolina coastal plain is representative of many coastal regions that are experiencing rapid rates of growth. Widespread urban and suburban expansion has led to a boom in the construction of stormwater ponds. There are now more than 21,000 manmade ponds in the eight coastal counties of South Carolina alone, a region where historically there were no natural ponds (Tweel *et al.*, 2016). These ponds are not static systems, overtime suspended particulate matter settles from the water column and accumulated as sediment. The net accumulation of sediment in stormwater ponds is environmentally significant for two reasons. First, the accumulation of sediment displaces water volume reducing the designed flood prevention potential of these ponds. South Carolina state regulations requires that stormwater ponds be dredged when sediment accumulation displaces 25% of the ponds' storage volume, which is assumed to occur every 5-10 years (SCDHEC 2005). This dredging can impose great financial burdens on property owners.

Second, while the primary design purpose of stormwater ponds is flood prevention, it is important to note that pond sediments also play a role in managing environmental pollutants and in carbon (C) and nutrient burial (Stanley 1996; Wu *et al.*, 1996; Comings *et al.*, 2000; Mallin *et al.*, 2002; Downing 2010; Weinstein *et al.*, 2010). Indeed, there is growing interest in the role inland waters play in global C cycling (Cole *et al.*, 2007; Tranvik *et al.*, 2009). Though lakes account for only 1% of the earth's surface area, conservative estimates predict that lakes and reservoirs bury 0.23 Pg C y^{-1}, a rate comparable to global C burial in ocean sediments (Cole *et al.*, 2007). In the continental United States, small artificial water bodies are estimated to account for 20%

of total surface water and have disproportionately high rates of C sequestration (Smith *et al.*, 2002; Downing *et al.*, 2006; Cole *et al.*, 2007; Downing *et al.*, 2008; Tranvik *et al.*, 2009). These high rates of organic C burial are hypothesized to be the result of increased internal production and deposition of algal biomass (Downing *et al.*, 2008; Anderson *et al.*, 2014; Clow *et al.*, 2015). Stormwater ponds, as small eutrophic waterbodies, are expected to follow this trend, though they are exposed to external sources of terrestrial biomass such as leaves and grass clippings (Grimm *et al.*, 2008).

In addition to their role in C cycling, stormwater ponds may also act as nutrient traps. Lake and reservoir sediments experience high rates of denitrification and thus remove significant amounts of available nitrogen from the water column (Harrison *et al.*, 2009). It is challenging to sequester N in the longer term, as mineralization of biomass in sediments will release highly soluble inorganic N to the water column (Saunders and Kalff 2001). Phosphorus cycling is more complex because inorganic P, or PO_4^{3-}, is less soluble than inorganic N. The particle reactive nature of P species creates the potential for two way exchange between sediments and water (Søndergaard *et al.*, 2005). Organic P as biomass buried in sediment can be mineralized to inorganic P and either adsorb to particles, remaining sequestered, or diffuse into the water column. Ultimately the particle reactive nature of inorganic P may increase P sequestration in sediments making stormwater ponds potentially greater sinks of P than N or C.

The goal of this project is to provide a comprehensive examination of sediment accumulation and nutrient sequestration in residential stormwater ponds of coastal South Carolina. Several factors, including morphometrics, catchment development density, and algaecide treatment regimen are examined to determine their impact on rates of sediment accumulation as well as bulk C and nutrient sequestration within the ponds. Additionally this project aims to identify the sources of organic matter loading to pond sediments, algal or terrestrial. This project's findings can aid in determining the role of stormwater ponds in regional carbon and nutrient cycles, as well as informing future management decisions in relation to flood prevention.

Chapter 2. Methods

Study Sites

This study examined fourteen stormwater wet detention ponds from the coastal region of South Carolina (USA) (Figure 2.1). All ponds were located in residential urban and suburban communities within Georgetown and Horry Counties. The ponds selected represent a wide range catchment development density and variable algaecide treatment regimes (Table 2.1).

The percentage of pond catchment covered by impervious surface (%Ip) was used as a proxy for development density. Impervious surfaces include any paved surface (roads, driveways, sidewalks, etc.) or building (Chiandet and Xenopoulos 2011; Jacobson 2011). The polygon tool in Google Earth Professional (available in free Google Earth Desktop App) was utilized to delineate pond catchment area (CA), pond surface are (SA), and the total area of impervious surface. Though error propagation and duplicate delineation there was found to be a 5.1% error associated %Ip.

Residential communities are engineered in such a way that all stormwater runoff is directed towards the detention pond. Thus, in communities with clear boundaries and generally higher development density, the pond catchment was defined as the community perimeter. In some larger communities with multiple ponds, catchment area is more difficult to define. It may not be feasible to define catchment as the perimeter, either because the area is too great for detailed delineation of impervious surfaces, or because the community has heterogeneous development density. In these circumstances, the ring road around the pond was identified, and the catchment drawn to encompass houses on the outer side of the ring road. For ponds not associated with a discrete community, the catchment was defined as an approximate two block (~200 – 250 m) radius from the pond.

The area of impervious surface was found by tracing the outline of all impervious surfaces as defined using the Google Earth polygon tool. Impervious surfaces were delineated at a map scale of ~ 1:1,000. SA was determined using satellite imagery of pond surface Our observations of stormwater ponds is that water level fluctuations were minimal and result in negligible changes to pond surface area.

Percent impervious surface coverage (%Ip) was calculated by the following equation:

$$Ip\% = \frac{A_{Ip}}{CA - PA}$$

Where A_{Ip} is the area of impervious surface, CA is the catchment area, and SA is the pond area.

Sediment thickness and bathymetry

A bathymetric survey of each pond was conducted using a small john boat with an OHMEX system, SonarMite V3 Echosounder and Trimble R8 GNSS. Depth readings were taken at 1.0 m intervals as the vessel traversed a path of concentric circles from pond bank to center followed by several crosshatching transects. Sediment thickness was determined by a survey of 8 to 46 cores per pond. The interface between modern and historic sediments was visually evident as a change in color and grain size; modern sediments were black and silty, historic basement sediments were light and generally sandy. The height between this interface and the sediment surface was measured twice at opposite sides of the polycarbonate liner; the mean was recorded as the sediment thickness. Sediment thickness survey cores were collected from a series of transects, where possible, or evenly distributed when features such as pond aeration fountains or unusual basin morphology made transects less feasible. Sample locations were recorded using the Trimble R8 GNSS.

ARC GIS 10.2.2 software was used to generate pond bathymetries and sediment thickness maps. Pond bathymetries were interpolated by kriging within the pond's perimeter (as defined using satellite imagery) (n = 7). Sediment thickness maps were mainly interpolated using kriging, however the variability of sediment thickness or "patchiness" in some ponds resulted in significant errors. In these ponds inverse distance weighting was used to interpolate sediment thickness (n = 7). Interpolated bathymetry and sediment thickness surfaces were integrated to calculate total pond volume and total sediment volume. Sediment accumulation rates (AR) for each pond were then calculated as:

$$AR = \frac{V_{sed}}{PA * age}$$

Where V_{sed} was the volume of sediment (m^3), SAwas pond surface area (m^2), and age was the age of the pond (y). Pond age was determined by reviewing real estate records in conjunction with historical aerial and satellite imagery. During the development of a community, ponds are dug immediately prior to the construction of houses. As a result, the age of the oldest house in a community provides a reasonable estimate of pond age, to within a year. The error associated with sediment volume was determined by cross validation of the kriging model, mean standardized error was converted to percent error, which was applied to sediment volume. Model errors for each pond ranged from 0.6 to 12%, ponds with more even gradients of sediment distribution exhibited lower model error. SA error was determined to be 2.7% by re-delineating a subsample of 4 ponds in triplicate. The AR error was subsequently determined by propagating the component errors. Pond volume loss was calculated as:

$$volume\ loss\ (\%) = \frac{V_{sed}}{V_{pond} + V_{sed}} * 100$$

Where V_{sed} was the volume of sediment (m^3) and V_{pond} was the bathymetric volume or volume of water stored at time of measurement (m^3). As stated earlier, ponds in this study tend to maintain a constant water level.

Sample Collection for Geochemical Analyses

A push corer with a 6.67 cm diameter by 60 cm length polycarbonate liner was used to collect five to eight sediment cores from each pond. Core collection sites varied with pond morphology, and included locations at influent points, effluent points, littoral regions, basin centers and any sub-basins. All cores reached the basement sand/clay layer and were recovered with a clear sediment water interface. Cores were extruded and sliced into 1 cm sections using an incremental core extruder, weighed to determine bulk wet mass (g). All samples were frozen at -20° C until laboratory analysis. From each pond, three cores were selected for carbon and nutrient analyses and two cores were selected for biomarker analyses. Cores were selected to represent spatial variability within the pond. A sub-sample of each core section was weighed, freeze-dried, and subsequently reweighed dry. Subsamples were then homogenized by mortar and pestle.

Carbon and nutrient analyses

Particulate C and particulate N were analyzed simultaneously with a Carlo Erba CHNO-S EA-1108 Elemental Analyzer. Two subsets of each sample were analyzed to determine the presence of inorganic C. The first was digested with 10% HCl for 12 hours remove inorganic C prior to C and N analysis. The second set was pre-combusted at 500˚C for 4.5 hours to remove organic C prior to C and N analysis. No detectable inorganic C was measured, thus all C values represent organic C. Samples were run with an atropine standard curve, alongside standard reference material (NIST RM 8704, buffalo river sediment) about 8% of samples were run in duplicate with an mean coefficient of variability of 0.0469 ± 0.0227 (SD) for C and 0.0520 ± 0.0229 for nitrogen (N).

Total particulate P (TPP) and particulate inorganic P (PIP) were analyzed using an ash/hydrolysis assay described in Aspila et al., (1976) as modified by Benitez-Nelson (2007). Particulate organic P (POP) was calculated as the difference between TPP and PIP. Samples were run alongside standard reference materials (NIST 1646a, estuarine sediment and NIST 1515, tomato leaves) and ~15% of samples were run in duplicate with an average coefficient of variability of 0.0976 ± 0.0336.

Sediment concentrations of C, N, and P were calculated as % of dry weight and the molar ratios C:P, C:N, and N:P were determined within each section. Mean core concentrations and ratios were then calculated as the average of all sections in that core. Due to core length variability, mean pond values were calculated as the average of the three core values to avoid biasing toward longer cores.

Biomarkers

From each pond, the surface sediments of two cores were selected for biomarker analysis. Pond values represent the mean of these two samples, and errors represent their range. For alkane extractions, 0.5 to 2 g of freeze-dried and homogenized sediment was sonicated in 50 mL of a 9:1 DCM:MeOH solution for 30 minutes and filtered through a Whatman glass fiber filter. Each sample was sonicated three separate times using fresh 50 mL 9:1 DCM:MeOH for a total of a 150 mL. The samples were subsequently dried down to ~5 ml under a stream of ultra high purity (UHP) N_2 and treated overnight with ~ 2 g of activated copper to remove sulfur. Samples were then dried and re-dissolved in 1 ml of hexane. Silica gel column chromatography (4 g activated silica gel with 40 ml hexane as mobile phase) was used to isolate alkanes. Samples were then dried down to 1 ml prior to GC-MS analysis.

Alkanes were quantified using an Agilent 7890B/5977A GC/MS, with an HP-5MS column, using He as a carrier gas, and a temperature program that began at 100°C, ramped up 8°C m^{-1} to 300°C, then held isothermal for 23 m. Scanning ion monitoring

(SIM), detecting ion m/z of 71, was used for the identification of n-alkanes. Quantification was completed using external standards (n-alkane standards C_{18}, C_{20}, C_{24}, C_{26}, and C_{30}). Laboratory blanks were analyzed with each sample set to assess contamination.

N-alkanes are a stable group of lipids biosynthesized by aquatic and terrestrial primary producers. Long chain length n-alkanes (> C_{21}) are associated with the epicuticular leaf waxes of vascular plants (Eglinton and Hamilton 1967). Shorter chain length n-alkanes, notably C_{17}, C_{19}, and C_{21} are associated with algal biomass production (Meyers 2003). There is a great deal of error inherent in direct comparisons of n-alkane concentration (either as μg g^{-1} sediment or as μg g^{-1} OC) because the percent recovery achieved by laboratory methods is unknown and may differ between samples and runs. To minimize this error, biomarker results are often expressed as a unitless ratio. Two proxy indices were applied in this project for their ability to discriminate between algae, terrestrial, and aquatic macrophyte signatures. The Terrestrial Aquatic Ratio (TAR_{HC}) shows the magnitude of terrestrial signals relative to algal material. The TAR_{HC} is calculated as the ratio from mass (Bourbonniere and Meyers 1996): reservoir

$$TAR_{HC} = \frac{C_{27} + C_{29} + C_{31}}{C_{15} + C_{17} + C_{19}}$$

In this study, however, the C_{15} alkane signal in our samples was often below the limit of detection. Thus, we used a modified TAR_{HC} as described by van Dongen, *et al*. (2008), where:

$$TAR_{HC} = \frac{C_{27} + C_{29} + C_{31}}{C_{17} + C_{19}}$$

The Portion Aquatic (P_{aq}) index delineates the relative signatures of aquatic macrophyte biomass versus terrestrial biomass. P_{aq} is calculated as the ratio from mass (Ficken *et al.*, 2000):

$$P_{aq} = \frac{C_{23} + C_{25}}{C_{23} + C_{25} + C_{29} + C_{31}}$$

Data analysis

Linear correlations were used to determine relationships between multiple independent and dependent variables including catchment percent impervious, sediment accumulation, nutrient burial, biomarkers, etc. Linear regressions were used also to determine down core trends of nutrient concentrations in sediment depth profiles. Single sample t-tests were used to determine general trends from nutrient profile regression data, testing the null hypothesis that regression slope = 0 for all cores within a sample population. A matched pairs t-test was used to compare the difference in magnitude between nutrient depth profile regression slopes.

Table 2.1 General characteristics of each pond sampled

Pond ID	Latitude (N)	Longitude (W)	Year built	Month sampled (2016)	%Ip	Pond SA (m^2)	Pond Perim (m)	Algaecide treatment
1	33˚ 24' 04"	79˚ 09 08"	1996	July	7	2850	250	N
2	33^{o} 24' 07"	79^{o} 19' 09"	1996	July	7	3810	280	N
3	33^{o} 22' 25"	79^{o} 11' 29"	1996	March	14	40560	2500	N
4	33^{o} 25' 34"	79^{o} 10' 41"	2004	March	26	6380	530	Y
5	33^{o} 25' 28"	79^{o} 10' 47"	2004	March	26	112890	590	Y
6	33^{o} 27' 27"	79^{o} 09' 06"	1994	May	28	1020	180	Y
7	33^{o} 27' 26"	79^{o} 08' 49"	1994	March	29	930	170	Y
8	33^{o} 43' 30"	78^{o} 51' 15"	1977	March	31	2570	290	N
9	33^{o} 26' 39"	79^{o} 07' 36"	2002	March	39	3560	290	N
10	33^{o} 44' 35"	78^{o} 50' 08"	1973	May	42	1380	200	N
11	33^{o} 36' 15"	79^{o} 01' 14"	2009	Sept	44	1690	190	Y
12	33^{o} 27' 01"	79^{o} 07' 19"	1998	July	48	1330	180	Y
13	33^{o} 27' 03"	79^{o} 07' 17"	1998	July	48	2360	260	Y
14	33^{o} 43' 44"	78˚ 51' 29"	1992	March	51	930	170	Y

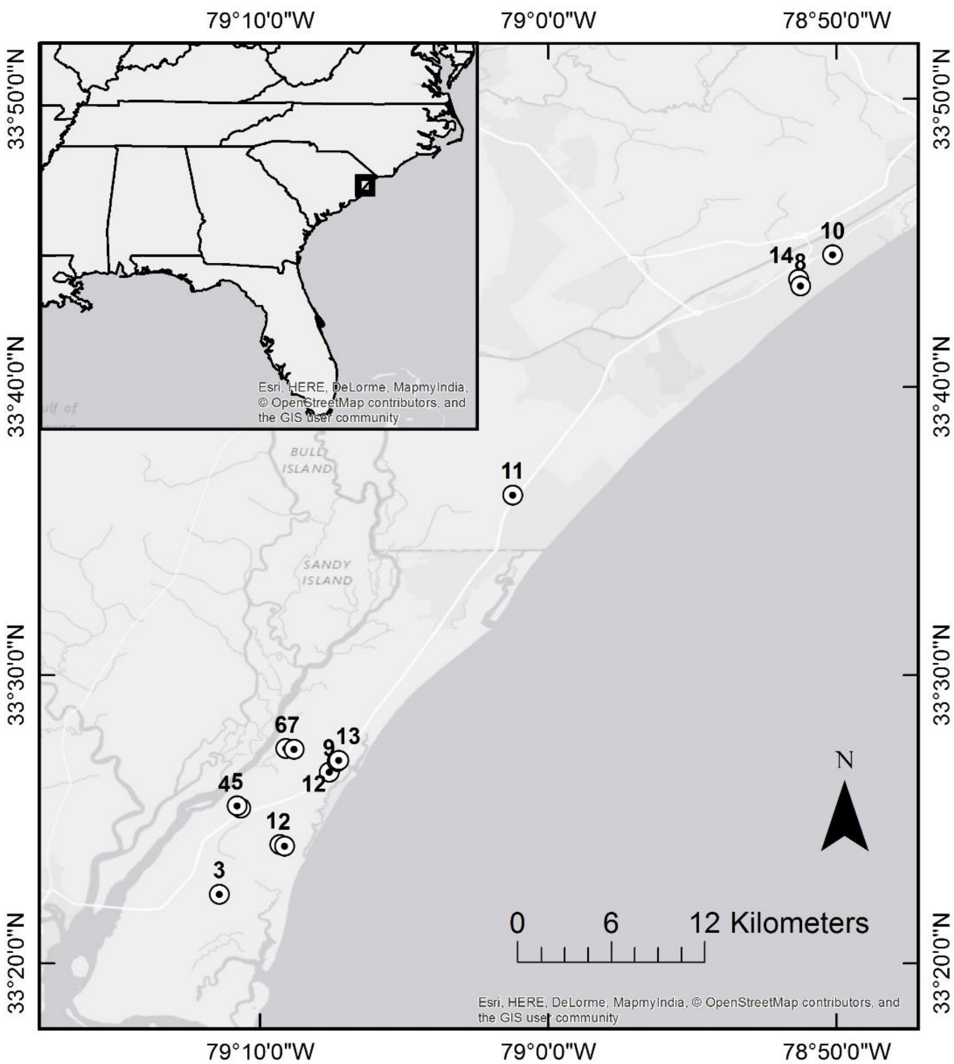

Figure 2.1 Map of sample pond locations.

Chapter 3. Results

Sediment accumulation and bulk density

Sediment thickness was highly variable within each pond generally spanning 1 to 2 orders of magnitude. Interpolated maps of sediment thickness, however, allowed for a mean sediment thickness to be determined in ponds with variable sediment thickness and accumulation patterns. Some sample ponds experienced an even gradient of sedimentation radiating from pond influent points (Figure 3.1 A), while others exhibited a patchy pattern of accumulation, not necessarily reflective of pond morphology (Figure 3.1 B). Mean sediment thickness varied between ponds and ranged from 1.2 ± 0.1 to 20.5 ± 0.8 cm. Using the sediment volume and bathymetric volumes calculated from interpolation models, it was found that pond volume loss ranged from 1.0 ± 0.2 to 17.5 ± 0.5% (Table 3.1). Sediment accumulation rates ranged from 0.06 ± 0.01 to 0.50 ± 0.03 cm y^{-1} with a mean accumulation rate across all ponds of 0.32 ± 0.16 cm y^{-1} (Table 3.1). Sediment accumulation rate was directly correlated to catchment %Ip (R^2 = 0.90, Figure 3.2), PA, and the PA:CA ratio (Table 3.1*)*. There was no relationship between sediment accumulation rate and volume loss or pond age. Sediment bulk density varied with a range of 0.20 to 0.51 g cm^{-3} with a mean of 0.32 ± 0.09 0.20 to 0.51 g cm^{-3} (Table 3.1).

N-alkane Biomarkers

Reported alkane chain lengths ranged from C_{17} to C_{32} and generally showed a bimodal distribution with peaks at C_{17} and C_{29}. The mean chain length was 26 ± 1.9, indicating a greater abundance of long chain n-alkanes. Total n-alkanes richness, the amount of n-alkanes relative to total C was variable (median: 211, range: 19.2 ± 4.4 to 645 ± 306 μg g^{-1} C), however it was significantly correlated to %Ip ($R^2 = 0.57$, $p = 0.002$). This positive relationship was driven by the long chain lengths n-alkanes; the richness of $C_{29} + C_{31}$ ranged from 6.2 ± 0.01 to 247 ± 117 μg g^{-1} C, with a median of 76.7 μg g^{-1} C (long chain n-alkanes versus %Ip $R^2 = 0.52$, $p = 0.004$). In contrast, there was no significant relationship between short chain n-alkane richness and %Ip ($R^2 = 0.04$, $p = 0.45$). The richness of short chain n-alkanes ($C_{17} + C_{19}$) was generally much lower , ranging from 4.1 ± 2.3 to 123 ± 38 μg g^{-1} C, with a median of 18.2 ± 29.5 μg g^{-1} C. One pond, Sum, was an outlier with short length n-alkane richness of 123 ± 38 μg g^{-1} C, 3 times higher than the next closest pond, and 3.3 standard deviations above the mean. This was the only pond that contains a significant pond sediment algal biomass signal. The pond was also anomalous in that poor landscaping within its catchments has left bare sandy soils, which seems to have resulted in high loading of mineral constituents to sediments. It was hypothesized that these mineral constituents were driving sediment accumulation and burying algal biomass before it can be mineralized at the sediment surface interface. As such, this pond was removed from Index regression analyses.

TAR_{HC} ranged from 0.73 ± 0.01 to 12.6 ± 2.4, with a mean of 7.0 ± 4.3, while P_{aq} ranged from 0.14 ± 0.09 – 0.49 ± 0.02 with an mean of 0.27 ± 0.10 (Table 3.1). The

TAR_{HC} values > 1 and P_{aq} values < 0.5 indicate that long chain n-alkanes dominate in both indices. TAR_{HC} had a significant positive correlation with %Ip, perimeter:PA, and AR, and negative a correlation with PA:CA (Table 3.2, Figure 3.3). TAR_{HC} had no correlation with TPP ($R^2 = 0.28$, $p = 0.07$). P_{aq} had a negative correlation with perimeter : PA, AR, and TPP ($R^2 = 0.35$, $p = 0.034$)., while it was positively correlated with SA: CA (Table 3.2). Algaecide treatment appeared to have no effect on either biomass source proxy.

Sediment nutrient composition

Mean sediment C, N, and P concentrations (mmol g^{-1}) were determined for each pond (Table 3.1). Pond sediment C concentrations varied from 6.84 to 21.5 % dry wt with a mean concentration across all ponds of 12.0 ± 3.9 % dry wt (Table 3.2). Individual pond N concentrations ranged from 0.408 to 1.26 % dry wt, and mean of 0.634 ± 0.227 % dry wt across all ponds (Table 3.1). TPP concentrations varied from 0.080 to 0.344 % dry wt with a mean of 0.190 ± 0.087 % dry wt across all ponds (Table 3.2). PIP represented 68 ± 9% of the total P pool. PIP values ranged from 0.037 to 0.244 % dry wt with a mean of 0.130 ± 0.061 % dry wt. POP varied from 0.035 to 0.139 % dry wt with a mean of 0.058 ±0.029 % dry wt (Table 3.1). The variability of C and nutrient concentrations across ponds was independent of catchment %Ip, perimeter:SA ratio, or PA/CA ratio (Table 3.3). Sediment nutrient concentration measured on a per unit volume scale, taking into account bulk density, showed slightly less variability. Mean C was 24.3 ± 6.16 g cm^{-3} (range 14.1 – 31.6 g cm^{-3}), N was 1.2 ± 0.24 g cm^{-3} (range 0.75 – 1.6 g cm^{-3}), and TPP was 0.489 ± 0.198 g cm^{-3} (range 0.200 – 0.820g cm^{-3}) (Table 3.2).

Sediment depth profiles revealed variable patters of down core nutrient distribution (Figure 3.1). Significant negative correlations were found for C and N versus depth in 27 of 29 cores ($p < 0.05$). Single sample t-tests rejected the null hypothesis that regression slopes were equal to zero (C, $p < 0.001$); N, $p < 0.001$). Depth profiles further showed N declines more rapidly than C, which was further confirmed by a matched pairs t-test of the two slopes ($p < 0.001$). TPP, PIP, and POP versus depth profiles showed greater variability relative to that of C and N. Of the 28 cores sampled for TPP, 10 had significant negative correlations (p-values < 0.05), 3 had significant positive correlations ($p < 0.05$), and the remainder had no significant correlation ($p > 0.05$). A single sample t-test failed to reject the null hypothesis that slopes of TPP versus depth were equal to zero ($p = 0.064$). For PIP, 6 had significant negative correlations ($p < 0.05$), 7 had significant positive correlations ($p < 0.05$), and the remainder had no significant correlation ($p > 0.05$). A single sample t-test failed to reject the null hypothesis that slopes of PIP versus depth were equal to zero ($p = 0.66$). POP values generally had greater errors than TPP, PIP, C, or N as POP was calculated as the difference of TPP and PIP (difference between two large numbers). For POP, 10 had significant negative correlations ($p < 0.05$), 4 had significant positive correlations ($p < 0.05$), and the remainder hadno significant correlation ($p > 0.05$). A single sample t-test failed to reject the null hypothesis that slopes of POP versus depth were equal to zero ($p = 0.81$).

Sediment stoichiometric ratios showed a 2 to 4 fold variability between ponds (Table 3.4). The mean of molar C:P ratio was 184 (range 91.9 – 377), C:N ratio was 24.3 (16.4 - 32.6), N:TPP ratio was 8.7 (4.3 – 19.0), and N:POP ratio is 26.0 (13.1 – 44.8). The mean ratio of C:N at the sediment surface (0 to 1 cm section) was 18.2 (15.5 – 24.8)

(Table 3.4). The C:N ratio calculated from the slope of the regression between C and N of all sections is 15.3 ($R^2 = 0.84$, n = 417). The ratio of C:TPP showed no correlation with any of the morphometric variables, while C:N is directly correlated with catchment %Ip, and N:TPP was inversely correlated to %Ip (Table 3.3). These correlations were largely driven by changes in C and P concentrations.

Burial rates of C, N, and P spaned more than an order of magnitude across all ponds (Table 3.4). Mean C burial was 80 ± 44 g m^{-2} y^{-1} (range 8.7 to 161 g m^{-2} y^{-1}). Mean nitrogen burial was 3.73 ± 1.77 g m^{-2} y^{-1} (range 0.65 to 6.43 g m^{-2} y^{-1}). Mean TPP burial was 1.61 ± 1.07 g m^{-2} y^{-1} (range 0.238 to 4.13 g m^{-2} y^{-1}). All nutrient burial rates were directly correlated with both catchment % impervious surface and perimeter : SA(Table 3.3).

Table 3.1 Sediment accumulation rates (AR), bulk density, and biomarker index results (TAR_{HC} and Paq).

					Biomarker indicies	
Pond ID	Sed Vol (m^3)	% Filled	AR (cm y^{-})	Bulk Density (g cm^{-3})	TARHC	Paq
1	50 ± 5.8	1.5% ± 0.2%	0.088 ± 0.01	0.39 ± 0.06	2.4 ± 1.2	0.23 ± 0.07
2	47 ± 7.7	1.0% ± 0.2%	0.062 ± 0.01	0.51 ± 0.12	1.0 ± 0.1	0.43 ± 0.06
3	1613 ± 91	±	0.20 ± 0.02	0.30 ± 0.11	3.0 ± 0.1	0.30 ± 0.08
4	201 ± 14	±	0.26 ± 0.03	0.32 ± 0.07	4.6 ± 3.0	0.33 ± 0.01
5	168 ± 23	±	0.12 ± 0.02	0.29 ± 0.09	2.6 ± 2.0	0.49 ± 0.02
6	67 ± 2.1	9.1% ± 0.3%	0.30 ± 0.02	0.27 ± 0.03	9.4 ± 2.7	0.24 ± 0.03
7	70 ± 2.0	15.2% ± 0.4%	0.34 ± 0.02	0.40 ± 0.04	10.8 ± 5.2	0.19 ± 0.02
8	333 ± 27	10.1% ± 0.8%	0.33 ± 0.03	0.14 ± 0.01	7.9 ± 1.9	0.14 ± 0.09
9	206 ± 7.2	5.0% ± 0.2%	0.41 ± 0.03	0.34 ± 0.14	11.2 ± 1.8	0.17 ± 0.01
10	283 ± 8.1	17.5% ± 0.5%	0.48 ± 0.02	0.20 ± 0.02	6.1 ± 0.8	0.24 ± 0.03
11	63 ± 5.8	3.1% ± 0.3%	0.50 ± 0.08	0.29 ± 0.02	0.7 ± 0.1	0.43 ± 0.06
12	113 ± 3.7	6.6% ± 0.2%	0.47 ± 0.03	0.30 ± 0.09	12.6 ± 2.4	0.14 ± 0.03
13	214 ± 5.5	5.5% ± 0.1%	0.50 ± 0.03	0.38 ± 0.07	11.6 ± 6.8	0.22 ± 0.07
14	111 ± 1.9	14.2% ± 0.2%	0.50 ± 0.03	0.30 ± 0.07	11.3 ± 0.9	0.21 ± 0.01
Mean	**253**	**8.1%**	**0.33**	**0.32**	**6.8**	**0.27**
Median	**141**	**6.6%**	**0.34**	**0.30**	**7.0**	**0.24**
St dev	**387**	**5.4%**	**0.15**	**0.09**	**4.2**	**0.11**

Table 3.2 Carbon and nutrient characteristics of sediments.

	Sediment characteristics							
Pond ID	C (% dry wt)	N (% dry wt)	TPP (% dry wt)	POP (% dry wt)	PIP (% dry wt)	C (g cm^{-3})	N (g cm^{-3})	TPP (g cm^{-3})
1	11.2 ± 2.74	0.68 ± 0.12	0.174 ± 0.057	0.046 ± 0.003	0.109 ± 0.042	29.9 ± 11.8	1.6 ± 0.51	0.896 ± 0.584
2	6.84 ± 2.02	0.49 ± 0.14	0.087 ± 0.005	0.050 ± 0.004	0.037 ± 0.005	14.1 ± 3.9	1.0 ± 0.34	0.386 ± 0.124
3	11.6 ± 1.11	0.71 ± 0.11	0.080 ± 0.009	0.035 ± 0.008	0.049 ± 0.009	26.7 ± 5.4	1.4 ± 0.09	0.200 ± 0.046
4	10.7 ± 1.75	0.59 ± 0.05	0.204 ± 0.036	0.058 ± 0.010	0.145 ± 0.044	25.9 ± 4.0	1.3 ± 0.33	0.557 ± 0.089
5	12.1 ± 1.80	0.40 ± 0.04	0.127 ± 0.004	0.037 ± 0.012	0.101 ± 0.008	29.2 ± 4.2	1.1 ± 0.12	0.363 ± 0.078
6	7.29 ± 1.44	0.46 ± 0.06	0.121 ± 0.003	0.037 ± 0.005	0.084 ± 0.001	14.4 ± 2.3	0.87 ± 0.10	0.308 ± 0.029
7	8.93 ± 1.01	0.45 ± 0.05	0.152 ± 0.015	0.046 ± 0.013	0.114 ± 0.006	28.4 ± 1.0	1.3 ± 0.12	0.642 ± 0.079
8	21.5 ± 3.11	1.26 ± 0.14	0.318 ± 0.003	0.139 ± 0.007	0.183 ± 0.009	26.2 ± 0.7	1.5 ± 0.02	0.409 ± 0.038
9	10.4 ± 2.38	0.45 ± 0.19	0.227 ± 0.021	0.049 ± 0.018	0.155 ± 0.052	15.3 ± 5.3	0.75 ± 0.30	0.453 ± 0.182
10	16.5 ± 0.78	0.91 ± 0.06	0.323 ± 0.024	0.094 ± 0.004	0.234 ± 0.032	23.9 ± 0.9	1.1 ± 0.04	0.611 ± 0.109
11	6.98 ± 0.17	0.41 ± 0.02	0.083 ± 0.004	0.026 ± 0.002	0.067 ± 0.005	17.5 ± 1.6	0.90 ± 0.07	0.226 ± 0.020
12	15.2 ± 1.62	0.74 ± 0.11	0.230 ± 0.025	0.066 ± 0.006	0.166 ± 0.029	31.6 ± 5.4	1.3 ± 0.16	0.570 ± 0.112
13	13.4 ± 0.27	0.59 ± 0.04	0.344 ± 0.097	0.085 ± 0.009	0.244 ± 0.081	25.3 ± 3.1	0.99 ± 0.03	0.820 ± 0.353
14	15.0 ± 2.34	0.72 ± 0.10	0.184 ± 0.051	0.049 ± 0.008	0.129 ± 0.046	32.4 ± 3.7	1.3 ± 0.07	0.405 ± 0.165
Mean	**12.0**	**0.63**	**0.190**	**0.058**	**0.130**	**24.3**	**1.2**	**0.489**
Median	**11.4**	**0.59**	**0.179**	**0.049**	**0.122**	**26.0**	**1.2**	**0.431**
St dev	**3.96**	**0.23**	**0.087**	**0.029**	**0.061**	**6.16**	**0.24**	**0.198**

Table 3.3 R^2 and p values for simple linear regressions between various sediment and morphometric variables.

	%Ip	Perim : SA	SA : CA
AR (cm y¯)	**0.90 (+) (<0.001)**	**0.44 (+) (0.009)**	**0.44 (-) (0.009)**
TAR	**0.73 (+) (<0.001)**	**0.65 (+) (0.002)**	**0.65 (-) (<0.001)**
Paq	0.30 (0.054)	**0.33 (-) (0.040)**	**0.45 (+) (0.012)**
C burial (g m¯² y¯)	**0.78 (+) (<0.001)**	**0.58 (+) (0.002)**	0.19 (0.12)
N burial (g m¯² y¯)	**0.75 (+) (<0.001)**	**0.60 (+) (0.001)**	0.25 (0.07)
P burial (g m¯² y¯)	**0.56 (+) (0.002)**	**0.29 (+) (0.047)**	0.12 (0.22)
C:P (molar)	0.16 (0.16)	0.08 (0.31)	0.27 (0.06)
C:N (molar)	**0.36 (+) (0.023)**	0.05 (0.46)	0.01 (0.87)
N:P (molar)	**0.33 (-) (0.030)**	0.13 (0.21)	0.27 (0.06)
C (% dry wt)	0.14 (0.18)	0.04 (0.50)	0.05 (0.47)
N (% dry wt)	0.02 (0.68)	0.02 (0.61)	0.11 (0.25)
TPP (% dry wt)	0.26 (0.060)	0.06 (0.39)	0.01 (0.77)
POP (% dry wt)	0.08 (0.34)	0.01 (0.70)	0.02 (0.68)

Table 3.4 Sediment stoichiometric ratios and C and nutrient burial rates.

	Stoichiometric Ratios				Burial rates		
Pond ID	C:P (molar)	C:N (molar)	N:TPP (molar)	N:POP (molar)	C (g m^{-2} y^{-})	N (g m^{-2} y^{-})	TPP (g m^{-2} y^{-})
1	230 ± 53	20.2 ± 2.5	12.1 ± 1.9	32.2 ± 6.6	26.2 ± 10.4	1.4 ± 0.4	0.787 ± 0.51
2	167 ± 68	16.4 ± 1.1	10.3 ± 3.9	19.8 ± 8.9	8.7 ± 2.4	0.65 ± 0.2	0.238 ± 0.08
3	377 ± 8	22.3 ± 3.6	19.0 ± 1.7	44.8 ± 7.3	53.2 ± 10.7	2.8 ± 0.2	0.398 ± 0.09
4	140 ± 8	27.3 ± 4.4	7.1 ± 0.9	30.3 ± 7.2	68.0 ± 10.4	3.3 ± 0.9	1.46 ± 0.23
5	215 ± 36	30.5 ± 3.1	7.3 ± 0.5	26.1 ± 1.0	36.2 ± 5.3	1.4 ± 0.2	0.450 ± 0.10
6	160 ± 31	18.9 ± 1.2	8.6 ± 1.5	21.6 ± 2.2	43.3 ± 6.8	2.6 ± 0.3	0.92 ± 0.09
7	137 ± 5	25.6 ± 0.5	5.9 ± 0.1	21.9 ± 2.3	97.1 ± 3.4	4.5 ± 0.4	2.19 ± 0.27
8	200 ± 11	21.5 ± 1.0	10.5 ± 0.5	26.0 ± 5.7	86.8 ± 2.4	4.9 ± 0.1	1.36 ± 0.12
9	92 ± 22	23.6 ± 1.9	4.3 ± 1.4	13.1 ± 8.3	63.4 ± 22.0	3.1 ± 1.2	1.87 ± 0.75
10	134 ± 13	23.6 ± 1.2	6.5 ± 0.8	23.4 ± 2.0	114 ± 4.4	5.5 ± 0.2	2.90 ± 0.52
11	201 ± 18	22.1 ± 0.5	9.4 ± 0.8	28.4 ± 1.8	87.0 ± 7.8	4.4 ± 0.4	1.12 ± 0.10
12	178 ± 4	27.3 ± 2.5	7.1 ± 0.5	27.8 ± 8.1	149 ± 25.6	6.3 ± 0.7	2.68 ± 0.53
13	135 ± 47	32.6 ± 2.8	5.3 ± 2.0	17.3 ± 2.9	128 ± 15.4	5.0 ± 0.1	4.13 ± 1.78
14	209 ± 25	28.5 ± 2.3	8.5 ± 1.1	32.0 ± 5.5	161 ± 18.5	6.4 ± 0.3	2.02 ± 0.82
Mean	**184**	**24.3**	**8.7**	**26.0**	**80.1**	**3.7**	**1.61**
Median	**172**	**23.6**	**7.9**	**26.0**	**77.4**	**3.9**	**1.41**
St dev	**65**	**4.4**	**3.5**	**7.5**	**44.3**	**1.8**	**1.07**

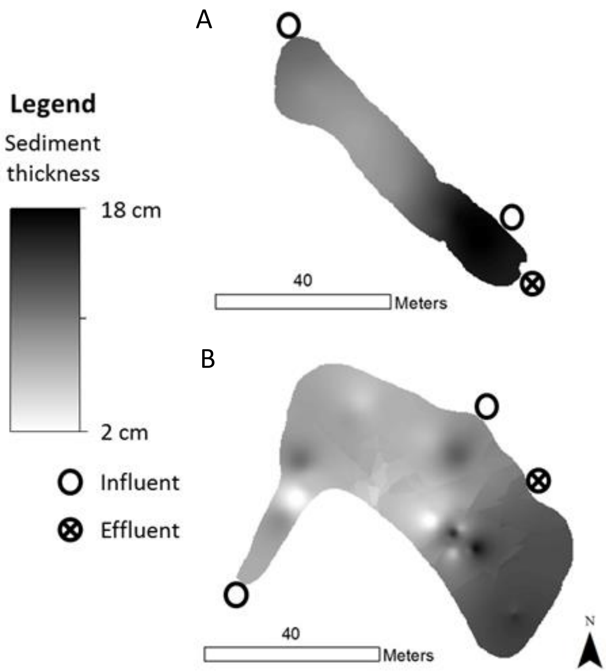

Figure 3.1 Maps of sediment thickness from two example ponds. Color scale depicts sediment thickness, ranging from 2 to 18 cm. A) Pond 14 B) Pond 13

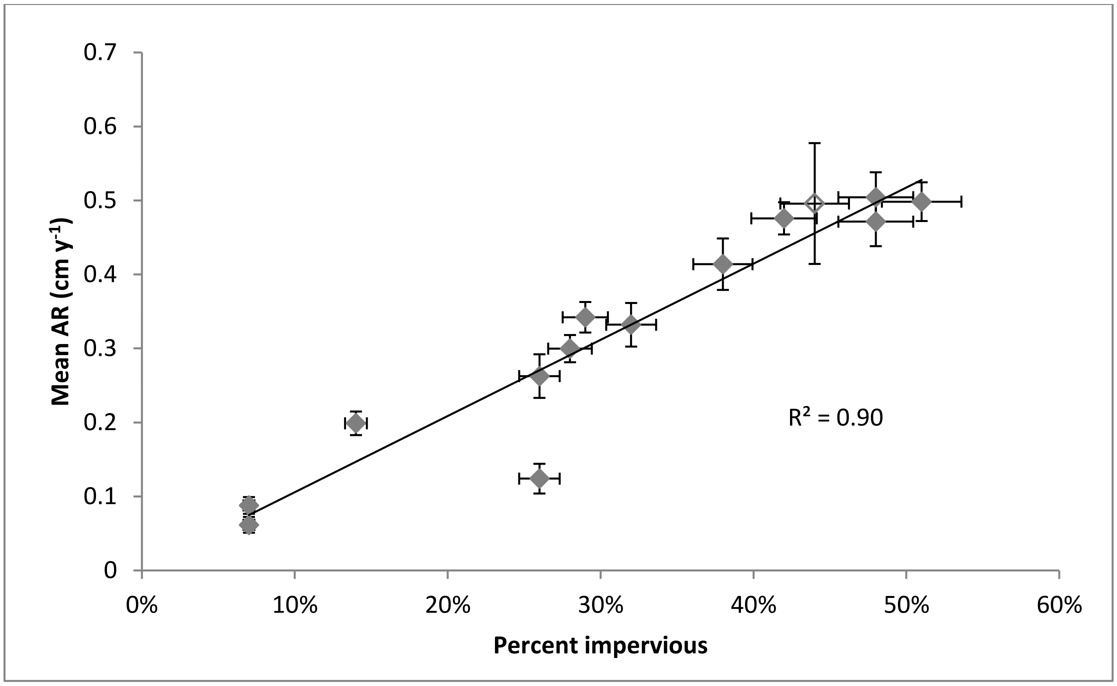

Figure 3.2 Simple linear regression between pond sediment accumulation rate and catchment %Ip. The regression is significant ($p < 0.001$, $y = 1.03x – 0.003$).

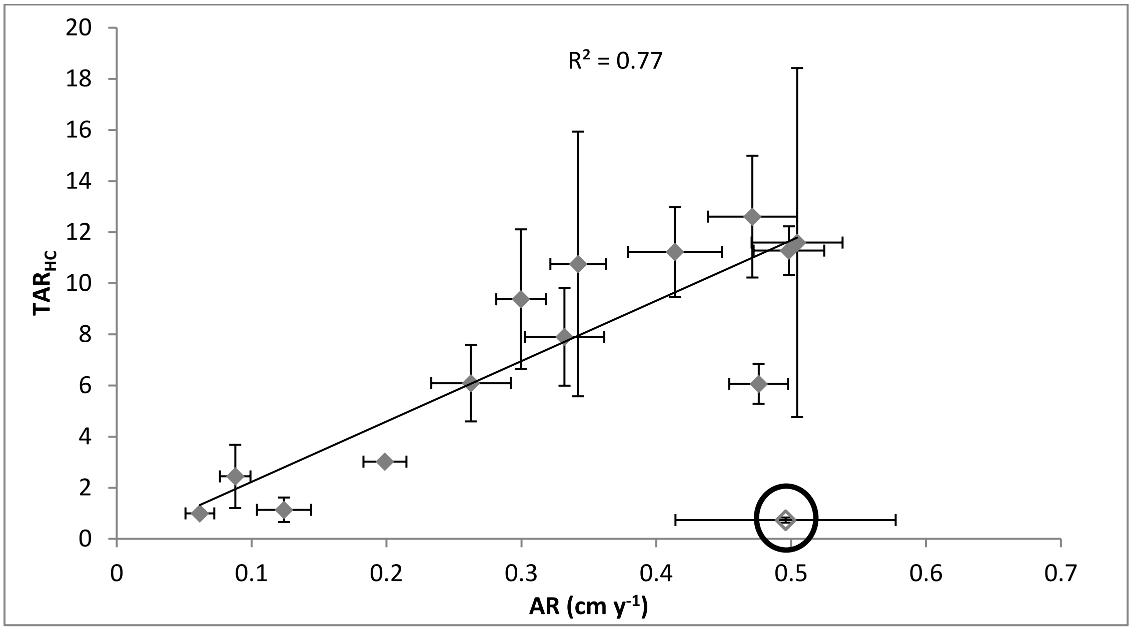

Figure 3.3 Linear regression between sediment accumulation rate and TAR_{HC}. Correlation is significant ($p < 0.001$), $y = 24x - 0.13$.

Chapter 4. Discussion

Sediment accumulation rates were low, predicted by level of development

The State of South Carolina mandates the implementation and maintenance of stormwater control structures for many coastal developments. These control structures often take the form of stormwater wet detention ponds and are employed to mediate flooding and to a secondary extent, reduce inputs of carbon, nutrient, and other contaminants into local rivers, streams, and coastal oceans (SCDHEC 2005). The State requires communities to dredge stormwater ponds when sediment accumulation displaces 25% of initial pond volume in order to effectively contain runoff (SCDHEC 2005). It has therefore been argued that coastal ponds should be dredged every 5 to 10 years. Here we show that, regardless of pond morphology and development intensity, coastal storm water ponds have much lower sedimentation rates than previously anticipated by SCDHEC (Table 3.1). Our estimates predicted it will take a median of 68 y (range 36.3 – 515 y) for the stormwater ponds to reach the 25% water volume displacement limit. These accumulation rates (Table 3.1) were significantly lower than those reported in agricultural impoundments (mean 5.9 cm y^{-1}, Downing et al., 2008), but were comparable to 10 Pennsylvania stormwater ponds albeit they are very different systems (range 0.06 – 0.53 cm y^{-1}, Brainard and Fairchild, 2012)

The major predictor of sedimentation rate was not herbicide treatment or pond morphology, but rather the relative percentage of impervious surfaces, such as roads, parking lots, and buildings surrounding the pond. The strong relationship between sedimentation rate and impervious surfaces (%Ip ,R^2 = 0.90, Figure 3.1) thus serves as a powerful tool for predicting pond infill rates and provides coastal communities with a method for managing stormwater detention pond effectiveness. The relative distribution of impervious surfaces is easily determined for most coastal communities using widely available and free software, such as Google Earth or Google Earth Professional as detailed within the methods section. Provided the relationship between sedimentation rate and impervious surfaces holds true for ponds in similar settings to those in this study, communities may be able to estimate sedimentation rates using Google Earth rather than directly collecting sediments.

Terrestrial biomass drives sediment accumulation

Given previous studies in lakes and reservoirs, it was hypothesized that internal algal production would be the major source of organic matter to sediments (Downing *et al.,* 2008; Anderson *et al.*, 2014). However, multiple indices showed that terrestrial biomass was the dominant source of sediment organic matter to SC coastal stormwater ponds. Sediment surface C:N ratios were consistently greater than 10 (averaging 18.2 ± 2.8), indicating that pond sediments stored more terrestrial than algal biomass (Meyers and Ishiwatari 1993). Additionally, both biomarker indices (Table 3.1) showed that terrestrial signatures were significantly stronger than algal or aquatic macrophyte signals (Ficken *et al.*, 2000). For simplicity, the rest of the discussion focuses on the TAR_{HC} index, as both TAR_{HC} and P_{aq} show similar patterns. The median TAR_{HC} value of this study, 7.0, shows a significantly greater terrestrial signature than values reported in the North American Great Lakes (median ~1.5) (Bourbonniere and Meyers 1996; Silliman *et al.*, 1996; Meyers 1997; Lu and Meyers 2009) though a significantly lower terrestrial signature than found in Russian rivers (range 17 – 80) (van Dongen *et al.*, 2008). Although TAR_{HC} does not provide absolute ratios of biomass, this index has been very useful for comparing relative changes through time or across features in an ecosystem (Bourbonniere and Meyers 1996) (van Dongen *et al.*, 2008). In this study, the direct correlation between TAR_{HC} and accumulation rate indicates that the greatest terrestrial signatures were observed in ponds with the greatest rates of sediment accumulation, again suggesting that terrestrial biomass drives sediment accumulation (Figure 3.1). We hypothesize that the dominance of terrestrial biomass in stormwater pond sediments is the result of high loading of terrestrial biomass and low rates of algal biomass burial.

Addressing the sources of terrestrial matter, just as the amount of impervious surface drove sedimentation rates (Fig 2), the proportion of terrestrial material was also strongly positively correlated to the amount of impervious surfaces. It may seem counterintuitive that ponds from catchments with the most impervious surfaces, and therefore least total terrestrial biomass (e.g., trees, etc.), had the greatest amount of sediment from terrestrial material (Table 3.2). We hypothesize that impervious surfaces provide an important mechanism for the rapid transport of terrestrial material to stormwater detention ponds from their catchments. In the South Carolina coastal plain, runoff from urban watersheds was found to have ~ 5 times greater volume and to carry ~ 5 times more suspended solids than runoff from forested watersheds (Corbett *et al.*, 1997). Though undeveloped catchments had greater terrestrial biomass, they lacked the runoff velocities required to transport biomass to the pond. The higher runoff velocities from more developed catchments were more capable of transporting organic matter into ponds either as sheet flow over lawns or as channeled through storm drains (Jacobson 2011). Here, it is important to note that impervious surface coverage never exceeded ~ 50%. Thus, at least half of each pond's catchment was open space, often taking the form of well landscaped and maintained lawns. These lawns produced of large quantities of easily transported grass clippings, providing a great source of external, terrestrial, biomass to detention ponds. Ultimately the impacts of human development could increase the export of terrestrial biomass to receiving waters, but high terrestrial loading alone does not account for the observed low algal signature.

Algal blooms were observed in our stormwater ponds at the time of sampling and have also been documented previously in South Carolina stormwater ponds (Siegel *et al.*, 2011; Reed *et al.*, 2015). Our results indicate that, in spite of this internal production of algae, algal biomass is not ultimately being stored in pond sediment. Therefore the algal biomass must have an alternate fate, which could be either direct export though weir structures or remineralization. Pond volumes are designed such that they are well flushed during rain events, potentially removing suspended algal biomass (SCDHEC 2005). Additionally, algal biomass is thought to be more labile than terrestrial biomass and undergoes preferential microbial remineralization (Zehnder and Svensson 1986; Bastviken *et al.*, 2004). This study did show clear signs of organic matter mineralization processes occurring in buried sediments. There was a universal decline of C and N concentrations with depth, which is expected as over time, biomass is mineralized to labile inorganic products (CO_2, CH_4, N_2, NO_3^-, NH_4^+). The oldest sediments have had most the most time for mineralization processes to occur. N concentrations decreased more rapidly with depth than did C, which suggests preferential remineralization of N rich compounds (Benner 1991; Hopkinson *et al.,* 1997). TPP did not exhibit uniform patterns of decline. A possible explanation of this pattern is the particle reactive nature of the PO_4^{-3} ion. As such, inorganic P remains in sediments after remineralization of organic forms. POP did not consistently decline with increasing depth in pond sediments, which could be a result of the high error inherent in the calculation of POP in PIP rich systems.

A number of factors control microbial remineralization of C, and therefore the missing algal biomass. Rates of microbial remineralization of organic C are controlled by temperature and oxygen availability (Zehnder and Svensson 1986; Bastviken *et al.,* 2004; Gudasz *et al.,* 2010). Large lakes and reservoirs commonly experience summer thermal stratification allowing hypolimnetic waters to remain between 4 – 10^{o}C year round and become seasonally anoxic (Boehrer and Schultze 2008). The small size and shallow nature (1-3m) of South Carolina stormwater ponds prevent them from stratifying. Their sediment water interfaces also thus experience mean summer temperatures as high as 30^{o}C and maintain near year round oxygen supply (Corbett *et al.,* 1997; Serrano and DeLorenzo 2008). Therefore, it is quite possible that stormwater ponds experience greater rates of microbial mineralization than larger lakes (Downing 2010). It is also possible that the morphology of stormwater ponds increases their relative terrestrial load. Their small size and generally irregular shape create large perimeter to surface area ratios. As lawns generally run to the edge of the pond, there is great potential for terrestrial biomass inputs. Larger lakes have inherently lower perimeter to surface area ratios reducing the potential load of terrestrial biomass per unit surface area.

Stormwater ponds are similar to natural lakes

Historically, stormwater ponds have been classified and studied as artificial water bodies. However, the sediment nutrient dynamics of the stormwater ponds in this study appear to be similar to those of natural lakes, and differ from other artificial waterbodies. The carbon content of lake sediments was one parameter that differed from other artificial water bodies. Mean pond sediment carbon concentration was 12% dry mass, comparable to that found in natural lakes, yet about 3 – 4 fold greater than concentrations reported in reservoir sediments (Table 4.1) (Brunskill *et al.,* 1971; Gorham *et al.,* 1974; Dean *et al.,* 1993; Downing *et al.,* 2008; Knoll *et al.,* 2014). N and P concentrations follow a similar pattern, with pond sediment concentrations comparable to natural lakes and slightly higher than reservoirs (Table 4.1) (Nürnberg 1988; Verstraeten and Poesen 2002; Gälman *et al.,* 2008; Knoll *et al.,* 2014). The high carbon richness in pond and lake sediments differences can likely be explained by patters of water flow management and mineral sediment loading. Reservoirs and impoundments are dammed waterbodies with continuous stream inputs, which may provide a means for greater transport of suspended solids to basins. This increased load of mineral sediments will dilute the nutrient rich organic sediments. The residential stormwater ponds sampled in this study only receive inputs during rain events. Further, the communities within these ponds' catchments have careful landscaping and lawn care, reducing erosion and transport of mineral sediments. The notable exception is the Sum pond community, where bare patches of lawn were common, revealing sandy soils. Sediments from this pond have a mean C concentration of 7.0% dry mass (Table 3.2), well below the all pond mean, suggesting greater mineral loading relative to biomass loading.

Trends in pond nutrient burial also follow those observed in small natural lakes, rather than those of reservoirs or impoundments. The mean C burial rate identified in this study (80 g m^{-2} y^{-1}, Table 3.4) is well within the range of mean burial rates reported in literature for natural lakes, but 1 to 2 orders of magnitude below reported literature burial rates of reservoirs (Table 4.1) (Mulholland and Elwood 1982; Höhener and Gächter 1993; Dean and Gorham 1998; Downing *et al.,* 2008; Mackay *et al.,* 2012; Knoll *et al.,* 2014). Direct measurements of N and P burial rates are rarely reported in literature. However, this study's mean N and P burial (N: 3.8 g m^{-2} y^{-1}, P: 1.6 g m^{-2} y^{-1}) were comparable to those of European lakes and Green Bay, Lake Michigan, while still an order of magnitude below reported reservoir burial rates (Table 4.1) (Höhener and Gächter 1993; Klump *et al.,* 1997; Mengis *et al.,* 1997; Mackay *et al.,* 2012; Knoll *et al.,* 2014). We hypothesize that the consistently higher burial rates of reservoirs is a result of their hydrology. The constant inputs of suspended solids and nutrients via rivers or streams to reservoirs leads to high rates of mass burial, which compensate for lower nutrient concentrations and result in very high total burial rates. The ponds in this study, as well as for many natural lakes, receive inputs more episodically and are often linked with precipitation events. These periodic inputs likely result in less total mass loading and ultimately lower carbon and nutrient burial rates. This study's rates of nitrogen burial are also significantly lower than published rates of denitrification in stormwater retention ponds (1.6 – 21 g m^{-2} y^{-1}), therefore looking at sediment burial rates of N alone likely underestimates total N removal by stormwater ponds (Zhu *et al.,* 2005).

Stormwater ponds as novel sinks in the urban hydrology

In urban systems many of the drivers of biogeochemical cycles are controlled by humans, for example impervious surface coverage and excess loading of nutrients from waste, fertilizer, and detergents (Kaye et al., 2006). These anthropogenic impacts can alter local hydrology, degrading stream quality and increasing nutrient export to receiving waters (Walsh et al., 2005; Booth et al., 2016). Stormwater ponds are ultimately designed as engineering control measures to mitigate impacts of urbanization to local hydrology and water quality. As ponds are designed to intentionally intercept sediment and nutrient export via stormwater flows, ponds are hotspots of biogeochemical activity, where nutrients can be passed between oxidation states, organic, and inorganic forms. Previous studies have found that stormwater detention ponds provide variable, yet significant, removal of nutrients and pollutants (Wu et al., 1996; Comings et al., 2000; Mallin et al., 2002). These previous studies have focused on the mass balance of influent and effluent. Our study addressed the removal of C and nutrient by quantifying the rate burial (change of storage) directly.

A first-cut at estimating the regional significance of pond C and nutrient sequestration rates can be made by scaling up results of this study to the total number of ponds that exist in coastal South Carolina. A recent estimate of small artificial water bodies in the eight coastal counties of South Carolina suggests there are more than 21,500 manmade ponds, representing a mix of rural, agricultural and development-related stormwater ponds (E. Smith, unpublished data). Of this total, 9,269 ponds are associated with coastal development, and 5,073 of these are associated with residential development similar to the ponds sampled in this study. These 5,073 ponds have a cumulative surface area of 25.3 km2. Assuming the mean burial rates observed in this study apply, just the residential ponds alone (representing 24% of the total pond population) bury 2.0 x 109 g C y-1, 9.5 x107 g N y-1, and 3.7 x107 g P y-1. The proliferation of ponds along this coastal zone thus represents a long-term storage of C, N and P that would otherwise have been transported to coastal receiving waters. Stormwater pond sequestration values show that these ponds serve as nontrivial C and nutrient sinks on the local and regional scale. What remains unclear, however, is whether these rates of sequestration are ecologically significant in the context of broader coastal eutrophication and climate change. Stormwater ponds are a fixture of urban hydrology, experiencing great anthropogenic nutrient loading, yet a full understanding of how these feature function in a complex hydrology is understudied. Further work is thus necessary if we are to integrate these small, but increasingly significant, ponds into a broader biogeochemical-hydrologic framework of coastal and urban systems.

Table 4.1 Comparison of sediment C, N, and P concentrations and burial rates between waterbodies in this study and others.

Source	Description	C (% dry wt)	N (% dry wt)	P (%dry wt)	C burial (g m^{-2} y^{-})	N burial (g m^{-2} y^{-})	TPP burial (g m^{-2} y^{-})
This study	Stormwater ponds† (14), SC	12 (6.8 – 22)	0.63 (0.41 – 1.3)	0.19 (0.080 - 0.34)	80 (8.7 - 161)	3.7 (0.65 – 6.4)	1.6 (0.24 – 4.1)
Dean et al., 1993	Lakes* (46), Minnesota	12 (3 - 29)			72		
Mulholland and Elwood 1982	Small Oligotrophic lakes* (14), USA				27 (3 - 128)		
Mulholland and Elwood 1982	Small Meso-Eutrophic lakes* (18), USA				94 (11 - 198)		
Höhener and Gächter 1993	Lakes* (10), EU					5.0 ± 1.6	
Mackay et al., 2012	Lake* (1), UK				44.3		
Mengis et al., 1997	Lakes* (2), Switzerland		0.29 (0.26 - 0.32)			3.6 (3.1 – 4.1)	
Klump et al., 1997	Green Bay, Lake Michigan* (1)			0.024			2
Gorham et al., 1974	Lakes* (20), UK	7 (4 - 13)					
Brunskill et al., 1971	Lakes* (23), Wisconsin	20					
Nürnberg 1988	Global mean P			0.3			
Verstraeten and Poesen 2002	Agriculture ponds† (12), Belgium			0.085 (0.051 - 0.20)			
Mulholland and Elwood 1982	Reservoirs† (24), USA				350 (52 - 2000)		
Downing et al., 2008	Agricultural impoundments† (40), Iowa	4.8			2122 (148 - 17400)		
Knoll et al., 2014	Reservoirs† (13), Ohio	2.3 (1.2 – 3.5)	0.32 (0.18 - 0.49)	0.1 (0.05 - 0.19)	246 (46 - 810)	33 (5.0 - 115)	13 (1.0 - 49)

Chapter 5. Conclusion

Stormwater ponds are designed to operate as part of an urban landscape, with much of their function directly controlled by surrounding land use. Here, we find that pond sediment accumulation rates are driven by terrestrial sources and are predicted by the development intensity of their catchments in coastal South Carolina. The shallow morphology of these ponds creates ideal conditions for rapid rates of microbial remineralization, resulting in limited algal derived biomass accumulation. Although driven by different processes, stormwater pond C and nutrient sediment composition and burial are remarkably similar to those of natural lakes from across the world. The biogeochemical consistency between pond and lake sediments suggests that, collectively, ponds could play significant roles in global carbon and nutrient cycling. The scope of this project was very narrow, limited to detention ponds in residential communities. To more accurately extrapolate C and nutrient sequestration in small waterbodies it would be valuable to identify burial rates associated with other land uses, such as commercial, urban, golf course, and agricultural from a diversity of climatic and hydrologic region

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Appendix A. Density and Nutrient Raw Data

Table A.1 Bulk density and nutrient raw data, ponds 1 and 2

	Dry sub samp mass (g)	Wet sub samp mass (g)	Bulk sect wet mass (g)	C (wt %)	err +/- (wt %)	N (wt %)	err +/- (wt %)	TPP (wt %)	err +/- (wt %)	POP (wt %)	err +/- (wt %)
Pond 1											
C1											
0	6.73	33.07	38.9	23.00	1.01	1.31	0.07	0.292	0.022	0.071	0.019
1	20.26	34.21	46.1	7.57	0.33	0.32	0.02	0.464	0.036	0.009	0.002
2	24.21	30.59	58.8	1.88	0.08	0.05	0.00	0.104	0.008		
C2											
0	8.51	27.05	33.5	6.01	0.26	0.45	0.02	0.104	0.008	0.052	0.014
1	18.94	24.66	61.6	0.50	0.02	0.05	0.00	0.009	0.001	0.002	0.001
C4											
0	0.66	16.14	30.8	20.95	0.92	1.38	0.07	0.189	0.020	0.083	
1	16.84	30.46	50.2	3.92	0.17	0.19	0.01	0.075	0.008	0.010	
2	25.25	34.26	57.3					0.041	0.004		
3	28.56	38.08	56.1					0.038	0.004		
4	24.88	33.60	59.2					0.052	0.006		
Pond 2											
C2											
0	15.52	30.55	50.1	2.85	0.12	0.23	0.01	0.085	0.015	0.058	
1	21.65	26.53	65.3					0.022	0.004		
2	23.69	28.70	60.4					0.020	0.003		
3	25.80	30.92	65.6					0.016	0.003		
4	26.16	31.25	63.0					0.035	0.006		
C4											
0	2.28	20.42	27.4	9.38	0.41	0.70	0.04	0.115	0.011	0.056	0.017
1	8.89	20.72	42.1	1.06	0.05	0.06	0.00	0.047	0.004	0.030	0.009
2	17.88	22.41	57.1					0.009	0.001	0.003	0.001
3	15.41	18.49	61.4					0.006	0.001	0.003	0.001
4	13.04	15.78	62.5					0.005	0.000	0.003	0.001
C5											
0	4.68	20.74	38.3	9.38	0.41	0.70	0.04	0.139	0.024	0.086	
1	18.21	25.94	44.1	1.06	0.05	0.06	0.00	0.054	0.009	0.016	
2	24.36	29.32	62.9					0.008	0.001		
3	29.46	34.86	64.9					0.008	0.001		

Table A.2 Bulk density and nutrient raw data, pond 3

	Dry sub samp mass (g)	Wet sub samp mass (g)	Bulk sect wet mass (g)	C (wt %)	err +/- (wt %)	N (wt %)	err +/- (wt %)	TPP (wt %)	err +/- (wt %)	POP (wt %)	err +/- (wt %)
Pond 3											
C3											
0	1.79	9.38	33.3	16.01	0.70	1.09	0.06	0.070	0.007	0.012	0.003
1	1.68	15.04	31.5	14.73	0.64	1.00	0.05	0.090	0.009	0.035	0.009
2	2.27	18.67	41.8	13.20	0.58	0.88	0.04	0.086	0.009	0.033	0.008
3	2.19	16.60	34.1	13.04	0.57	0.84	0.04	0.090	0.009	0.030	0.007
4	2.88	17.48	36.1	12.77	0.56	0.77	0.04	0.106	0.011	0.033	0.008
5	4.72	18.54	44.7	10.40	0.46	0.49	0.03	0.108	0.011	0.016	0.004
6	22.25	29.78	73.1	3.06	0.13	0.03	0.00	0.028	0.003		
C5											
0	4.99	24.64	42.1	13.74	0.60	0.81	0.04	0.073	0.005	0.034	0.008
1	11.85	22.34	54.6	5.36	0.23	0.16	0.01	0.052	0.003	0.021	0.005
2	25.88	32.22	62.2	3.35	0.15	0.03	0.00	0.023	0.002		
C6											
0	2.15	19.16	36.3	15.32	0.67	1.07	0.05	0.104	0.007	0.059	0.015
1	2.23	17.81	34.7	13.64	0.60	0.92	0.05	0.089	0.006	0.045	0.011
2	2.94	18.86	33.1	11.86	0.52	0.80	0.04	0.101	0.007	0.049	0.012
3	7.73	20.36	45.5	7.02	0.31	0.37	0.02	0.048	0.003		
4	20.52	27.17	59.7	2.60	0.11	0.04	0.00	0.041	0.003		

Table A.3 Bulk density and nutrient raw data, ponds 4 and 5

	Dry sub samp mass (g)	Wet sub samp mass (g)	Bulk sect wet mass (g)	C (wt %)	err +/- (wt %)	N (wt %)	err +/- (wt %)	TPP (wt %)	err +/- (wt %)	POP (wt %)	err +/- (wt %)
Pond 4											
C1											
0	1.75	24.55	35.3	17.47	0.76	1.78	0.09	0.289	0.030	0.172	0.043
1	2.79	20.21	36.3	16.58	0.73	1.78	0.09	0.285	0.029	0.150	0.038
2	3.67	16.33	32.0					0.155	0.016	0.076	0.019
3	6.56	19.05	39.7	7.86	0.34	1.15	0.06	0.143	0.015	0.008	0.002
4	18.55	27.47	54.0					0.064	0.007	0.038	0.009
5	11.05	23.18	47.1	4.77	0.21	0.28	0.01	0.183	0.019	0.142	0.035
6	13.30	22.39	45.0					0.062	0.006		
7	17.20	27.87	48.5	1.83	0.08	0.11	0.01	0.083	0.009	0.037	0.009
8	13.41	25.66	43.1					0.097	0.010	0.039	0.010
9	5.78	18.57	42.0	5.98	0.26	0.38	0.02	0.111	0.011	0.037	0.009
10	6.87	20.92	35.3					0.152	0.016	0.073	0.018
11	7.61	21.86	40.5	6.43	0.28	0.31	0.02	0.129	0.013	0.043	0.011
12	11.64	23.68	42.3					0.097	0.010	0.045	0.011
13	16.97	30.39	47.4	4.99	0.22	0.13	0.01	0.080	0.008		
14	26.51	35.03	67.0					0.110	0.011		
15	21.43	26.12	61.6					0.009	0.001		
C3											
0	1.23	29.00	45.1	16.10	0.70	1.09	0.06	0.222	0.026	0.068	0.017
1	4.08	18.27	29.1	12.87	0.56	0.42	0.02	0.297	0.034	0.021	0.005
2	5.79	19.29	34.0					0.333	0.039	0.023	0.006
3	8.00	23.31	35.1	13.76	0.60	0.31	0.02	0.272	0.032		
4	11.91	26.34	41.7	10.82	0.47	0.25	0.01	0.216	0.025	0.043	
5	17.40	23.29	58.2					0.035	0.004		
C4	3 38_T12 Dup										
0	1.74	9.44	5.9	14.17	0.62	1.03	0.05	0.188	0.021	0.069	0.036
1	4.52	23.03	27.4	13.91	0.61	0.95	0.05	0.200	0.022	0.059	0.031
2	10.31	33.13	41.4	12.08	0.53	0.48	0.02	0.216	0.023		
3	13.56	22.47	23.2	4.86	0.21	0.12	0.01	0.143	0.016		
4	22.61	28.29	56.9					0.012	0.001		
Pond 5											
C1											
0	4.02	13.08	24.1	11.16	0.49	0.66	0.03	0.171	0.023	0.058	0.015
1	14.02	27.36	49.1	6.01	0.26	0.19	0.01	0.099	0.013		
2	14.35	19.68	49.0	1.07	0.05	0.03	0.00				
C3											
0	3.86	28.68	38.5	14.57	0.64	0.64	0.03	0.189	0.021	0.018	0.009
1	22.63	31.02	60.2	1.08	0.05	0.03	0.00	0.060	0.006	0.019	0.010
2	22.57	28.55	58.4					0.003	0.000		
C4											
0	3.58	26.34	33.7	14.60	0.64	0.60	0.03	0.149	0.016	0.039	0.021
1	9.50	22.27	37.4	11.53	0.50	0.30	0.02	0.094	0.010	0.033	0.017
2	16.86	27.81	55.9	4.63	0.20	0.11	0.01	0.046	0.005		
3	23.71	30.08	58.1					0.011	0.001		

Table A.4 Bulk density and nutrient raw data, pond 6

	Dry sub samp mass (g)	Wet sub samp mass (g)	Bulk sect wet mass (g)	C (wt %)	err +/- (wt %)	N (wt %)	err +/- (wt %)	TPP (wt %)	err +/- (wt %)	POP (wt %)	err +/- (wt %)
Pond 6											
C6											
0	1.72	23.02	43.1	17.81	0.78	1.01	0.05	0.163	0.013	0.072	0.018
1	2.97	24.80	38.5	17.07	0.75	0.98	0.05	0.144	0.012	0.063	0.016
2	3.84	24.37	38.3	11.39	0.50	0.71	0.04	0.145	0.012	0.051	0.013
3	4.25	21.13	32.3	10.49	0.46	0.52	0.03	0.142	0.011	0.051	0.013
4	6.05	25.93	35.4	7.20	0.32	0.44	0.02	0.127	0.010	0.040	0.010
5	4.86	20.21	39.5	7.07	0.31	0.37	0.02	0.135	0.011	0.049	0.012
6	4.82	19.64	36.8	7.59	0.33	0.43	0.02	0.123	0.010	0.036	0.009
7	7.01	22.98	34.7	6.57	0.29	0.35	0.02	0.106	0.009	0.027	0.007
8	9.53	24.96	35.5	4.98	0.22	0.23	0.01	0.096	0.008	0.027	0.007
9	15.25	27.42	43.8	3.09	0.14	0.12	0.01	0.076	0.006	0.014	0.004
10	18.85	29.29	57.3					0.042	0.003	0.003	0.001
C8											
0	1.78	19.02	23.5	8.84	0.39	0.69	0.04	0.165	0.013		
1	3.00	20.62	35.7	6.62	0.29	0.53	0.03	0.155	0.012	0.055	0.015
2	3.50	19.75	33.7	7.26	0.32	0.48	0.02	0.153	0.012	0.046	0.012
3	3.95	20.99	34.4	7.41	0.32	0.54	0.03	0.152	0.012	0.072	0.019
4	3.35	16.31	35.1	6.39	0.28	0.42	0.02	0.143	0.011	0.042	0.011
5	3.86	15.46	35.8	6.01	0.26	0.38	0.02	0.134	0.010	0.064	0.017
6	6.36	17.25	41.0	3.66	0.16	0.24	0.01	0.081	0.006	0.011	0.003
7	9.56	21.38	40.1	3.21	0.14	0.21	0.01	0.011	0.001		
8	10.24	19.35	49.4	4.04	0.18	0.19	0.01	0.104	0.008	0.030	0.008
9	14.96	21.37	44.8	2.15	0.09	0.09	0.00	0.065	0.005	0.008	0.002
C9											
0	1.65	25.99	40.3	8.96	0.39	0.68	0.03	0.160	0.012	0.059	0.016
1	3.56	22.75	32.7	6.62	0.29	0.47	0.02	0.141	0.011	0.051	0.014
2	7.50	25.76	35.7					0.116	0.009	0.031	0.008
3	7.62	20.38	37.8	3.02	0.13	0.19	0.01	0.097	0.007	0.015	0.004
4	10.95	21.50	45.3	2.37	0.10	0.14	0.01	0.127	0.010	0.034	0.009
5	16.69	24.97	47.4	2.11	0.09	0.07	0.00	0.043	0.003	0.004	0.001
6	19.34	26.28	74.8	0.58	0.03			0.028	0.002		
7	15.45	23.75	48.7					0.061	0.005	0.023	0.006

Table A.5 Bulk density and nutrient raw data, pond 7

	Dry sub samp mass (g)	Wet sub samp mass (g)	Bulk sect wet mass (g)	C (wt %)	err +/- (wt %)	N (wt %)	err +/- (wt %)	TPP (wt %)	err +/- (wt %)	POP (wt %)	err +/- (wt %)
Pond 7											
C3											
0	1.92	22.22	33.5	14.73	0.64	1.03	0.05	0.211	0.032	0.086	0.022
1	3.30	24.14	37.0	12.54	0.55	0.82	0.04	0.186	0.028	0.066	0.017
2	7.06	30.53	40.7	9.42	0.41	0.55	0.03	0.172	0.026	0.052	0.013
3	8.75	25.63	34.5	7.94	0.35	0.40	0.02	0.158	0.024	0.027	0.007
4	11.31	29.07	43.6	7.59	0.33	0.74	0.04	0.153	0.023	0.022	0.006
5	10.82	28.00	35.4	7.32	0.32	0.32	0.02	0.149	0.022	0.030	0.008
6	12.72	31.73	46.3	7.30	0.32	0.30	0.02	0.148	0.022	0.040	0.010
7	11.95	26.82	44.0	6.99	0.31	0.33	0.02	0.099	0.015	0.012	0.003
8	15.22	30.85	42.3	6.10	0.27	0.23	0.01	0.145	0.022	0.052	0.013
9	16.76	30.30	43.5	5.02	0.22	0.23	0.01	0.106	0.016	0.002	0.000
10	15.58	25.97	49.4	5.25	0.23	0.17	0.01	0.089	0.013	0.002	0.001
11	14.70	25.59	46.7	4.82	0.21	0.22	0.01	0.115	0.017	0.010	0.003
12	25.53	36.20	61.9	2.92	0.13	0.14	0.01	0.095	0.014	0.020	0.005
13	25.77	34.64	52.0	2.00	0.09	0.09	0.00	0.072	0.011	0.022	0.005
14	19.83	28.61	50.6	4.35	0.19	0.16	0.01	0.124	0.019	0.047	0.012
15	20.98	32.57	48.6	4.18	0.18	0.19	0.01	0.087	0.013	0.001	0.000
16	14.76	22.90	52.1					0.065	0.010	0.003	0.001
17	14.25	18.53	51.3					0.033	0.005	0.011	0.003
C4											
0	1.29	18.13	21.4	18.21	0.80	1.18	0.06	0.183	0.008	0.091	0.025
1	2.69	25.59	42.9	15.49	0.68	0.96	0.05	0.173	0.008	0.069	0.019
2	2.82	20.42	34.1	12.27	0.54	0.64	0.03	0.159	0.007	0.057	0.015
3	3.47	18.03	33.0	10.65	0.47	0.55	0.03	0.155	0.007	0.056	0.015
4	5.08	21.53	34.4	10.30	0.45	0.63	0.03	0.154	0.007	0.043	0.012
5	6.63	23.84	35.7	9.93	0.43	0.48	0.02	0.141	0.006	0.035	0.009
6	7.48	23.94	41.4	8.59	0.38	0.41	0.02	0.141	0.006	0.036	0.010
7	6.91	20.61	37.3	7.64	0.33	0.41	0.02	0.146	0.006	0.036	0.010
8	9.81	25.70	44.9	7.09	0.31	0.29	0.01	0.156	0.007	0.039	0.011
9	9.35	22.20	39.1	6.64	0.29	0.28	0.01	0.147	0.006	0.029	0.008
10	10.52	23.66	42.1	6.54	0.29	0.29	0.01	0.142	0.006	0.034	0.009
11	8.64	19.82	27.2	6.85	0.30	0.28	0.01	0.137	0.006	0.036	0.010
12	12.02	26.63	47.2	6.78	0.30	0.27	0.01	0.130	0.006	0.016	0.004
13	12.53	26.94	42.2	6.46	0.28	0.27	0.01	0.126	0.006	0.026	0.007
14	11.35	23.08	38.3					0.107	0.005	0.002	0.000
15	11.25	22.76	49.8	4.40	0.19	0.21	0.01	0.092	0.004	0.020	0.005
16	10.81	25.38	41.8	4.94	0.22	0.22	0.01	0.100	0.004	0.017	0.005
17	9.21	21.90	44.8	4.52	0.20	0.21	0.01	0.111	0.005	0.016	0.004

Table A.6 Bulk density and nutrient raw data, pond 7 continued

	Dry sub samp mass (g)	Wet sub samp mass (g)	Bulk sect wet mass (g)	C (wt %)	err +/- (wt %)	N (wt %)	err +/- (wt %)	TPP (wt %)	err +/- (wt %)	POP (wt %)	err +/- (wt %)
Pond 7											
C5											
0	0.70	16.35	23.1	18.26	0.80	1.10	0.06	0.206	0.009	0.094	0.025
1	1.22	17.02	27.9	18.09	0.79	1.10	0.06	0.207	0.009	0.091	0.024
2	2.71	20.02	33.7	14.42	0.63	0.73	0.04	0.169	0.007	0.056	0.015
3	3.73	17.49	35.8	12.10	0.53	0.54	0.03	0.165	0.007	0.058	0.015
4	4.66	16.00	36.3	7.64	0.33	0.33	0.02	0.163	0.007	0.038	0.010
5	7.43	20.80	41.5	7.44	0.33	0.31	0.02	0.178	0.008	0.036	0.010
6	8.96	22.75	42.0	8.38	0.37	0.34	0.02	0.363	0.016	0.085	0.023
7	6.92	16.45	39.6	8.56	0.37	0.34	0.02	0.341	0.015	0.208	0.055
8	9.46	21.11	44.0	7.50	0.33	0.31	0.02	0.350	0.015	0.216	0.057
9	13.96	25.40	42.5	7.12	0.31	0.28	0.01	0.142	0.006	0.037	0.010
10	18.51	24.47	55.3	1.26	0.06	0.06	0.00	0.032	0.001		
11	23.34	28.75	63.7					0.036	0.002	0.006	0.001

Table A.7 Bulk density and nutrient raw data, pond 8

	Dry sub samp mass (g)	Wet sub samp mass (g)	Bulk sect wet mass (g)	C (wt %)	err +/- (wt %)	N (wt %)	err +/- (wt %)	TPP (wt %)	err +/- (wt %)	POP (wt %)	err +/- (wt %)
Pond 8											
C1											
0	0.66	21.25	28.0	34.43	1.51	2.31	0.12	0.274	0.025	0.188	0.047
1	1.22	23.24	31.7	29.49	1.29	1.96	0.10	0.226	0.021	0.155	0.039
2	1.56	23.39	35.0	37.23	1.63	2.56	0.13	0.221	0.020	0.144	0.036
3	1.32	19.76	32.3					0.248	0.023	0.172	0.043
4	1.70	23.16	33.0	36.51	1.60	2.51	0.13	0.236	0.022	0.152	0.038
5	1.50	19.11	30.5	28.09	1.23	1.81	0.09	0.262	0.024	0.168	0.042
6	1.71	19.62	35.5					0.277	0.025	0.162	0.041
7	1.69	17.90	33.5					0.292	0.027	0.156	0.039
8	1.96	19.49	32.3	23.59	1.03	1.50	0.08	0.363	0.033	0.202	0.050
9	2.10	19.27	24.8					0.361	0.033	0.162	0.041
10	2.22	20.90	43.6	23.37	1.02	1.40	0.07	0.348	0.032	0.130	0.033
11	4.25	22.22	32.9	10.96	0.48	0.65	0.03	0.410	0.038	0.252	0.063
12	3.69	21.35	42.3	28.26	1.24	1.87	0.10	0.409	0.038	0.198	0.050
13	2.55	18.09	33.4	22.22	0.97	1.28	0.07	0.440	0.040	0.258	0.064
14	2.81	17.77	35.5	19.47	0.85	1.08	0.06	0.197	0.018	0.005	0.001
15	2.77	17.76	35.0	25.73	1.13			0.402	0.037	0.176	0.044
16	2.43	16.20	33.9	18.21	0.80	1.02	0.05	0.362	0.033	0.101	0.025
17	3.03	17.12	30.7					0.296	0.027	0.065	0.016
18	2.95	15.84	36.2	15.92	0.70	0.87	0.04	0.333	0.031	0.061	0.015
19	3.42	16.42	35.8	18.99	0.83	0.96	0.05	0.306	0.028	0.092	0.023
20	4.05	18.09	36.9	13.67	0.60	0.63	0.03	0.329	0.030	0.070	0.018
21	4.49	16.11	33.4					0.268	0.025	0.060	0.015
22	7.95	19.63	41.2	6.77	0.30	0.27	0.01	0.284	0.026	0.165	0.041
C3											
0	1.20	25.77	29.5	35.02	1.53	2.41	0.12	0.262	0.017	0.195	0.049
1	1.28	25.98	30.7	33.65	1.47	2.35	0.12	0.272	0.018	0.196	0.049
2	1.50	27.13	35.4					0.273	0.018	0.204	0.051
3	1.37	22.79	29.7	31.66	1.39	2.19	0.11	0.287	0.019	0.188	0.047
4	2.18	25.88	33.2	21.59	0.95	1.34	0.07	0.321	0.021	0.205	0.051
5	1.42	18.79	32.4	27.56	1.21	1.81	0.09	0.361	0.024	0.185	0.046
6	2.52	24.25	31.7					0.433	0.029	0.192	0.048
7	3.22	21.60	34.1	23.90	1.05	1.39	0.07	0.383	0.025	0.183	0.046
8	3.30	23.62	36.2					0.361	0.024	0.159	0.040
9	4.08	24.36	35.4	17.52	0.77	1.04	0.05	0.301	0.020	0.092	0.023
10	4.71	25.59	35.3	19.57	0.86	1.16	0.06	0.294	0.020	0.125	0.031
11	3.77	22.09	33.5					0.341	0.023	0.084	0.021
12	6.28	27.49	39.9	15.08	0.66	0.76	0.04	0.264	0.018	0.104	0.026
13	6.21	22.29	38.5	15.11	0.66	0.68	0.03	0.248	0.016	0.068	0.017
14	9.58	27.54	41.3	2.53	0.11	0.08	0.00	0.271	0.018	0.045	0.011
15	9.13	26.58	38.0	7.40	0.32	0.52	0.03	0.503	0.033	0.165	0.041

Table A.8 Bulk density and nutrient raw data, pond 8 continued

	Dry sub samp mass (g)	Wet sub samp mass (g)	Bulk sect wet mass (g)	C (wt %)	err +/- (wt %)	N (wt %)	err +/- (wt %)	TPP (wt %)	err +/- (wt %)	POP (wt %)	err +/- (wt %)
Pond 8											
C2											
0	0.66	21.25	28.0	34.43	1.51	2.31	0.12	0.274	0.031	0.188	0.038
1	1.22	23.24	31.7	29.49	1.29	1.96	0.10	0.226	0.025	0.155	0.032
2	1.56	23.39	35.0	30.14	1.32	2.01	0.10	0.221	0.025	0.144	0.029
3	1.32	19.76	32.3	32.19	1.41	2.14	0.11	0.248	0.028	0.172	0.035
4	1.70	23.16	33.0					0.236	0.026	0.152	0.031
5	1.50	19.11	30.5	28.09	1.23	1.81	0.09	0.262	0.029	0.168	0.034
6	1.71	19.62	35.5	27.68	1.21	1.75	0.09				
7	1.69	17.90	33.5					0.292	0.033	0.156	0.032
8	1.96	19.49	32.3	23.59	1.03	1.50	0.08	0.363	0.041	0.202	0.041
9	2.10	19.27	24.8	24.62	1.08	1.58	0.08	0.361	0.041	0.162	0.033
10	2.22	20.90	43.6	25.78	1.13	1.72	0.09	0.348	0.039	0.130	0.027
11	4.25	22.22	32.9	10.96	0.48	0.65	0.03	0.410	0.046	0.252	0.051
12	3.69	21.35	42.3	23.77	1.04	1.32	0.07	0.409	0.046	0.198	0.040
13	2.55	18.09	33.4	22.22	0.97	1.28	0.07	0.440	0.049	0.258	0.052
14	2.81	17.77	35.5	19.47	0.85	1.08	0.06	0.197	0.022	0.005	0.001
15	2.77	17.76	35.0					0.402	0.045	0.176	0.036
16	2.43	16.20	33.9	18.21	0.80	1.02	0.05	0.362	0.041	0.101	0.021
17	3.03	17.12	30.7					0.296	0.033	0.065	0.013
18	2.95	15.84	36.2	15.92	0.70	0.87	0.04	0.333	0.037	0.061	0.012
19	3.42	16.42	35.8					0.306	0.034	0.092	0.019
20	4.05	18.09	36.9	13.67	0.60	0.63	0.03	0.329	0.037	0.070	0.014
21	4.49	16.11	33.4	17.95	0.79	0.85	0.04	0.268	0.030	0.060	0.012
22	7.95	19.63	41.2	10.51	0.46	0.43	0.02	0.284	0.032	0.165	0.034
23	6.54	19.46	39.9	15.42	0.68	0.45	0.02	0.403	0.045		

Table A.9 Bulk density and nutrient raw data, pond 9 and 10

	Dry sub samp mass (g)	Wet sub samp mass (g)	Bulk sect wet mass (g)	C (wt %)	err +/- (wt %)	N (wt %)	err +/- (wt %)	TPP (wt %)	err +/- (wt %)	POP (wt %)	err +/- (wt %)
Pond 9											
C1											
0	1.53	24.54	39.2	19.68	0.86	1.31	0.07	0.257	0.018	0.101	0.025
1	2.50	22.65	35.5	13.84	0.61	0.86	0.04	0.253	0.018	0.097	0.024
2	3.40	22.10	32.7	4.95	0.22	0.23	0.01	0.209	0.015	0.031	0.008
3	8.94	21.24	46.4					0.175	0.012	0.013	0.003
C3											
0	7.41	23.66	37.1	8.07	0.35	0.40	0.02	0.255	0.018	0.015	
1	25.54	32.36	60.1	0.24	0.01			0.012	0.001	0.000	
C4											
0	5.71	25.52	47.9	1.38	0.06	0.05	0.00	0.117	0.013	0.055	0.011
1	22.92	33.92	47.2	1.48	0.06	0.04	0.00	0.029	0.003		
2	13.31	19.43	66.5					0.085	0.010	0.030	0.006
Pond 10											
C1											
0	0.81	22.55	31.4	24.08	1.05	2.14	0.11	0.302	0.025	0.148	0.046
1	2.13	24.92	38.7	18.94	0.83	1.64	0.08	0.234	0.019	0.117	0.036
2	1.47	17.45	31.2	21.70	0.95	1.59	0.08	0.251	0.021	0.092	0.029
3	1.52	18.32	32.0	19.13	0.84	1.26	0.06	0.283	0.023	0.111	0.035
4	1.65	19.60	32.7	19.03	0.83	1.18	0.06	0.298	0.024	0.088	0.027
5	1.94	19.29	33.0	17.31	0.76	1.02	0.05	0.287	0.023	0.081	0.025
6	2.17	17.90	32.5	17.24	0.76	0.89	0.05	0.591	0.048	0.155	0.048
7	2.37	16.71	32.9	15.91	0.70	0.84	0.04	0.557	0.046	0.351	0.110
8	3.27	22.29	34.4	14.74	0.65	0.76	0.04	0.504	0.041	0.312	0.098
9	3.54	22.96	35.2	15.77	0.69	0.82	0.04	0.255	0.021	0.071	0.022
10	3.09	19.08	35.1	15.96	0.70	0.81	0.04	0.242	0.020	0.062	0.019
11	3.52	22.28	35.0	16.17	0.71	0.91	0.05	0.232	0.019	0.071	0.022
12	3.65	22.05	36.0	14.25	0.62	0.81	0.04	0.229	0.019	0.083	0.026
13	3.45	19.47	33.2	14.33	0.63	0.82	0.04	0.206	0.017	0.061	0.019
14	3.12	21.04	35.4	15.32	0.67	0.94	0.05	0.221	0.018	0.077	0.024
15	3.38	20.76	33.9	13.94	0.61	0.82	0.04	0.215	0.018	0.061	0.019
16	3.42	17.86	37.7					0.213	0.017	0.061	0.019
17	3.84	19.36	32.1	13.10	0.57	0.67	0.03	0.217	0.018	0.066	0.021
18	3.87	17.15	37.1	11.95	0.52	0.58	0.03	0.212	0.017	0.047	0.015
19	4.78	18.53	36.5	11.41	0.50	0.50	0.03	0.216	0.018	0.026	0.008
20	4.88	17.89	36.7	13.17	0.58	0.49	0.03	0.296	0.024	0.020	0.006
21	6.26	20.27	38.1	10.84	0.47	0.42	0.02	0.338	0.028	0.032	0.010
22	14.82	26.17	51.2	3.18	0.14	0.13	0.01	0.074	0.006		

Table A.10 Bulk density and nutrient raw data, pond 10 continued

	Dry sub samp mass (g)	Wet sub samp mass (g)	Bulk sect wet mass (g)	C (wt %)	err +/- (wt %)	N (wt %)	err +/- (wt %)	TPP (wt %)	err +/- (wt %)	POP (wt %)	err +/- (wt %)
Pond 10											
C2											
0	2.35	26.74	29.4	19.07	0.83	1.19	0.06	0.392	0.023	0.140	0.035
1	2.41	23.94	31.9	18.98	0.83	1.12	0.06	0.375	0.022	0.127	0.032
2	2.65	26.58	32.9					0.321	0.019	0.087	0.022
3	2.23	22.80	33.5	18.11	0.79	1.12	0.06	0.307	0.018	0.115	0.029
4	2.21	21.59	31.8	17.60	0.77	1.02	0.05	0.283	0.017	0.101	0.025
5	2.94	24.62	32.5	17.26	0.76	1.12	0.06	0.274	0.016	0.099	0.025
6	3.78	27.79	35.4	17.08	0.75	0.99	0.05	0.245	0.015	0.073	0.018
7	2.59	23.05	32.3	16.71	0.73	0.93	0.05	0.260	0.016	0.071	0.018
8	2.16	21.40	34.3	16.37	0.72	0.96	0.05	0.326	0.019	0.102	0.026
9	3.46	25.73	34.7	17.05	0.75	0.90	0.05	0.306	0.018	0.064	0.016
10	4.75	24.56	36.2	15.47	0.68	0.75	0.04	0.378	0.023	0.069	0.017
11	5.45	25.11	35.2	15.65	0.69	0.58	0.03	0.600	0.036	0.075	0.021
12	6.00	26.42	35.5	16.78	0.73	0.55	0.03	0.800	0.048	0.024	0.007
13	5.92	24.00	37.5	14.59	0.64	0.49	0.03	0.669	0.040	0.098	0.027
14	5.36	22.14	35.0	15.34	0.67	0.58	0.03	0.532	0.032	0.082	0.020
15	6.01	27.84	39.7	13.65	0.60	0.63	0.03	0.399	0.024	0.086	0.022
16	5.34	22.46	38.3	11.80	0.52	0.54	0.03	0.396	0.024	0.109	0.027
17	6.93	21.94	38.8	11.14	0.49	0.49	0.03	0.430	0.026	0.098	0.025
18	12.85	24.27	50.7	4.64	0.20	0.18	0.01	0.313	0.019	0.088	0.022
19	23.86	33.34	55.1	1.62	0.07	0.05	0.00	0.147	0.009	0.084	0.021
20	20.21	25.85	61.0					0.021	0.001	0.004	
C3											
0	0.61	26.40	34.2	24.06	1.05	1.90	0.10	0.309	0.025	0.120	0.033
1	1.51	22.22	30.0	19.45	0.85	1.45	0.07	0.308	0.025	0.103	0.029
2	1.34	22.72	31.4					0.355	0.029	0.121	0.034
3	1.81	23.62	31.0	21.11	0.92	1.32	0.07	0.395	0.032	0.125	0.034
4	2.16	22.07	31.1	20.05	0.88	1.04	0.05	0.388	0.032	0.098	0.027
5	2.03	19.26	32.9	20.55	0.90	1.10	0.06	0.409	0.033	0.110	0.030
6	2.44	20.52	35.0	21.05	0.92	0.95	0.05	0.408	0.033	0.112	0.031
7	3.11	25.36	35.0	19.24	0.84	1.06	0.05	0.331	0.027	0.120	0.033
8	2.47	20.27	29.5					0.246	0.020	0.100	0.028
9	2.63	17.66	35.2	16.74	0.73	0.96	0.05	0.224	0.018	0.088	0.024
10	2.20	17.58	31.6					0.246	0.020	0.138	0.038
11	2.80	22.18	33.4	16.93	0.74	0.96	0.05	0.266	0.022	0.130	0.036
12	3.32	22.72	34.5					0.237	0.019	0.071	0.020
13	3.71	24.81	33.6	15.50	0.68	0.85	0.04	0.242	0.020	0.092	0.025
14	3.10	20.19	35.9	14.70	0.64	0.80	0.04	0.220	0.018	0.084	0.023
15	3.96	24.80	36.8	15.29	0.67	0.84	0.04	0.216	0.018	0.094	0.026
16	3.43	20.68	34.9	14.88	0.65	0.81	0.04	0.235	0.019	0.077	0.021
17	5.40	24.86	39.1	14.99	0.66	0.63	0.03	0.248	0.020	0.066	0.018
18	10.56	24.03	44.5	10.29	0.45	0.30	0.02	0.366	0.030	0.016	0.004
19	7.93	26.63	37.9	9.23	0.40	0.28	0.01	0.544	0.045	0.101	0.028
20	13.87	24.54	48.5	4.84	0.21	0.11	0.01	0.297	0.024	0.115	0.032

Table A.11 Bulk density and nutrient raw data, pond 11

	Dry sub samp mass (g)	Wet sub samp mass (g)	Bulk sect wet mass (g)	C (wt %)	err +/- (wt %)	N (wt %)	err +/- (wt %)	TPP (wt %)	err +/- (wt %)	POP (wt %)	err +/- (wt %)
Pond 11											
C1											
0	2.72	26.04	36.5	8.94	0.39	0.64	0.03	0.141	0.019	0.044	0.012
1	2.99	22.47	30.7	9.30	0.41	0.64	0.03	0.144	0.020	0.050	0.013
2	3.99	20.37	34.6	7.07	0.31	0.44	0.02	0.109	0.015	0.031	0.008
3	6.57	20.41	36.5	5.95	0.26	0.29	0.01	0.081	0.011	0.018	0.005
4	7.34	16.88	37.1	5.32	0.23	0.24	0.01	0.075	0.010	0.011	0.003
5	8.32	17.18	46.7	3.90	0.17	0.18	0.01	0.055	0.007	0.011	0.003
6	16.22	27.74	45.6	1.69	0.07	0.08	0.00	0.019	0.003	0.002	0.001
7	13.87	21.46	49.7	0.88	0.04	0.04	0.00	0.009	0.001	0.001	0.000
8	15.34	26.60	63.9					0.004	0.001	0.000	0.000
C2											
0	0.99	17.28	19.6	11.43	0.50	0.88	0.04	0.168	0.018	0.060	0.041
1	1.32	20.08	26.1	10.60	0.46	0.79	0.04	0.121	0.013	0.014	0.010
2	2.68	18.52	32.8					0.117	0.012	0.023	0.016
3	3.99	24.60	35.9	6.87	0.30	0.45	0.02	0.057	0.006		
4	4.28	21.09	36.8	6.51	0.29	0.34	0.02	0.083	0.009	0.014	0.010
5	5.42	19.68	33.4	6.08	0.27	0.33	0.02	0.083	0.009	0.024	0.016
6	6.90	20.43	34.2	5.69	0.25	0.22	0.01	0.079	0.008	0.025	0.017
7	7.39	20.22	37.4	4.90	0.21	0.25	0.01	0.069	0.007	0.014	0.010
8	10.39	25.55	36.8	6.15	0.27	0.25	0.01	0.034	0.004		
9	11.01	23.69	44.7	6.17	0.27	0.28	0.01	0.085	0.009	0.022	0.015
C6											
0	3.18	24.96	31.3	9.57	0.42	0.65	0.03	0.132	0.014	0.043	0.029
1	2.90	19.52	33.2	8.09	0.35	0.52	0.03	0.116	0.012	0.051	0.035
2	5.67	26.65	35.9	6.90	0.30	0.42	0.02	0.000	0.000		
3	7.61	27.57	39.0	6.46	0.28	0.35	0.02	0.110	0.012	0.042	0.029
4	6.99	20.91	37.8	6.36	0.28	0.30	0.02	0.081	0.009		
5	7.30	19.77	40.9	5.18	0.23	0.27	0.01	0.066	0.007	0.023	0.016
6	9.26	22.12	41.7	6.21	0.27	0.27	0.01	0.080	0.009	0.021	0.015
7	11.34	23.92	44.3	6.22	0.27	0.24	0.01	0.071	0.008		
8	11.57	21.32	40.5	3.01	0.13	0.11	0.01	0.032	0.003	0.003	0.002
9	16.23	23.12	36.2	1.03	0.05	0.04	0.00	0.011	0.001		
10	20.01	26.03	63.0	1.95	0.09			0.005	0.001	0.001	0.001

Table A.12 Bulk density and nutrient raw data, pond 12

	Dry sub samp mass (g)	Wet sub samp mass (g)	Bulk sect wet mass (g)	C (wt %)	err +/- (wt %)	N (wt %)	err +/- (wt %)	TPP (wt %)	err +/- (wt %)	POP (wt %)	err +/- (wt %)
Pond 12											
C1											
0	0.89	14.88	20.2	21.73	0.95	1.23	0.06	0.289	0.023	0.089	0.022
1	2.02	23.03	31.3	21.08	0.92	1.20	0.06	0.285	0.023	0.077	0.019
2	2.32	21.99	32.1	20.26	0.89	1.06	0.05	0.285	0.023	0.067	0.017
3	2.74	23.28	34.7	19.87	0.87	1.11	0.06	0.256	0.021	0.080	0.020
4	2.03	16.04	31.0	18.15	0.79	0.94	0.05	0.261	0.021	0.069	0.017
5	2.75	21.58	32.6	18.04	0.79	0.97	0.05	0.264	0.021	0.059	0.015
6	2.83	21.37	32.6	17.72	0.78	0.90	0.05	0.258	0.021	0.025	0.006
7	3.07	22.81	31.9	18.37	0.80	0.97	0.05	0.245	0.020	0.045	0.011
8	3.71	26.77	33.5	17.37	0.76	0.87	0.04	0.253	0.020	0.036	0.009
9	3.64	26.38	36.7	17.99	0.79	0.91	0.05	0.254	0.020	0.043	0.011
10	3.80	26.57	34.0	17.13	0.75	0.87	0.04	0.248	0.020	0.033	0.008
11	3.98	26.16	37.9	17.42	0.76	0.87	0.04	0.247	0.020		
C4											
0	1.70	22.73	32.3	20.31	0.89	1.16	0.06	0.253	0.028	0.089	0.047
1	2.54	23.98	35.7	20.78	0.91	1.12	0.06	0.234	0.026	0.095	0.050
2	3.04	25.20	33.4	19.87	0.87	0.98	0.05	0.219	0.024	0.102	0.054
3	3.25	25.57	34.0	18.19	0.80	0.99	0.05	0.236	0.026	0.087	0.046
4	3.44	25.78	33.8	17.62	0.77	0.89	0.05	0.221	0.024	0.073	0.039
5	4.34	27.26	34.0	15.26	0.67	0.82	0.04	0.205	0.022	0.079	0.041
6	2.48	17.96	33.9	14.96	0.65	0.79	0.04	0.189	0.021	0.082	0.043
7	4.73	26.42	36.5	13.85	0.61	0.72	0.04	0.189	0.021	0.074	0.039
8	6.65	27.87	34.2	13.63	0.60	1.79	0.09	0.189	0.021	0.080	0.042
9	9.24	27.20	39.5	16.80	0.74	0.64	0.03	0.169	0.018	0.077	0.040
10	13.30	33.28	45.7	12.56	0.55	0.43	0.02	0.231	0.025	0.070	0.037
11	7.72	24.29	36.7	12.89	0.56	0.43	0.02	0.284	0.031	0.076	0.040
12	6.14	18.58	37.7	13.95	0.61	0.44	0.02	0.360	0.039	0.072	0.038
13	7.42	21.64	38.6	18.38	0.80	0.50	0.03	0.335	0.037	0.075	0.040
14	7.69	21.91	35.1	15.53	0.68	0.46	0.02	0.320	0.035	0.047	0.025
C3											
0	1.94	19.62	32.0	20.75	0.91	1.00	0.05	0.236	0.027	0.097	0.020
1	2.21	19.77	31.0	18.30	0.80	0.86	0.04	0.211	0.024	0.087	0.018
2	3.14	22.73	33.8					0.204	0.023	0.071	0.014
3	2.76	18.47	34.5	16.90	0.74	0.77	0.04	0.212	0.024	0.075	0.015
4	3.34	18.38	35.0	15.60	0.68	0.70	0.04	0.166	0.019	0.039	0.008
5	6.11	23.64	37.3	13.37	0.59	0.58	0.03	0.185	0.021	0.084	0.017
6	7.44	21.56	46.8	17.69	0.77	0.74	0.04	0.285	0.032	0.103	0.021
7	8.70	20.10	41.1	3.81	0.17	0.16	0.01	0.196	0.022		

Table A.13 Bulk density and nutrient raw data, pond 13

	Dry sub samp mass (g)	Wet sub samp mass (g)	Bulk sect wet mass (g)	C (wt %)	err +/- (wt %)	N (wt %)	err +/- (wt %)	TPP (wt %)	err +/- (wt %)	POP (wt %)	err +/- (wt %)
Pond 13											
C4											
0	1.05	18.85	25.5	14.54	0.64	0.85	0.04	0.275	0.017	0.115	0.029
1	1.61	22.99	32.2	22.08	0.97	1.36	0.07	0.292	0.018	0.123	0.031
2	2.25	26.91	37.8	20.98	0.92	1.18	0.06	0.284	0.017	0.097	0.024
3	1.95	22.56	30.3	20.46	0.90	1.17	0.06	0.311	0.019	0.118	0.030
4	2.59	24.53	30.7	19.52	0.85	1.18	0.06	0.283	0.017	0.121	0.030
5	3.75	27.21	36.0	17.12	0.75	0.84	0.04	0.278	0.017	0.074	0.018
6	6.23	26.64	34.9	18.02	0.79	0.63	0.03	0.281	0.017	0.084	0.021
7	10.02	27.10	42.5	12.52	0.55	0.39	0.02	0.282	0.017	0.078	0.020
8	15.62	30.75	43.6	3.89	0.17	0.11	0.01	0.404	0.025	0.171	0.043
9	18.33	33.35	43.2	5.50	0.24	0.15	0.01	0.265	0.016		
10	10.32	30.18	42.0	9.49	0.42	0.28	0.01	0.474	0.029		
11	7.88	27.58	32.3	13.35	0.58	0.41	0.02	0.648	0.039	0.061	0.015
12	6.04	24.46	37.4	21.02	0.92	0.68	0.03	0.647	0.039	0.050	0.013
13	7.00	26.41	36.7	14.38	0.63	0.36	0.02	0.550	0.034	0.021	0.005
14	7.98	26.94	39.0	12.53	0.55	0.37	0.02	0.612	0.037	0.086	0.021
15	9.47	27.88	41.9	7.96	0.35	0.23	0.01	0.690	0.042	0.199	0.050
16	14.76	31.44	46.4	6.80	0.30	0.19	0.01	0.617	0.038	0.036	0.009
17	10.25	26.64	48.2	9.84	0.43	0.25	0.01	0.495	0.030		
18	14.20	28.99	47.4	5.40	0.24	0.14	0.01	0.541	0.033	0.314	0.083
19	19.76	35.41	44.2	4.02	0.18	0.11	0.01	0.256	0.016		
C5											
0	1.74	21.31	26.4	21.60	0.95	1.23	0.06	0.204	0.022	0.108	0.027
1	2.36	22.20	27.4	20.54	0.90	1.16	0.06	0.190	0.020	0.099	0.025
2	1.87	17.51	31.2	21.22	0.93	1.05	0.05	0.174	0.019	0.079	0.020
3	2.99	20.86	31.0	16.50	0.72	0.81	0.04	0.177	0.019	0.095	0.024
4	3.07	20.19	34.6	19.41	0.85	1.07	0.05	0.162	0.017	0.083	0.021
5	2.40	18.00	30.9	18.83	0.82	0.93	0.05	0.144	0.015	0.069	0.017
6	2.73	20.04	33.3	18.91	0.83	0.97	0.05	0.145	0.016	0.068	0.017
7	3.14	18.22	32.8	16.28	0.71	0.87	0.04	0.151	0.016	0.070	0.018
8	6.49	23.89	42.9	16.09	0.70	0.72	0.04	0.145	0.016	0.065	0.016
9	10.22	21.30	40.2	3.58	0.16	0.14	0.01	0.036	0.004		
10	10.83	21.20	44.9	5.62	0.25	0.21	0.01	0.077	0.008	0.018	0.005
11	8.26	18.40	42.6	5.34	0.23	0.20	0.01	0.108	0.012	0.049	0.012
12	8.32	18.77	44.0	9.21	0.40	0.33	0.02	0.144	0.015	0.026	0.006
13	8.94	19.28	40.1	8.49	0.37	0.28	0.01	0.223	0.024	0.090	0.022

Table A.14 Bulk density and nutrient raw data, pond 14

	Dry sub samp mass (g)	Wet sub samp mass (g)	Bulk sect wet mass (g)	C (wt %)	err +/- (wt %)	N (wt %)	err +/- (wt %)	TPP (wt %)	err +/- (wt %)	POP (wt %)	err +/- (wt %)
Pond 14											
C1											
0	1.13	21.00	34.1	20.69	0.91	2.28	0.12	0.285	0.023	0.099	0.028
1	1.61	18.16	31.8	19.00	0.83	1.14	0.06	0.274	0.022	0.095	0.026
2	3.48	24.13	35.1					0.243	0.020	0.081	0.023
3	2.86	16.25	34.4	15.36	0.67	0.62	0.03	0.203	0.017	0.051	0.014
4	4.98	18.97	32.2	15.33	0.67	0.49	0.03	0.189	0.015	0.051	0.014
5	7.05	23.07	38.8	14.16	0.62	0.54	0.03	0.167	0.014	0.043	0.012
6	5.10	17.33	39.5	15.70	0.69	0.40	0.02	0.396	0.032	0.025	0.007
7	10.05	18.44	51.5	6.02	0.26	0.12	0.01	0.383	0.031	0.172	0.048
8	14.45	19.89	55.1	1.25	0.05	0.03	0.00	0.080	0.007		
9	13.59	17.32	60.8	0.44	0.02			0.019	0.002		
C3											
0	2.03	28.77	33.7	20.49	0.90	1.26	0.06	0.208	0.020	0.079	0.020
1	2.39	21.41	35.5	18.80	0.82	1.09	0.06	0.196	0.019	0.054	0.014
2	2.62	23.21	35.1	18.45	0.81	0.95	0.05	0.219	0.021	0.077	0.019
3	3.10	24.14	35.0	20.20	0.88	1.00	0.05	0.219	0.021	0.026	0.007
4	3.20	25.02	35.9	18.70	0.82	1.02	0.05	0.242	0.023	0.061	0.015
5	2.46	18.07	31.3	19.11	0.84	0.92	0.05	0.226	0.022	0.061	0.015
6	2.95	19.83	29.2	17.86	0.78	0.86	0.04	0.219	0.021	0.048	0.012
7	2.67	15.58	24.4	21.12	0.92	1.05	0.05	0.204	0.019	0.052	0.013
8	3.38	19.39	35.0	17.88	0.78	0.76	0.04	0.175	0.017	0.028	0.007
9	4.11	24.20	36.4	19.10	0.84	0.85	0.04	0.218	0.021	0.039	0.010
10	3.52	19.67	34.6	19.48	0.85	0.81	0.04	0.212	0.020	0.043	0.011
11	3.52	17.56	31.9	17.29	0.76	0.65	0.03	0.225	0.021	0.040	0.010
12	4.49	17.38	38.5	17.47	0.76	0.62	0.03	0.216	0.021	0.064	0.016
13	5.79	20.59	36.4	17.02	0.75	0.50	0.03	0.215	0.021	0.028	0.007
14	5.72	19.98	37.9	16.13	0.71	0.44	0.02	0.318	0.030		
15	4.75	18.44	37.4	17.70	0.77	0.49	0.03	0.212	0.020		
16	5.04	19.17	36.4	16.34	0.72	0.56	0.03	0.167	0.016	0.023	
17	5.02	18.06	36.9	16.52	0.72	0.45	0.02	0.335	0.032		
18	5.06	16.72	38.6	17.20	0.75	0.47	0.02	0.276	0.026		
19	10.93	22.88	40.1	14.53	0.64	0.39	0.02	0.125	0.012		
20	23.13	32.14	65.4	15.11	0.66	0.33	0.02	0.142	0.013		
C4											
0	2.14	16.55	25.0	15.61	0.68	0.88	0.04	0.137	0.016	0.057	0.014
1	5.63	23.27	43.1	9.10	0.40	0.52	0.03	0.105	0.012	0.053	0.013
2	11.78	20.55	41.7					0.044	0.005	0.017	0.004
3	22.05	33.25	54.4	2.05	0.09	0.09	0.00	0.028	0.003	0.016	0.004
4	10.49	23.35	40.5					0.092	0.011	0.062	0.016
5	7.39	24.54	41.5	10.70	0.47	0.53	0.03	0.103	0.012	0.027	0.007
6	10.23	20.54	46.7	6.67	0.29	0.33	0.02	0.070	0.008	0.041	0.010
7	19.32	25.12	64.0	2.64	0.12	0.12	0.01	0.007	0.001		
8	22.36	28.15	58.5	0.36	0.02	0.02	0.00	0.008	0.001		