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Ecological Effects of Nutrient Enrichment on a Coastal Fringe Mangrove Forest

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**ECOLOGICAL EFFECTS OF NUTRIENT ENRICHMENT ON A
COASTAL FRINGE MANGROVE FOREST**

BY

BRITA JULIET JESSEN

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

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UNIVERSITY OF RHODE ISLAND

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DOCTOR OF PHILOSOPHY DISSERTATION
OF
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ABSTRACT

Mangrove ecosystems are highly productive coastal wetlands that connect tropical terrestrial and marine systems. Increasing human populations and land use changes are enhancing nutrient loading to tropical coastlines, potentially leading to eutrophic conditions for marine systems. The carbon (C) cycle is critical for mangrove forest structure, function, and resilience under environmental change. Increasing trends of nutrient enrichment in tropical coastal waters may have an effect on organic C mineralization by alleviating nutrient limitation of the heterotrophic microbial community, which may lead to a loss of within-stand carbon sequestration. To better understand and predict the consequences of increased nutrient input, a fertilization study within a fringe mangrove system in southeast Puerto Rico was established to mimic high-nitrogen agriculture runoff (N:P ratio of 50:1) or urban runoff with higher phosphorus (N:P ratio of 16:1) for an annual loading rate of $70 \text{ g N m}^{-2} \text{ y}^{-1}$ and 3.1 or $9.7 \text{ g P m}^{-2} \text{ y}^{-1}$. Bi-weekly pulses of fertilization began in October 2011 and continued for two years.

Chapter 1 investigates nutrient enrichment effect on organic carbon mineralization by sediment microbial respiration rates and above- and below-ground litter decomposition. Neither of the fertilization scenarios had an effect on any of the C mineralization processes compared with ambient conditions in this two-year study. Sediment respiration rates ranged from 0.54 to $2.63 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$. Above-ground litter was calculated to completely decompose within 38 to 220 days by microbial activity alone. This work agrees with previous studies of nutrient enrichment and organic C decomposition rates in mangrove systems, yet differences in the reported values of C

mineralization between sites suggest that forest type, environmental conditions, and location may play a substantial role in mangrove C dynamics.

Chapter 2 evaluates above-ground production (tree biomass and litter production) in response to nutrient enrichment. Mangrove tree response was characterized by above-ground wood production and litterfall input. Basal area ranged from 17.1 to 32.7 m⁻² m⁻². Above-ground biomass (wood and foliage) ranged from 3.9 to 15.4 kg dry mass m⁻². Mangrove above-ground growth was highly variable and was not affected by nutrient treatment. Litterfall was strongly seasonal, with higher rates associated with the start of the rainy season in late summer. Total litterfall for this fringe mangrove ranged from 1061 to 1217 g dry mass m⁻² y⁻¹, which was on the higher range of neo-tropical fringe mangroves. Total litter production was not affected by nutrient treatment, but agriculture treatment (high N:P) enhanced leaf and stipule production ($p = 0.04$ and $2.2e^{-06}$, respectively). These results suggest that two years of high N:P nutrient addition results in a small positive effect for above-ground production within a fringe mangrove, and that litterfall may be a more sensitive response than above-ground biomass for a short-term (two years) assessment. Considering the different effects to mangrove production by the nutrient enrichment regimes (high vs. intermediate N:P loading), further work is needed to assess N and P interactions that may affect above-ground mangrove production.

In Chapter 3, a one-time spike of ¹⁵N stable isotope tracer was added to ambient (receiving local channel water) and chronically nutrient enriched (receiving 70 g N m⁻² y⁻¹ and 9.7 g P m⁻² y⁻¹ for 21 to 24 months) sites within a coastal fringe mangrove forest in southeastern Puerto Rico to determine if nutrient enrichment was being retained in the mangrove ecosystem, and to identify mangrove N sinks. Measurements for ¹⁵N retention

occurred at 1 month, 3 months, and 10 months after the initial spike. ^{15}N tracer was recovered in all components (mangrove foliage, standing litter, surface sediment, and fine roots) within ambient and fertilized sites. The highest proportion of tracer retention (28 to 59% under ambient conditions and 14 to 28% under nutrient enriched conditions) occurred in the organic layer of the forest floor (standing litter, surface sediment, and surficial fine roots). ^{15}N retention within the mangrove canopy represented the smallest N sink, although foliar $\delta^{15}\text{N}$ continued to increase throughout the measurement period. Tracer retention within the organic layer of the forest floor indicates strong recycling and retention of nutrients that supports a highly-productive system in an oligotrophic marine environment. Chronically nutrient enriched sites retained more ^{15}N tracer than ambient sites, but a smaller proportion of the applied ^{15}N fertilizer, suggesting the capacity of nutrient retention had been exceeded by the added nutrient load. The culmination of this work suggests resilience of mangrove ecosystem function within the first two years of nutrient enrichment.

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When it was time to take a break from work, our time in Puerto Rico was enriched by wonderful personal connections. Dr. Juan Gonzalez Lagoa enhanced our knowledge

of the natural history of Puerto Rico, and generously supported undergraduate students on this project. While our heads were focused on research, our hearts were fulfilled by caring for the *satos* who wandered into our world. Mary Eldergill and Dr. Hector Martínez were our guides for street dog rehabilitation and rescue, in exchange for some conversation on the current status of mangrove ecology.

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My life-long gratitude goes to my two major professors and mentors, Scott Nixon and Candace Oviatt. Dr. Nixon picked the horse, and Dr. Oviatt saw her through. I am likewise thankful for my committee of brilliant teachers – Drs. Arthur Gold, Charles Roman, Ariel Lugo, and Serena Moseman-Valtierra.

I could fill another ten pages with names of family and friends who led me through this long stretch. Drs. Kiersten Curti, J. Stanley Cobb, and Megan O'Connor top the long, heartfelt list. The most generous and devoted friend has been Adam O'Donnell, who came with me to the north woods so I could complete this work and continue onward together.

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Dedication

I dedicate this work to my parents and mentor,

H.N.S., J.M.J, and S.W.N.

All future work will be in honor of C.A.O. and the future he belongs to.

PREFACE

This dissertation is written in the manuscript format specified by the University of Rhode Island Graduate School. The body of this dissertation has been divided into three chapters corresponding to three manuscripts, each formatted for a specific journal. Chapter 1 is written for *Hydrobiologia* with Candace Oviatt, Cathleen Wigand, David Johnson, Ryann Rossi, Chelsea Duball, and Scott Nixon as coauthors. Chapter 2 is written for *Aquatic Botany* with Candace Oviatt, Ariel Lugo, Ernesto Medina, Jessica Foley, Megan O'Connor, Susanne Hoeppe, and Scott Nixon as coauthors. Chapter 3 is written for the *Journal of Experimental Marine Biology and Ecology* with Arthur Gold, Autumn Oczkowski, Rick McKinney, Kenneth Miller, and Ryan Quinn as coauthors. These manuscripts will be submitted for peer review and publication upon completion of this dissertation. The supplement information provided in Appendix A includes additional data that may be referred to in the text. Appendix B contains original litterfall data. Appendix C contains original stable isotope and nutrient content data. At the end of the dissertation is a complete bibliography.

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Chapter 1

BENTHIC RESPIRATION AND LITTER DEGRADATION UNDER NUTRIENT LOADING SCENARIOS IN A FRINGE *RHIZOPHORA* *MANGLE* (L.) FOREST

To be submitted to Hydrobiologia

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BENTHIC RESPIRATION AND LITTER DEGRADATION UNDER NUTRIENT LOADING SCENARIOS IN A FRINGE *RHIZOPHORA* *MANGLE* (L.) FOREST

ABSTRACT

The carbon (C) cycle is critical for mangrove forest structure, function, and resilience under environmental change. Increasing trends of nutrient enrichment in tropical coastal waters may have an effect on organic C mineralization by alleviating nutrient limitation of the heterotrophic microbial community, which may lead to a loss of within-stand carbon sequestration. For this study, I enriched a coastal fringe *Rhizophora mangle* (L.) mangrove system for two years with two fertilizer regimes to mimic high-nitrogen agriculture runoff (N:P ratio of 50:1) or urban runoff with higher phosphorus (N:P ratio of 16:1) for an annual loading rate of $70 \text{ g N m}^{-2} \text{ y}^{-1}$ and 3.1 or $9.7 \text{ g P m}^{-2} \text{ y}^{-1}$. Carbon mineralization was measured by sediment microbial respiration rates and above- and below-ground litter decomposition. Neither of the fertilization scenarios had an effect on any of the C mineralization processes compared with ambient conditions in this two-year study. Sediment respiration rates ranged from 0.54 to $2.63 \text{ } \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ and was consistent across measurement periods. Time to 50% decay of above-ground leaf litter ranged from 61 to 110 days (average 79 days) by microbial activity alone. Below-ground leaf litter material was fully decomposed by 22 months after burial. Nutrient enrichment effects on organic C mineralization appear to be constrained by the highly refractory mangrove material. Slow C mineralization is an important mechanism of organic peat formation and nutrient conservation within the mangrove wetland. Differences in the reported values of C mineralization between sites suggest that forest

type, environmental conditions, and location may play a substantial role in mangrove C dynamics.

INTRODUCTION

Mangrove ecosystems are often attributed for providing services such as storm buffering (Das & Vincent, 2009), wastewater depuration (Corredor & Morell, 1994), sea level rise resilience (McKee et al., 2007), enhancement of secondary production (Mumby et al., 2004), and carbon sequestration (Bouillon et al., 2008; Donato et al., 2011). Each of these processes is directly linked to organic matter production and turnover rates within the mangrove system; thus the mechanisms and driving factors of organic matter production, decomposition, and retention are necessary elements for understanding mangrove ecosystem services. The mangrove habitat – ranging from warm temperate to tropical coastlines – is subject to increasing anthropogenic nutrient (nitrogen, N and phosphorus, P) loading rates due to rising human populations, urban development, and changing land use practices (Corredor et al., 1999; Downing et al., 1999; Nixon et al., 2007). Globally, regions with the greatest increase of inorganic nutrient input to coastal waters (over 500 kg DIN km⁻² y⁻¹) include densely populated areas of the Indian Ocean, southwest Pacific, and to a smaller extent the Caribbean Sea (Deegan et al., 2012) where mangroves dominate the vegetated coastline. While temperate coastal systems are considered to be primarily N-limited, tropical coastal ecosystems have been found to be either N and/or P limited depending on factors such as sediment delivery, N-fixing microbial activity, and sediment cation exchange capacity (Corredor et al., 1999; Howarth & Marino, 2006; Reef et al., 2010). The rapid anthropogenic enhancement of biologically-available inorganic nutrients (Howarth, 2008) combined with the central importance of the carbon cycle for coastal ecosystem function drives the need for an

understanding of organic carbon processes under enriched nutrient conditions in mangrove systems.

The main source of new organic material within the mangrove habitat is high primary production rates of mangrove trees (Bouillon et al., 2008; Kristensen et al., 2008). The evolutionary effects of resource limitation and environmental regulation (sensu Twilley & Rivera-Monroy, 2005) are physiological adaptations by the mangrove trees to conserve nutrients, limit herbivory, and maintain internal osmotic balance (Ball, 1988). These adaptations lead to low energetic quality of mangrove organic matter (OM): Nutrient (nitrogen, N and phosphorus, P) concentrations of senescent leaves are low due to efficient resorption before leaf abscission (Feller et al., 1999); high tannin levels deter herbivory of live leaves (Feller, 1995); high leaf sclerophylly limits water loss from evapotranspiration (Ball, 1988). Given the poor nutritional quality of this recalcitrant material, it is assumed that higher trophic levels do not gain a great amount of energy from the direct consumption of mangrove OM. A prevailing theory of mangrove ecosystem energetics is the detrital pathway described by Odum & Heald (1975), which postulates that mangrove OM quality is enhanced and made available for secondary trophic level use via microbial decomposition. Coincident with this pathway, microbial OM remineralization promotes nutrient recycling within the forest system for primary producer uptake (Holguin et al., 2001). Thus the rate of mangrove OM degradation is a bottleneck step for system-wide energy flow, with slow rates supporting within-stand nutrient conservation (Reef et al., 2010). Furthermore, any mangrove OM that is not directly consumed, decomposed, or physically exported becomes retained within the soil matrix (Cebrián et al., 1998). Mangrove systems with low decomposition rates and low

flushing conditions develop deep structural platforms of peat and a biological capacity to maintain elevation relative to sea level rise (McKee et al., 2007). An enhancement of OM decomposition in coastal wetlands by nutrient enrichment may deter this ability to maintain structural peat (Deegan et al., 2012).

Increased nutrient availability within a system may directly or indirectly affect OM decomposition rates. Indirect effects of nutrient enrichment include changes to the substrate quality or input rate. Nutrient resorption before leaf senescence and abscission can be regulated by the local availability of the same nutrient (Vitousek, 1984; Schlesinger et al., 1989; Killingbeck, 1996). Feller et al. (1999; 2009) demonstrated a negative relationship between nutrient input and leaf nutrient resorption in fertilized mangrove systems, allowing more of the nutrient to be “lost” to the benthic community under enriched conditions. With regards to substrate quantity, Boto & Wellington (1983) measured greater leaf production within the first year of fertilization of a north Queensland mangrove, presumably enhancing the amount of organic matter available to the decomposer community. Thus it is reasonable to predict greater rates of OM decomposition given a more favorable quality and availability of substrate under enriched nutrient conditions. An example of direct effect to OM decomposition by nutrient enrichment would be nutrient limitation relief for the microbial decomposer community by supplementing inorganic nutrients in place of organic substrate-derived nutrients (Debusk & Reddy, 2005). However, there is evidence of negative control on recalcitrant OM by nutrient enrichment if the inorganic nutrient supply decreases the “need” for OM breakdown by the microbial community (Knorr et al., 2005; Craine et al., 2007). The

overall effect of nutrient enrichment on OM decomposition continues to present as complex and variable.

Previous studies have demonstrated enhanced heterotrophic microbial activity under direct nutrient stimulus in freshwater systems (Robinson & Gessner 1999), salt marshes (Wigand et al., 2009; Deegan et al, 2012), and subtropical wetlands (Corstanje et al., 2006; Debusk & Reddy 2005). Mangrove studies, on the other hand, have presented mixed results of OM decomposition under enriched nutrient conditions. Tam et al. (1998) found no relationship between mangrove litter decay rates along a nutrient gradient extending from a sewage treatment plant at Shenzhen, China. Similarly, Feller et al. (1999) found no difference in decomposition rates of submerged leaves within a fertilized dwarf *Rhizophora* mangle at Twin Cays, Belize, although below-ground decomposition was enhanced with buried fertilizer cores. Keuskamp et al. (2015) used a multi-factorial design to differentiate source material enrichment versus direct nutrient enrichment of decomposing litter at sites in Belize and Florida. In a P-limited mangrove system, enhancement of litter quality with P fertilization stimulated OM decomposition rates; however, direct fertilization of the decomposition matrix without pre-enriched litter did not affect OM decomposition rates. From these works it appears that OM decomposition and retention are modulated via the indirect pathway of substrate quality and not necessarily by direct nutrient input.

This study examines organic carbon mineralization under direct nutrient application as well as sourced organic material from mangrove trees that have encountered nutrient enrichment. The objective of this study is to determine if two years of a surface-level pulse of nutrients would affect mangrove OM degradation. The degradation process was

examined by three mechanisms: (1) sediment OM mineralization, (2) leaf litter decomposition, (3) below-ground OM decomposition. I anticipated that the “fast turnover” sediment microbial community would respond to nutrient enrichment more strongly and favorably than “slow turnover” mangrove tree production. I expected a positive response of sediment respiration under direct nutrient enrichment, whereas mangrove leaf decomposition would depend on initial substrate composition.

METHODS

Site description

This study was conducted in a fringe mangrove at the eastern edge of the mouth of Jobos Bay (17° 55.5'N 60° 12.2'W) in southeastern Puerto Rico (Figure 1-1). Mean annual rainfall ranges 106 – 114 cm, with a dry season from December through March and a rainy period from July through October (Capella, 2008; Appendix). Air temperature is relatively constant throughout the year, with a range of 16.5 – 35.7° C and an annual average of 26.4° C (Appendix). Several small rivers and intermittent streams empty into the bay, but no freshwater discharge reaches the mangrove cays at the mouth of the bay. The tidal profile is mixed diurnal microtidal (17 – 36 cm) with largest tides of the year occurring in October (Field 2008).

Site selection was determined by the least relative amount of anthropogenic nutrient input to the local environment, based on the following information: (i) Mangroves at the mouth of Jobos Bay receive overflowing tidal water from a channel that flows directly from the Caribbean Sea into the bay; (ii) Stable isotope (¹⁵N) signatures suggest that rooted vegetation communities of Jobos Bay are disconnected from mainland-derived

nutrient runoff (Bowen & Valiela, 2008); (iii) Any potential input from the nearest residential community (Punta Pozuelo) would be buffered by a region of sand dunes and forest, and sewage from the community is discharged away from the bay; (iv) The closest Jobos Bay National Estuarine Research Reserve monitoring station (Station 20) has consistently lower ambient nutrient (DIN, DIP) levels compared with stations within the bay.

The experimental site is contained within a *Rhizophora mangle* (L.) dominated community, which extends from the shoreline 10 to 20 m and transitions into an *Avicennia germinans* (L.) forest. Floristic characterization of the site is presented in Chapter 2, and microtopographic measurements are presented in the Appendix.

Nutrient enrichment

A two-year nutrient enrichment protocol was conducted with three levels of nutrient enrichment: high N:P (50N:1P), intermediate N:P (16N:1P), and control (ambient channel water). High N:P fertilizer represented nutrient input from agriculture sources (sugarcane watershed drainage N:P = 43.9; Faithful et al., 2007), and intermediate N:P fertilizer represented nutrient input from urban sources (urban drainage N:P = 12.6; Hopkins & Day, 1980). The annual loading rates were $70 \text{ g N m}^{-2} \text{ y}^{-1}$ and $3.1 \text{ g P m}^{-2} \text{ y}^{-1}$ (“agriculture” high N:P fertilizer), $70 \text{ g N m}^{-2} \text{ y}^{-1}$ and $9.7 \text{ g P m}^{-2} \text{ y}^{-1}$ (“urban” intermediate N:P fertilizer), or 1 L local channel water without fertilizer (“control”). With the assumption that the experimental area is submerged by 6 cm of tidal water for half of the year (approximate mean high water; Appendix), the total annual nutrient load is approximately 30 times the amount of DIN loading by tidal overflow (NERRS, 2015; Appendix). An estimate of P loading increase is difficult to make because channel water

phosphate levels were below the detection limit over 80% of the experiment time period (NERRS, 2015).

The experiment design employed a randomized block method, where three blocks were spaced at least 100 m apart along the coastal edge (5 m from the shoreline). Within each block, three 4 m² quadrats were established with at least 3.5 m spacing. Nutrients were added every-other week, coinciding with low tide as often as was feasible. For each quadrat, a stock solution of NH₄Cl and KH₂PO₄ was prepared in 250 mL deionized water at the laboratory within one week of application, which was then mixed with 1 L of local channel water immediately before application with a hand-pumped sprayer. Care was taken to keep the spray nozzle close to the forest floor to minimize volatilization, and to spray evenly throughout the quadrat. Workers stepped outside of the quadrat perimeter or balanced on sturdy prop roots so the forest floor was not disturbed.

Sediment characterization

At the end of the experiment (October 2013), surface layer (2 to 5 cm) sediment cores were sampled to determine bulk density, percent organic content, and total C and N. For bulk density (g dry weight/cm³), two cores of sediment were sampled using a commercial film canister (30.4 cm³), after fine roots were cut around the circumference to avoid compaction from a strong insertion force. The samples were dried at 45° C until a constant weight was reached. The same samples were used to calculate percent organic content by burning at 400° C for at least four hours to obtain an ash-free dry weight.

The organic layer of sediment (0 to 2 cm) was sampled with a cut-off syringe (2 cm diameter) at three locations within each quadrat. Mangrove roots with a diameter greater than 2 mm were sieved out, and the samples were ground with a mortar and pestle.

Triplicate subsamples of the homogenized sediment were analyzed for total C and N on a Flash EA-112 CHNSO analyzer.

Sediment respiration

Carbon dioxide flux from the sediment surface under unflooded conditions was measured during the dry season (March 2013; 72 weeks from the start of nutrient enrichment) and wet season (October 2013; 104 weeks from the start of nutrient enrichment). All three experimental blocks were measured during daytime of March 2013, but due to the timing and magnitude of tidal flooding only block 1 was available for daytime measurement and block 3 for night-time measurement in October 2013. An additional measurement was made for all blocks during daytime in May, 2014, following 30 weeks of “recovery” from chronic nutrient enrichment pulsing.

For each measurement of CO₂ efflux, three to five replicate areas within each quadrat were haphazardly selected to place sediment collars. The selection criteria were areas that did not have significant ($> 5 \text{ cm}^2$) macroalgae cover, *L. racemosa* pneumatophores or *R. mangle* aerial roots, numerous (> 5) or large ($> 1 \text{ cm}$) crab burrows, and had not been previously disturbed by coring. If a large below-ground root blocked a complete collar insertion, a new location was selected. To maintain consistency between locations, any large pieces of recent litter fall (e.g., new leaf fall that had not become part of the sediment matrix) were carefully removed by hand and the area was left to rest for at least 30 minutes. PVC sediment collars (5 cm wide, 10 cm diameter) were hand-pushed or gently hammered into the ground to at least 2 cm depth. Attention was given to minimally disturb sediment at the inner edge of the collar and to keep the collar horizontally aligned during insertion. The exposed collar height was

measured at four points and the average value was used to calculate the final chamber volume. Pertinent features of the measurement area (crab burrow count and size, macro-algae area) were measured. A soil temperature probe was inserted 2 cm into the soil approximately 1 cm from the outer edge of the collar at the time of each measurement.

A Li-Cor 8100 Infra-Red Gas Analyzer (IRGA) chamber was placed over each soil collar, using foam rings to ensure an air-tight seal. Ambient CO₂ concentration within the chamber was measured every two seconds for a total incubation of three and a half minutes. The initial 30-seconds of the incubation period was not included in this analysis to allow for gas flushing through the lines.

The values within an incubation period were plotted using the software package LI-8100 Viewer and a linear regression was performed to calculate a rate of change in CO₂ concentration over the incubation period. Flux values calculated for each incubation were averaged by treatment or by block prior to statistical analysis.

Above-ground Litter Decomposition

Decomposition of leaf material on the forest floor was measured with litter decomposition bags (Karberg et al., 2008) over a two-month period from July to October (2013). Locally-sourced senescent leaves that had recently fallen on the forest floor (identified as yellow to light-gold color) were collected within each experimental plot and kept cool during transport to the laboratory. It was assumed that leaves collected within each quadrat were sourced by trees that encountered nutrient treatment for that quadrat. The leaves were rinsed in distilled water and air-dried for 24 hours at room temperature. Four to five air-dried leaves were sealed within a 14 cm x 14 cm fiberglass mesh litter bag with 1 mm² pores to exclude macroinvertebrate shredders. Care was taken to ensure

that the leaves lay flat and separated within the litter bags for consistent exposure to the forest surface.

Approximately 50 additional leaves were collected from the surrounding area of all experimental units for a fresh weight to dry weight conversion factor. The leaves were rinsed and air-dried for 24 hours, weighed (“fresh weight”), then dried at 45° C until a constant weight was reached (“dry weight”). A linear regression of fresh weight to dry weight was used to convert the fresh weight of the initial litterbag samples to dry weight for comparison with the oven-dry recovered leaf tissue (Appendix)

Immediately after preparation, five bags were deployed at each experimental plot (day 0). One litterbag was removed from each plot at 9, 32, 60, and 90 days and placed in a cooler for transport to the laboratory. At the laboratory, the contents of the bag were submerged in distilled water and cleaned to remove sediment. The litter bag samples were gently cleaned with a soft-bristled paintbrush. After cleaning, the contents of each bag were dried at 45°C until a constant weight was reached.

The amount of organic material lost over the decomposition period was expressed as a percentage of the initial mass:

$$\text{Percent mass remaining} = [(\text{final dry weight})/(\text{calculated initial dry weight})]*100$$

Most of the decomposing litter displayed a linear decay trend within the study time; therefore, a linear regression was used to compare the mass loss among all of the decomposition time series with the Y-intercept set at 80% (2012) or 100% (2013). Based on similar mangrove litter decomposition studies (Tam et al., 1998: 10 weeks; Ake-Castillo et al., 2006: 21.5 weeks; Keuskamp et al., 2015: 36 weeks), the degradation trends would likely follow an exponential decay if the incubation period were longer. To

compare our decay rates (k) with other studies that used an exponential decay model, we used the linear model to calculate the time to reach 50% decay ($t_{0.5}$), which was then fit within the experimental decay model $X = X_0 e^{-kt}$, where X is the final sample weight, X_0 is the initial sample weight, k is the decay rate, and t is the time of decomposition in days. Thus k is calculated by

$$[\ln (0.5)] / t_{0.5} = k$$

Collected litter samples were ground using a Wiley-grinding mill with a #20 sieve. Triplicate subsamples were analyzed for C:N ratios using a Flash EA-112 CHNSO analyzer.

Below-ground leaf decomposition

In July 2012, locally-sourced recently fallen leaves were collected and processed using the same methods as described for above-ground litter bags. Three leaves were sealed in a 5 cm x 10 cm fiberglass mesh bag with 1 mm² pores. For each quadrat, an approximate 20 cm cut was made into the forest floor at three haphazardly-selected locations. One litter bag was buried within each slice with the long end vertical. The top of the bag was approximately 5 cm from the surface, with leaf material buried between 5-15 cm. At each quadrat, one litter bag was collected at six months, one year, and 22 months after burial. Extraction of the litter bags often involved cutting mangrove root ingrowth; any mangrove roots inside the bag were separated from the decomposed leaf material as carefully as possible. The extracted litter was cleaned and dried as described for the 2013 above-ground litter bags, and initial to final weights were calculated as described above.

Data analyses

A two-way ANOVA with interaction (treatment x time) and a randomized block effect was used to compare sediment respiration and litter decomposition rates. For decomposition (percent mass remaining) rates and sediment percent organic matter, the data were arcsine transformed. All tests were conducted with SAS version 9.3 with a significance level of 0.05 (“significant”) to 0.08 (“small significance”). If a significant effect was found, a post-hoc Tukey’s HSD pair-wise test for variance was performed to test for significant differences between treatments.

RESULTS

Sediment properties

The mangrove forest floor is highly heterogeneous, as demonstrated by the range of bulk density, organic matter content, and percent C and N within and between blocks of the mangrove forest (Table 1-1). Due to this variance, there was no significance of sediment C:N between blocks ($p = 0.4$). There was a small treatment effect on sediment C:N ($p = 0.08$), which was driven by a greater amount of total sediment C in the fertilized plots. Total C accounted for 25 to 49% of sediment organic matter content. No significant relationship was found between sediment organic content and sediment C:N (data not shown).

Across all quadrats, sediment bulk density and OM content were negatively correlated ($p = 0.01$; Figure 1-2). Block 1 had the highest bulk density and lowest organic matter content, likely owing to a greater trapping of mineral sediment on the forest floor compared with the more frequently flushed blocks 2 and 3 (Appendix).

Block 3 had similar organic content as block 1 but a lower bulk density. The greatest difference in organic content was seen in block 2, which had the highest organic content and lowest bulk density in the top sediment layer.

Sediment respiration

Across all measurement periods (March, October 2013 and May 2014), sediment respiration rates ranged from 0.54 to 2.63 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ during daytime measurements and 0.24 to 0.52 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ during night time measurements (Figure 1-3). No significant difference of sediment respiration rates between treatments was found for any measurement period ($p = 0.4$). A significant difference was found between the daytime measurement at block 1 and the night-time measurement at block 3 during October 2013 ($p < 0.001$). No block effect was found for respiration rates during March 2013. A small block effect was observed during the recovery period, May 2014 ($p = 0.07$) where sediment respiration rates measured within block 3 were lower compared with the other two blocks.

Linear regressions showed no relationship between sediment respiration rates and the number of crab burrows, surface sediment temperature, or sediment C:N values (data not shown). Sediment respiration rates after a 30-week recovery period without nutrient enrichment (May, 2013) were not significantly different from respiration rates measured during the nutrient enrichment period (March, 2013) within the same treatment.

Leaf litter decomposition

Incubation time was a significant factor in leaf litter mass loss ($p < 0.0001$; Figure 1-4). In the first month of incubation, 0 to 30% of leaf litter mass was lost under control and agriculture treatments, and 15 to 40% of litter mass was lost under urban treatment

(Figure 1-5). The percent of litter mass remaining ranged from 19 to 45% by 90 days (Figure 1-5). Nutrient treatments had no significant effect on litter decomposition values across any time point ($p = 0.5$). The time to 50% mass decay (t_{50}) ranged from 61 to 110 days, with an average of 79 days (Table 1-2). The decay constant (k) was 0.009 d^{-1} (range 0.006 to 0.011 d^{-1}). As decomposition constant (k) values are calculated from mass loss trends, there was also no significant effect of nutrient treatment on k values ($p = 0.7$).

Incubation time was a significant factor for litter C:N values ($p < 0.0001$; Figure 1-6). Nutrient treatment had a small effect on the relationship between litter decay and C:N content ($p = 0.07$), with lower C:N values for urban-enriched litter.

More than 80% of initial leaf material had decomposed within the first six months of below-ground incubation (Figure 1-7). There was little decomposition of the buried leaf material between six months and one year. At the final below-ground litter bag collection (22 months after burial), the remaining leaf material had disintegrated into small pieces ($< 0.25 \text{ cm}^2$) and was completely integrated with the fine root matrix. Thus I determined all leaf material to be completely decomposed after 22 months of shallow burial for all quadrats. There was no significant effect of nutrient treatment on below-ground decomposition for any of the incubation periods.

DISCUSSION

The purpose of this experiment was to determine if organic carbon mineralization rates on a mangrove forest floor would be modified under anthropogenic nutrient

enrichment. Within a single mangrove stand, there was considerable variation in terms of edaphic structure (sediment bulk density, organic matter (OM) content) and environmental conditions (tidal inundation duration and frequency) along the coastal fringe. Yet considering the differences between experimental blocks, treatments, and time periods, rates of sediment respiration and OM decomposition were remarkably consistent.

Sediment Respiration

Given little temporal or treatment-driven difference between sediment respiration values, the grand average of daytime respiration across all units and measurement periods was $1.42 \pm 0.06 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$, with a range of 0.54 to $2.63 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ (Figure 1-3). The high value of this range exceeds that reported by Kristensen et al. (2008) from extracted sediment cores of Tanzanian mangroves (maximum value of $0.69 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$). A review of CO_2 efflux measurements from exposed mangrove sediments also does not reach the high values found in this system ($0.80 \pm 0.09 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$; Alongi, 2009). However, a survey of globally-distributed dwarf and fringe mangroves by Lovelock et al. (2008) found a range of mean sediment respiration from approximately – 0.25 to $2.97 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$, which contains the range of values presented here.

The greatest difference in sediment respiration values was observed in October 2013, when block 3 CO_2 flux was measured at night (Figure 1-3). This result contrasts with work by Kristensen et al. (2008), who found that CO_2 flux measurements under light and dark conditions of extracted mangrove sediment cores were not strongly different. In this study, the strong difference of respiration values between blocks 1 and 3 was not observed during the other two measurement periods, which suggests a factor

associated with day and night drives the difference. Microbial respiration activity is often temperature-dependent (Qiu et al., 2005), but sediment temperatures at this period were just under one degree apart from day to night (27.4° C vs. 26.5° C, respectively). The average air temperature during this measurement period shifted from a daytime high of 30° C to a nighttime low of 25° C (NERRS 2015), which may have played a role in the lower nighttime value of benthic respiration. It would be useful to examine the contribution of mangrove roots to surface CO₂ flux rates (Lovelock et al. 2006; Kuzyakov 2002), and whether a day/night difference in mangrove below-ground respiration contributes to this difference.

Regarding the lack of microbial response to nutrient enrichment, an appropriate concern is whether the benthic microbial heterotrophs encountered the additional N at a dose level or time interval that would lead to a measurable response. Work by Corredor & Morrell (1994) and Whigham et al. (2009) show rapid enhanced denitrification rates in mangrove sediments in response to nitrate enrichment. Corredor & Morrell (1994) measured denitrification rates in a mangrove forest along a nutrient gradient extending from a sewage treatment plant. Sediment denitrification rates decreased at greater distance from the sewage source, although potential denitrification rates (with available substrate) were maintained. Whigham et al. (2009) found higher rates of denitrification for several days after monthly doses of aqueous nitrate in a Florida stunted *Avicennia germinans* forest. Based on the rapid positive response by the denitrifier community under both scenarios, it may be possible the added nutrients were effectively removed, thereby preventing a long-term pool of available N. However, stable isotope analysis of ¹⁵N tracer (see Chapter 3) and enhanced efflux of DIN from the sediment to overlying

tidal water (Appendix) demonstrate that added N was retained within the surface sediment and overlying organic layer for an extended time period (weeks to months).

The lack of a microbial response to nutrient enrichment is confirmed by previous work in mangrove systems. Lovelock (2008) notes that anthropogenic land use was not the primary driver of sediment respiration rates in a global survey of dwarf and fringe mangrove sites. Kristensen et al. (2011) likewise found no effect of nutrient enrichment on OM mineralization (except see below). One possible explanation of a lack of response to nutrient enrichment is the “nitrogen mining theory” (Craine et al., 2007), which postulates that N-limited microbial communities break down recalcitrant OM to acquire nitrogenous compounds; when the N limitation is lifted, the microbes have less energetic incentive to continue the decomposition process. Thus N fertilization may actually inhibit microbial decay of highly refractory organic substrate, which constitutes the bulk of mangrove peat (Middleton & McKee, 2001). In support of this concept for mangrove systems, Keuskamp et al. (2012) found that N enrichment alone had no effect on the rate of sediment OM mineralization in mangrove sites, but microbial activity spiked upon the co-introduction of labile C (glucose) and N enrichment. They concluded that sediment OM mineralization was energy limited due to the refractory OM matrix, which could be further inhibited by high tannin content (Robertson, 1988). Kristensen et al. (2011) found no effect of nutrient enrichment from a sewage site on mangrove microbial processes, but a greater input of labile organic C from an algae bloom “of anthropogenic origin” enhanced CO₂ efflux in the intertidal zone. Thus, nutrient enrichment may affect sediment mineralization rates via a cascade effect, where nutrient

enrichment enhances algae production, which delivers labile organic carbon to the mangrove sediments, which stimulates heterotrophic decomposition.

Based on these works, a broader examination of the nutrient mining theory for benthic mangrove response to nutrient enrichment is needed, especially with the consideration that labile organic substrate may be linked with nutrient enrichment via primary-treatment sewage and septic systems, agriculture practices that utilize urea or animal wastes, or enhanced organic material production in eutrophic coastal waters.

Leaf Litter Decomposition

While sediment CO₂ flux measures heterotrophic microbial activity within the top layer of the mangrove peat platform, leaf litter decomposition values indicate microbial use of recently-fallen organic material that is in a constant state of flux into and out of the mangrove system. The rate of litter decomposition depends on the quality and availability of the substrate as well as several other factors including macroinvertebrate (shredder) activity, physical shearing forces (e.g., tidal submersion), temperature, oxidation state of the local environment, and resource limitations of the decomposer community such as nutrient availability (Benner & Hodson, 1985; Mackey & Smail, 1996; Twilley et al., 1997). Thus a comparison of litter decomposition rates between systems is somewhat difficult without all biological and environmental factors taken into consideration. However, the values presented in Table 1-3 demonstrate that litter decomposition rates from this study fit within previously reported decomposition values from other fringe mangrove systems, whether natural (Twilley et al., 1986; 1997; Aké-Castillo et al., 2006) or provided with additional nutrients (Tam et al. 1998). These studies suggest that nutrient enrichment does not necessarily play a dominant role in

mangrove litter decomposition, and the factors described above are important covariates to be considered for an accurate prediction of decomposition rates. For example, Keuskamp et al. (2015) reported that physical setting (Florida vs. Belize) was a better predictor of litter decomposition rates than nutritional status, presumably due to other environmental factors.

The process of OM decomposition can be described in two phases: (1) an initial leaching stage, where soluble compounds and labile material are easily dissolved within the aqueous medium; (2) a colonization and slow decomposition stage, where refractory compounds such as lignins are chemically broken down (Chale, 1993; Davis et al., 2003). The curves of litter mass loss were generally linear throughout this study, suggesting that the decomposition stage had not fully matured to the slow process of refractory material decomposition. The time to reach 50% decay ranged from 61 to 110 days, which is comparable to litter decomposition in a similar fringe mangrove studied by Aké-Castillo et al. (2006; Table 1-3). This t_{50} range was faster than that reported by Twilley et al. (1986) in basin mangroves, which are less regularly flushed than fringe mangroves (Lugo and Snedaker 1974). The range of t_{50} was much higher in Tam et al. (1998) compared with this study, but those decomposition rates under wastewater application were not significantly different than control sites (Tam et al. 1998). Tam et al. (1998) report rainfall levels an order of magnitude greater than received at Jobos Bay, which suggests that the freshwater input has a positive influence on above-ground litter decomposition.

Mangrove leaf litter became fully decomposed and integrated within the mangrove root complex within two years of burial. Middleton & McKee (2001) reported 27 +/- 5% mass remaining of buried leaves after 230 days of incubation, which was similar to the

values at one year of incubation in this study. As I used fiberglass mesh litterbags, this rate precluded the effect of macroinvertebrate shredding, which would have enhanced the decomposition rate. The relatively fast break-down of buried mangrove leaves is an indication that mangrove leaf litter is not a primary component of mangrove peat material (Middleton & McKee, 2001).

Under both ambient and fertilized treatments, mangrove litter C:N decreased as decomposition progressed (Figure 1-6). The main driver of this nutritional change is N immobilization by microbial colonization of the OM substrate. Microbial colonization and break-down of organic substrate is linked to exo-enzyme secretion (Keuskamp et al., 2015b) and nitrogen fixation (Holguin et al., 2001), which enrich the OM-microbial complex with nitrogenous compounds. Additionally, plant tannins may bind available N (Kraus et al., 2003), further immobilizing the N in the OM matrix. The similar C:N values of control and fertilized decomposing litter suggests that either the microbial community was not strongly limited by N or that the tannin content in fertilized leaves was reduced by N enrichment (Kraus et al., 2003), which allowed more of the available N to be leached from the leaf litter matrix.

CONCLUSION

Organic carbon cycling within the mangrove system is driven by highly refractory material. The slow process of C mineralization and strong N immobilization are critical factors for ecosystem function, including peat formation and carbon sequestration to nutrient conservation within the mangrove stand. Given the nutrient enrichment amount and duration of this experiment, it appears that the benthic decomposer community is not

strongly limited by available N and/or P. I recommend a future evaluation of mangrove litter decomposition with an emphasis on physical and environmental setting as well as nutrient availability. I also recommend more work to pursue the role of labile organic C in conjunction with nutrient enrichment for benthic respiration activity in a variety of mangrove environmental settings.

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TABLES AND FIGURES

Figure 1-1. Satellite image of Jobos Bay, located in southeastern Puerto Rico. The boundaries of the Jobos Bay National Estuarine Research Reserve are outlined in red. A white arrow indicates the location of the nutrient enrichment experiment at offshore keys, approximately 3 km from the mainland (image credits: Zitello et al. 2008; NOAA-NERR 2015).

Table 1-1. Edaphic characterization of experimental quadrats grouped within three blocks of a fringe mangrove forest. For each block, three quadrats were randomly assigned a nutrient regime of high (50:1) N:P fertilizer (“Agriculture”), intermediate (16:1) N:P fertilizer (“Urban”), or locally-sourced channel water (“Control”). Samples were collected after two years of nutrient enrichment (October, 2013). Values are mean $\pm$ 1 S.E. “ND” indicates that the data are not available. There was no effect of nutrient treatment on bulk density or percent organic matter. There was a small treatment effect on molar C:N ($p = 0.08$).

	Block 1			Block 2			Block 3		
	Control	Urban	Agriculture	Control	Urban	Agriculture	Control	Urban	Agriculture
Bulk density (g/cm³) (n = 3)	0.53 (0.05)	0.48 (0.07)	0.38 (0.03)	0.17 (0.03)	0.18 (0.02)	0.23 (0.02)	0.23 (0.02)	0.35 (0.05)	0.28 (0.03)
Organic matter (%) (n = 2)	12.9 (1.4)	15.4 (2.5)	26.8 (14.4)	47.6 (14.9)	45.4 (5.1)	36.3 (0.6)	18.2 (4.7)	22.4 (7.2)	24.0 (2.1)
Total C (% by weight) (n = 3)	3.34 (0.60)	5.46 (0.79)	ND	19.46 (0.88)	20.66 (1.85)	ND	8.97 (1.58)	10.90 (0.42)	ND
Total N (% by weight) (n = 3)	0.13 (0.03)	0.19 (0.03)	ND	0.74 (0.03)	0.77 (0.08)	ND	0.34 (0.05)	0.34 (0.02)	ND
Molar C:N (n = 3)	32.0 (1.8)	33.4 (1.0)	ND	30.6 (0.4)	31.4 (1.2)	ND	30.9 (1.7)	37.6 (3.5)	ND

Figure 1-2. Sediment bulk density (dry mass by volume) and percent organic content (ash-free dry weight content) of the surface organic layer of the mangrove forest sediment (0 to 5 cm) Data were averaged from collections in July 2011 and October 2013. Circles represent block 1, crossed lines represent block 2, squares represent block 3. Linear regression line for all nine quadrats.

Figure 1-3. Sediment respiration measured by CO₂ flux from the unflooded forest floor at three time periods: (A) March 2013, 72 weeks of nutrient enrichment; (B) October 2013, 104 weeks of nutrient enrichment; (C) May 2014, 30 weeks after nutrient enrichment ended. Values are means $\pm$ 1 S.E. Blocks 2 and 3 was constantly flooded during the day for October 2013, so gas exchange could not be measured.

Figure 1-4. Percent mass remaining for below-ground mangrove leaf litter decomposition. The litter was buried at 5 to 15 cm depth in July 2012. Values are means across blocks ($n = 3$). Error bars indicate ± 1 S.E. Litter material recovered at 22 months past the burial date was integrated with fine root material and was considered fully degraded.

Figure 1-5. Leaf litter decomposition under three nutrient conditions (described in Methods) during July – October 2013. Leaf litter was incubated in mesh bags on the forest floor and subjected to tidal flow. Linear regression (not presented) was used to determine the number of days for 50% decay (t_{50}). Circles represent block 1, Squares represent block 2, Crosslines represent block 3.

Table 1-2. 50% decay rate (t_{50}) as determined from a linear regression of litter decay (see Figure 1-4) and decay constant (k) calculated from the exponential decay curve $X = X_0 e^{-kt}$ with time (t) set at the day that litter decay reached 50% of initial weight during the incubation period. There was no effect of nutrient treatment on k values ($p = 0.7$).

Treatment	Block	t_{50}	k
Control	1	92	0.0075
	2	88	0.0079
	3	71	0.0098
Agriculture	1	82	0.0084
	2	76	0.0091
	3	61	0.0114
Urban	1	110	0.0063
	2	66	0.0105
	3	65	0.0107

Figure 1-6. Molar C:N ratio of decaying leaf litter under the intermediate N:P fertilization treatment (“Urban,” black triangles) and ambient conditions (“Control,” open circles). Samples were collected from litter bags that had incubated on the forest floor from July to October 2013. Incubation time had a significant effect ($p < 0.0001$) on litter C:N under both nutrient regimes. There was a small effect by nutrient treatment on litter C:N ($p = 0.07$).

Figure 1-7. Percent mass remaining for below-ground mangrove leaf litter decomposition. The litter was buried at 5 to 15 cm depth in July 2012. Values are means across blocks ($n = 3$). Error bars indicate ± 1 S.E. Litter material recovered at 22 months past the burial date was integrated with fine root material and was considered fully degraded.

Table 1-3. Reported values of litter decomposition (50% decay rate (t_{50}) and decay constant (k)) from mangrove systems across the world with classification (Lugo and Snedaker 1974). All studies used a form of the litter bag method to measure decomposition. If the decay constant (k) was not reported in the study, I calculated it using the exponential decay curve $X = X_0e^{-kt}$ with time (t) set at the day that litter decay reached 50% of initial weight during the incubation period.

Study location	Mangrove type/species	Nutrients added	t_{50}	k (day ⁻¹)	Reference
Shenzhen, China	<i>Fringe: K. candel</i> <i>Fringe: A. corniculatum</i>	Wastewater	13	0.052	Tam et al. (1998)
		Wastewater	48	0.015	
Mexico	<i>Fringe: R. mangle</i>	None	70 to 144	0.0048 to 0.0084	Aké-Castillo et al. (2006)
	<i>Riverine: Rhizophora spp.</i>	None	43 to 231		Twilley et al. (1997)
Ecuador			98 to 165	0.003 to 0.016	Twilley et al. (1986)
Florida	<i>Basin: R. mangle</i>	None	61 to 110	0.0071	
Puerto Rico	<i>Fringe: R. mangle</i>	Spray fertilizer		0.006 to 0.011	This study

Chapter 2

EFFECT OF NUTRIENT ENRICHMENT ON ABOVE-GROUND PRODUCTION IN A PUERTO RICAN MANGROVE FOREST

To be submitted to Aquatic Botany

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EFFECT OF NUTRIENT ENRICHMENT ON ABOVE-GROUND PRODUCTION IN A PUERTO RICAN MANGROVE FOREST

ABSTRACT

Mangrove ecosystems are highly productive coastal wetlands that connect tropical terrestrial and marine systems. Increasing human populations and land use changes are enhancing nutrient loading to tropical coastlines, potentially leading to eutrophic conditions for marine systems. To better understand and predict the consequences of increased nutrient input, a fertilization study within a fringe mangrove system in southeast Puerto Rico was established to mimic high-nitrogen agriculture runoff (N:P ratio of 50:1) or urban runoff with higher phosphorus (N:P ratio of 16:1) for an annual loading rate of $70 \text{ g N m}^{-2} \text{ y}^{-1}$ and 3.1 or $9.7 \text{ g P m}^{-2} \text{ y}^{-1}$. Bi-weekly pulses of fertilization began in October 2011 and continued for two years. Mangrove tree response was characterized by above-ground wood production and litterfall input. Basal area ranged from 17.1 to $32.7 \text{ m}^{-2} \text{ m}^{-2}$. Above-ground biomass (wood and foliage) ranged from 3.9 to $15.4 \text{ kg dry mass m}^{-2}$. Mangrove above-ground growth was highly variable and was not affected by nutrient treatment. Litterfall was strongly seasonal, with higher rates associated with the start of the rainy season in late summer. Total litterfall for this fringe mangrove ranged from 1061 to $1217 \text{ g dry mass m}^{-2} \text{ y}^{-1}$, which was on the higher range of neo-tropical fringe mangroves. Total litter production was not affected by nutrient treatment, but agriculture treatment (high N:P) enhanced leaf and stipule production ($p = 0.04$ and 2.2×10^{-6} , respectively). These results suggest that two years of high N:P nutrient addition results in a small positive effect for above-ground production

within a fringe mangrove, and that litterfall may be a more sensitive response than above-ground biomass for a short-term (two years) assessment. Considering the different effects to mangrove production by the nutrient enrichment regimes (high vs. intermediate N:P loading), further work is needed to assess N and P interactions that may affect above-ground mangrove production.

INTRODUCTION

Mangrove forests are valuable coastal wetland habitats that provide ecosystem services on a local and global scale. Local benefits include shoreline stabilization, essential faunal habitat, organic material outwelling, nutrient and contaminant interception, and ecotourism (Alongi 2009). On a global scale, mangrove ecosystems are increasingly recognized as an important component of coastal carbon (C) sequestration via high rates of primary production and organic C retention (Donato et al. 2011; Kauffman et al. 2011; Bouillon 2011; Pendleton et al. 2012). Through these processes mangroves contribute a disproportionate amount of carbon capture per area: 12% of global coastal carbon burial is maintained by mangrove systems, which comprise just 0.5% of the world's coastal area (Alongi 2009). For a reciprocal perspective of mangrove C capture efficiency, Donato et al. (2011) calculate that the current global loss rates of mangrove habitat at 1-2% per year may be contributing 0.02 to 0.12 Pg C yr⁻¹ of carbon emissions. On either scale of local ecosystem services or global budgeting, mangrove system resiliency and function are dependent upon within-stand C cycling.

The amount of C stored within a coastal wetland system is based on ratios of production, decomposition, and belowground biomass allocation (and to a variable extent, C deposition and outwelling). Studies in temperate coastal wetlands have shown that cultural nutrient enrichment can alter these components of within-stand C cycling along bi-directional pathways: While above-ground production may be enhanced by added nutrients (Turner et al. 2009), other altered processes such as greater organic material decomposition and a reduction of below-ground biomass can lead to a destabilization of structural peat and eventual habitat loss (Turner et al. 2009; Deegan et

al. 2012). Recently, tropical coastlines have been subject to accelerating cultural nutrient input (Downing et al. 1999; Corredor et al. 1999), with nitrogen (N) and phosphorus (P) promoting significant change in coastal ecosystems such as shifting community composition, increased hypoxic events, or changes in the productivity regime (Rabalais and Nixon 2002; Valiela 2006; Nixon and Fulweiler 2009). Strong trends of population growth in tropical urban regions (Martinuzzi et al. 2009) are associated with greater availability of nutrients via sewage effluent, impervious surface coverage, and nitrogenous combustion products (Ortiz-Zayas et al. 2006). Land-use change in tropical settings is exemplified by the amount of inorganic fertilizer consumption in Latin America and the Caribbean, which increased over 1500% during the past five decades (IFIA 2015). Previous work on the effects of nutrient enrichment for temperate coastal wetlands (Valiela et al. 1976, Deegan et al. 2006, Darby and Turner 2008) are useful as a reference but not as a predictive model for tropical coastal system response to altered nutrient conditions. Complimentary studies are now needed to understand and predict ongoing change to the C cycle within tropical vegetated coastlines.

Autochthonous production is an important component of the mangrove C cycle, and can be the main source of below-ground C storage (Bouillon et al. 2003; Bouillon et al. 2008; Kristensen et al. 2008). A standard metric of mangrove productivity is litter production (Pool et al. 1975; Day et al. 1987; Twilley et al. 1986; Woodroffe et al. 1988), which also allows researchers to identify seasonal or inter-annual trends of mangrove leaf production and reproduction efforts. In addition to litter production, species-specific allometric equations that are typically based on stem diameter and/or tree height have been developed to estimate biomass components and growth rates (Sherman et al. 2003;

Smith and Whelan 2006; Komiyama et al. 2008). The combination of litter production and allometrically-derived biomass estimates are useful methods for a non-destructive estimate of standing biomass, growth rates, and organic C flux estimates.

A standard method to investigate the effects of nutrient enrichment on ecosystem function is by experimental nutrient supplement within a relatively unencumbered (often described as pristine) ecosystem (salt marsh: Valiela et al. 1976, Deegan et al. 2007; seagrass: Short 1987; lake: Schindler et al. 1971). The majority of mangrove nutrient enrichment field studies have been conducted using buried fertilizer (Boto and Wellington 1983; Feller 1995; Feller et al. 2003; Lovelock et al. 2009). The benefit of this method is that fertilizer is not lost by tidal action or volatilization, but a limitation is that the added nutrients are not first encountered and modified by the microbial community or biogeochemical context on the surface of the forest floor (Whigham et al. 2009). Anthropogenic nutrients are often transported to coastal ecosystems via water channels (Howarth et al. 1996) and are likely to interact with components of the intertidal system differently compared with belowground cores of fertilizer (Deegan et al. 2007). Therefore, this study measures mangrove production response to surface-level aqueous nutrient application to more closely mimic current-day anthropogenic nutrient input.

The main purpose of this study is to report on mangrove above-ground production under two years of periodic nutrient enrichment with three scenarios of nutrient enrichment: high N:P (50N:1P), intermediate N:P (16N:1P), and control (ambient channel water). High N:P fertilizer represents nutrient input from agriculture sources (sugarcane watershed drainage N:P = 43.9; Faithful et al. 2007), and intermediate N:P fertilizer represents nutrient input from urban sources (urban drainage N:P = 12.6;

Hopkinson and Day 1980). The rate of N addition is equivalent for both fertilization scenarios, with P addition altered for the appropriate ratio (see Methods). Fertilizer is applied on a plot-level (4 m²) scale every-other week to mimic pulsing events by aqueous flow. Two commonly-used measures of production are reported to assess mangrove production: litter production from the mangrove canopy, and estimates of standing biomass based on allometric relationships. The following questions are addressed by this study:

1. Do mangrove above-ground biomass growth rates change under different levels of cultural nutrient enrichment?
2. Is there a discernable change in quantity or composition of mangrove litter production under nutrient enrichment?

As fringe mangroves are primarily N-limited (Reef et al. 2010), I expected that mangrove trees would respond to agriculture and urban treatments with increases in above-ground production over the two-year enrichment period. Keeping in mind that the diametric growth of mangrove stems may not be observable within two years of nutrient enrichment, I anticipated that an increased trend of litter production (Boto and Wellington 1983; Feller 1995; Feller et al. 2003) would be more evident.

METHODS

Study site

Jobos Bay is a coastal plain estuary located in southeastern Puerto Rico (17° 56'N, 66° 13'W). The mouth of the bay is mainly enclosed by mangrove-fringed limestone cays extending from a barrier coral reef. The local tidal cycle is mixed diurnal and ranges from 17 to 36 cm, with the largest tides in October (Field 2008). The average residence time of the bay 5.5 days, with surface water entering through the cay channels, flowing north into a series of channels (Mar Negro) or clockwise through the northeast cove, and exiting as bottom water through the western opening of the bay (Capella 2008).

The region is classified as Subtropical Dry Forest Life Zone (Ewel and Whitmore, 1973), with an average annual temperature of 26° C (range 24.3° to 27.5°) and average annual rainfall of 980 mm. While there is no strong seasonal component for air temperature, precipitation exhibits a seasonal trend with a dry season from January to April and a rainy season from June to November (see Appendix). This seasonal trend drives intermittent freshwater flow to Jobos Bay via small rivers, but surface freshwater flow is considered negligible (Bowen and Valiela 2008). It is proposed that two sources of groundwater supply freshwater to the fringing mangrove forests: a shallow (3 to 23 m deep) mainland source, and a deeper source (24 to 42 m deep) that flows under the bay to the outer cays (Zitello et al. 2008; Capella 2008).

The Jobos Bay watershed is a mixed landscape of agriculture, low-density urban communities, and several industrial facilities including two electrical power production plants and a petroleum refinery (see Zitello et al. 2008). Historically, sugar cane plantations dominated the region from Spanish Colonial times to the mid-20th century.

Much of the Jobos Bay coastline is now under protection status: the Jobos Bay National Estuarine Research Reserve (JBNERR) was established in 1981 and spans 1,133 ha of the northern coastline and much of the cays. The eastern coastline and two eastern-most cays are under the domain of the Aguirre State Forest (2,390 ha).

The location of this study is a fringe (*sensu* Lugo and Snedaker 1976) mangrove wetland positioned at the most southeastern channel of the bay (Figure 2-1), within the domain of the Aguirre State Forest. We selected this location as the least anthropogenically affected site for Jobos Bay, having the greatest distance from anthropogenic land use and constant seawater flow from the relatively low-nutrient Caribbean (NERRS 2015; Appendix). Additionally, stable isotope work by Bowen and Valiela (2008) has demonstrated that rooted vegetation at sites within Jobos Bay are largely disconnected from anthropogenic nitrogen sources due to low hydrologic connectivity.

The mangrove stand at our study site follows a typical neo-tropical zonation pattern: *Rhizophora mangle* (L.) dominates the coastal edge with intermittent white mangrove (*Laguncularia racemosa* (L.) c.f. Gaertn.) stems. A transition zone of thin, densely packed *R. mangle* leads to an *Avicennia germinans* monoculture stand upland. The *R. mangle* coastal edge zone of the extends approximately 10-15 m upland of the subtidal region. The average canopy height is 4.24 m (range 0.76 to 7.09 m) and the average diameter at breast height (1.3 m above the forest floor) is 5.26 cm (maximum 21.7 cm).

Experiment design

Three replicate blocks were established within the mangrove forest with at least 100 m spacing. The blocks were positioned parallel to the coastline and 5 m inland from the coastal edge. Each block contained three 4 m² quadrats (“experimental units”) with at least 3 m of buffer spacing between the units. Extensive personal observations concluded that flood water above the mangrove platform did not flow laterally between experimental units, but mainly flowed in a north-south (upland-channel) direction via tidal forcing. Dense canopy coverage also limited surface water mixing above the mangrove floor by deflecting wind.

The experimental units were randomly assigned a nutrient treatment (ambient; high nitrogen/low phosphorus fertilization; high nitrogen/moderate phosphorus fertilization) applied every-other week for two years beginning October 2011. The treatments were applied by hand with a pressurized sprayer, with care taken to ensure that the spray was applied evenly within the quadrat and positioned close to the forest floor to limit volatilization. When possible, treatments were scheduled to coincide with low tides. Ambient treatment was 1 L of offshore channel water collected at the time of fertilization. Fertilized treatment was 1 L of locally-collected channel water with dissolved ammonium chloride and potassium phosphate, for an annual fertilization of 70 g N m⁻² y⁻¹ and 3.1 g P m⁻² y⁻¹ (“agriculture” high N:P fertilizer) or 70 g N m⁻² and 9.7 g P m⁻² (“urban” intermediate N:P fertilizer). With an estimate that the experimental area is submerged by 10 cm of tidal water for half of the year (based on tidal inundation data, Appendix), the nutrient loading rate of this study is approximately 30 times the amount of DIN loading by tidal overflow (NERRS 2015; Appendix). An estimate of P loading

increase is difficult to make because channel water phosphate levels were below the detection limit over 80% of the experiment time period (NERRS 2015).

Sampling

Tree identification and measurement

Each mangrove tree with at least one aerial root or set of pneumatophores located on the edge or within one of the 4m² experimental units was tagged, characterized, and measured before the start of the experiment (July – October 2011) and at the end of the experiment (August – October 2013). Tags were securely placed on the main stem to mark the appropriate level for repeated measurements of each tree.

Basal area and stem density

Basal area (*ba*) is defined as the amount of forest floor that is occupied by stem growth. To calculate a plot basal area, individual trees were measured for the diameter at breast height (DBH), which is 1.3 m above the forest floor. The *ba* was calculated from the DBH assuming a cylindrical shape of the tree stem:

$$ba = \pi (DBH/2)^2$$

The stand basal area (stand *ba*) is the sum of individual stem basal areas divided by the total area measured (in this case, the experimental plot area, or 4m²):

$$\text{Stand } ba = \frac{\sum ba_i}{A}$$

Where *ba_i* is the basal area of each tree within the plot, and A is the plot area.

Due to the serpentine-like structure or multiple branching of the mangrove trees, the classical DBH measurement was adjusted in the following ways:

- Four of the 78 trees measured had multiple stems that branched at the tree base. Following Clough et al. (1997), each stem was treated as an individual tree for biomass estimates only.

- If a fork, unusual growth, or termite nest occurred at 1.3 m, a measurement was made adjacent to the irregularity at a point that best represented the typical diameter of the stem.

Stem density (number of trees/m²) was determined by the number of live trees with main stems that were contained (or had at least 50% of the basal area) within an experimental unit perimeter.

The assumption was made that each experimental block had the same basal area and stem density; thus, the calculated basal area and stem densities for each experimental unit within a block was averaged ($n=3$) for a whole-block value.

Above-ground biomass

Several allometric relationships have been developed to estimate mangrove biomass for above- and below-ground components of different species (Sherman et al. 2003; Smith and Whelan 2006; Komiyama et al. 2008). I selected the relationship by Smith and Whelan (2006) developed in southern Florida because of the close geographical area, a similar range of main stem diameter, and the sole use of DBH rather than DBH plus tree height, which is difficult to accurately measure without felling. Using Smith and Whelan (2006), above-ground dry biomass was calculated using the following allometric relationship of dry biomass and DBH of *R. mangle* and *L. racemosa*:

$$\log_{10}y = a \log_{10}(\text{DBH}) + b$$

where y = aboveground dry biomass in kg and DBH is in cm

The following constants were used with the above equations (Smith and Whelan 2006):

Species	Slope constant (a)	Interept constant (b)
<i>R. mangle</i>	1.731	-0.112
<i>L. racemosa</i>	1.930	-0.441

I assumed a constant growth rate during the experimental period; therefore, above ground biomass differences between 2011 and 2013 were divided by 2 years for an annual growth rate. The mean annual change in above-ground biomass within an experimental unit (g dry weight stem⁻¹ year⁻¹) was multiplied by the stem density of the corresponding block (stem count m⁻²) for an area-based value.

Tree height

The height of individual trees was measured using a graduated telescoping pole and three sets of eyes (two people directly under the tree and one at a distance away). The total height of each tree was determined as the linear distance from the forest floor to the highest point of the tree canopy.

Litter production

Two 0.25 m² litter collection baskets were established for each experimental unit, one located in the center of the quadrat, and one sited under tagged trees with canopies that extended beyond the quadrat perimeter. The baskets were constructed with fiberglass window screen mesh and wire framing and mounted on PVC poles at approximately 50 cm above the forest floor (above the highest tide level). Mangrove material captured by the baskets was collected every-other week. The samples were placed in plastic bags and kept cool until they were brought to the laboratory, then transferred to paper bags and placed in a drying oven at the 65° C for at least one week.

The dried samples sorted by category (leaves, stipules, flowers, propagules, wood, unidentified material) and re-dried to a constant weight for dry mass measurement. Stipules, propagules, and *R. mangle* flowers were counted as well as weighed.

Litter material collected by duplicate litter collection baskets were averaged by experimental unit, scaled from 0.25m² to 1 m², and divided by the number of days elapsed between each collection for a daily litterfall rate.

Stipule fall is a sensitive indicator of leaf production (Boto and Wellington 1983). Following the work by Boto and Wellington (1983), stipule fall count for the experimental period was summed for each collection basket and averaged (2 replicates) per experimental unit. A linear regression (stipule count by days of experimental nutrient enrichment) was performed for each unit. As there was only one replicate per treatment level within blocks, it was assumed that a block effect was insignificant.

Data analyses

Mangrove annual above-ground growth was evaluated with a two-factor analysis of co-variance (ancova) with blocking effect and initial (2011) above-ground biomass as a cofactor. To test whether nutrient treatment affects the rate of stipule fall over the experimental period, a one-factor analysis of variance (anova) was used. For this test, it was assumed that blocking had no effect (see above). Mangrove litter production (total litter and leaves, stipules, and reproductive components) was evaluated using a two-factor repeated measures analyses of variance (anova) with blocking and treatment*year interaction for total and component annual litterfall. The reproductive structure (propagules and flowers) component presented high variance that skewed the residual homogeneity of variance; therefore a log-transformation was performed on the data for

analysis. As the total and component litterfall production rates are related, a family-wise adjustment of error rates is typically performed; however, with few replicates (6 baskets per treatment per year), the design power is too low to detect significant results with this transformation. Therefore p-values were maintained at 0.05. For all analyses, when significant differences were presented a post-hoc Tukey honest significant test was used to evaluate pair-wise differences between factors.

Cumulative stipule analysis was conducted in R (v 3.1.1) with the “Stats” package. All other analyses were conducted with SAS (v. 9.3).

RESULTS

Differences in mangrove tree characterization between the three blocks demonstrate the variation of forest structure within a continuous mangrove stand. Stem density was lowest at block 2 (0.9 stems m^{-2}) and highest at block 3 (1.2 stems m^{-2}). Basal area increased slightly over the two-year observation period across all blocks (Table 2-1). Block 2 had the lowest basal area (17.1 to 17.9 $\text{m}^{-2} \text{m}^{-2}$) and block 3 had the highest basal area (31.6 to 32.7 $\text{m}^{-2} \text{m}^{-2}$). Tree height ranged from 3 to 5 m, and the average stem diameter was between 3 and 6 cm (Table 2-2). Above-ground biomass varied several fold between quadrats within blocks, ranging from 3.9 to 14.7 kg DW m^{-2} in 2011 and 4.8 to 15.4 kg DW m^{-2} in 2013 (Table 2-2). Annual above-ground biomass production rate of was highly variable between and within and between blocks of the mangrove stand (Figure 2-2). There was no significant effect of nutrient treatment on above-ground biomass change ($p = 0.4$): quadrats that presented the lowest (0.2 kg $\text{m}^{-2} \text{y}^{-1}$) and highest (0.6 kg $\text{m}^{-2} \text{y}^{-1}$) average biomass growth were both under agriculture nutrient enrichment.

Average annual litterfall across the two observation years was $1061 \text{ g m}^{-2} \text{ y}^{-1}$ under control treatment; $1217 \text{ g m}^{-2} \text{ y}^{-1}$ under agriculture treatment, and $1167 \text{ g m}^{-2} \text{ y}^{-1}$ under urban nutrient treatment. Total litterfall was strongly seasonal (Figure 2-3); however, the timing of litter production peaks and troughs was different between observation year 1 (Oct. 2011 to Oct. 2012) and observation year 2 (Oct. 2012 to Oct. 2013). For observation year 1, the lowest litter production rate occurred between December and April, with a peak in June through August. Low production rates in year 2 occurred around the same time as year 1 (November to April), but the litter peaks were delayed until late July.

There was no overall treatment effect for total litterfall production rates ($p = 0.6$) and no treatment effect in observation year 1 ($p = 0.3$); however, there was a slight difference in treatments for observation year 2, with production under agriculture treatment ($3.31 \text{ g dry mass m}^{-2} \text{ d}^{-1}$) different than urban and control production rates (2.44 to $2.47 \text{ g dry mass m}^{-2} \text{ d}^{-1}$; $p = 0.06$ and 0.07 , respectively; Figure 2-4A and Table 2-3). Neither agriculture nor control treatment effects on total litter production were strongly different between observation years, but litter production under urban nutrient enrichment was significantly different between observation years ($p = 0.04$), due to the high propagule and flower production in observation year 1 (Figure 2-4C).

There was an overall treatment effect on the leaf component of litterfall rate ($p = 0.04$; Table 2-3) with higher leaf production under agriculture nutrient enrichment compared with control (year 1 $p = 0.03$; year 2 $p = 0.05$) and slightly higher leaf production compared with urban nutrient enrichment (year 1 $p = 0.05$; year 2 $p = 0.1$). Leaf production under urban nutrient enrichment was not significantly different from

control in either observation year ($p = 0.6$ to 0.8). There was no significant difference in leaf production rates between observation years 1 and 2 under any nutrient condition (Figure 2-4B).

The reproductive component of litterfall (propagules and flowers) showed strong variation between observation years (Figure 2-4C). Reproductive components were highest under urban nutrient enrichment in year 1, but the highest reproductive component production switched to agriculture nutrient enrichment in year 2 (treatment*year interaction $p = 0.002$; Table 2-3). There was a slight overall treatment difference in flower and propagule production for observation year 1 only ($p = 0.07$), with a significant difference between agriculture and urban treatments ($p = 0.03$).

Nutrient treatment significantly impacted stipule production rate ($p = 0.03$), with a slight treatment*year effect ($p = 0.06$; Figure 2-4D and Table 2-3). In observation year 1, stipule production under agriculture nutrient enrichment was different compared with control ($p = 0.009$) and urban nutrient treatment ($p = 0.005$). In observation year 2, there was a smaller difference stipule production between agriculture and control treatments ($p = 0.05$), and no significant difference of stipule production between agriculture and urban enrichment treatments ($p = 0.3$). Stipule production rates under urban and control were not significantly different for either observation year ($p = 0.3$). Cumulative stipule fall across the study period was significantly enhanced by agriculture nutrient treatment ($p = 2.19 \times 10^{-6}$), while urban nutrient enrichment had no difference compared with production under control conditions (Figure 2-5).

A comparison of all litter components demonstrates the dominance of leaves and reproductive parts (propagules and flowers) across all treatments and seasons (Figures 2-

4 and 2-6). Twigs and unidentified organic matter constituted a small and intermittent proportion of the litter input. Leaves were the major factor of litter production at 70% or greater of the dry weight for the majority of the two-year measurement period (Figure 2-6). The period of greatest reproductive effort typically coincided with peak litter production periods (late summer into early fall).

DISCUSSION

Above-ground biomass and growth

On a global scale, mangrove biomass is inversely related with latitude (Saenger and Snedaker 1993). At the latitude of this study site (18° N), biomass range is reported to be 5 to 63 kg dry mass m⁻² (Alongi 2009). Biomass estimates from this study range from 4.2 to 15.4 kg dry mass m⁻² (Table 2-2), which is on the lowest end of the global range. These values reflect the importance of local environmental conditions such as freshwater input, nutrient availability, and tidal flow within the global reference frame. On a protected fringe mangrove site at the Mar Negro lagoon in northern Jobos Bay, Lugo et al. (2007) measured canopy height up to 9 m compared with a maximum average height of 5.5 m at this study site in the southern cays. Environmental differences between these sites include sources of groundwater and river input (low to negligible at the cay site of this study) and wind exposure (higher at the cay site), which are likely to affect above-ground production and structure. There is also a strong difference of inorganic nutrient levels between Mar Negro and the southern cays; ammonium levels in Mar Negro waters are approximately 12 to 15 µM, compared with 2 to 6 µM DIN concentration for channel water at the cay site (Appendix). In contrast to a two-year nutrient enrichment

experiment, the high nutrient levels at Mar Negro have existed for decades as a result of local septic systems, large-scale agriculture, and slow turnover of the lagoon (Lugo et al. 2007, Zitello et al. 2008). While a comparison of these two sites within Jobos Bay is made difficult given a several different environmental and resource conditions between the sites, it is a recommended next step to better understand mangrove production within long-term nutrient gradients.

There was no effect of nutrient enrichment on annual above-ground standing biomass change within any of the blocks, due in part to high variability of initial standing mass. I suspect DBH-based allometric measurements for mangrove biomass may be affected by changes in seasonal water uptake (Vandegehuchte et al. 2014) or small differences in readings by multiple field workers. However, it is likely that two years is not an appropriate period to observe a measurable difference in slow-turnover components such as above-ground woody biomass. Mangrove leaf turnover rates range from 6 months to 1 year (Pool et al. 1975), therefore litter production is likely to be a more sensitive indicator of nutrient uptake and use.

Litter production

In contrast to the relatively low standing biomass values, the range of annual average litter production measured for this study (1061 to 1217 g dry mass m⁻² y⁻¹) was on the high range for fringe mangroves in the Caribbean and Latin America (480 to 1690 g dry mass m⁻² y⁻¹; Table 2-4) and close to the median of global mangrove litter production (130 to 1870 g DW m⁻² y⁻¹; Saenger and Snedaker 1993). Mangrove litter production is related to forest structure classification (Lugo and Snedaker 1974), latitude (Saenger and Snedaker), and environmental conditions such as temperature, rainfall, and

interstitial salinity (Day et al. 1996). Lugo et al. (2007) reported a higher litterfall rate ($1690 \text{ g dry mass m}^{-2} \text{ y}^{-1}$) at a fringe mangrove site in the Mar Negro lagoon of northern Jobos Bay. As described for above-ground biomass, higher litter production of the Mar Negro mangroves may be related to greater amounts of freshwater delivery via groundwater and river discharge.

The strong seasonal pattern of the total litter production (Figure 2-3) agrees with previous work (Twilley et al. 1986; Tam et al. 1998; Lugo et al. 2007). Twilley et al. (1986) measured greater litter production in a basin mangrove during the same period as found in this study (August to October), which they link with soil salinity levels. This explanation is unlikely for a fringe system that is regularly flushed by tides and therefore maintains a consistent interstitial salinity. Tam et al. (1998) report peak litter fall during the summer rainy season, and Lugo et al. (2007) reported a spike in litter production after a significant rainfall event. It is possible that increased energy associated with storms would enhance the litter fall. Peak litter fall in this study corresponded with the rainy season; however, there was no relationship between monthly litter production and total monthly rainfall (data not shown).

In addition to seasonal variation, inter-annual differences of litter production were observed, particularly for reproductive components (propagules and flowers; Figure 2-4). Inter-annual fluctuations of litter reproductive components has also been previously observed: Steinke and Ward (1988; as reported by Tam et al. 1998) measured rates of high propagule production followed by a drop in production within *Avicennia marina* stand. Woodroffe (1982) also reported significant variation in propagule production.

These works demonstrate the importance of multi-year studies for stand-level dynamics that may be missed by short-term observations.

The stand canopy of this fringe mangrove is dense and interwoven, with canopies from mangroves located outside of the experimental unit extending over the study sites. Therefore litter collection baskets were receiving litter from the targeted trees as well as outside trees. My attempt to mitigate this confounding factor was to place one litter basket in the center of the experimental unit and one basket outside the unit but strategically placed to receive litter from experimental trees. Work by Feller and colleagues (2003, 2007) employed a more sensitive technique to observe mangrove tree response to nutrient enrichment by examining stem branching and apical bud production. Although some signal of enhanced litter production was detected through the litter catch, it may have been diluted by neighboring trees.

Mangrove production response to nutrient enrichment scenarios is evidently site-specific (Table 2-5), which may be due to within-system interactions of biotic (e.g., mangrove species, herbivore pressure, benthic microbial activity) and environmental (e.g., salinity, benthic redox status, background nutrient availability) factors (Twilley and Rivera-Monroy 2005; Reef et al. 2010). N limitation relief appeared to enhance above-ground production within a fringe mangrove in northern Australia (Boto and Wellington 1983), and within fringe and dwarf mangrove stands in Florida (Feller et al. 2003; Whigham et al. 2009). However, by stimulating a reduction of below-ground root structure (which limited water uptake), N enrichment enhanced mortality rates of a drought-stricken scrub forest (Lovelock et al. 2009). For studies that applied distinct scenarios of N or P enrichment, the two nutrients appeared to function in reciprocal

patterns at the site level: where N enrichment stimulated production or mortality, P enrichment had no effect (Boto and Wellington 1983; Feller et al. 2003; Lovelock et al. 2009). Correspondingly, sites that responded to P limitation relief showed no effect with N enrichment (Boto and Wellington 1983; Feller 1995). The previous only study that applied both N and P on a plot scale (versus individual tree targeting) by wastewater discharge found no effect on litter production (Tam et al. 1998).

In contrast, this study found enhanced stipule and leaf production under agriculture (high N:P) but not urban (intermediate N:P) nutrient enrichment (Figures 2-4 and 2-5). As previous work has demonstrated that fringe mangroves are primarily N-limited (works above and Reef et al. 2010), it is surprising that the two nutrient treatments with the same amount of N enrichment had different effects. These results suggest an interaction of N and P (either directly or indirectly) that affects mangrove production. Further investigation into foliar nutrient concentrations and nutrient use efficiencies is currently ongoing and may provide more insight into the effect of N:P ratio on mangrove productivity.

Results of ecosystem-based manipulative studies are conditioned on the duration of the experiment as well as the scale of the modified area. The goal of this study was to simulate nutrient delivery by enriched tidal waters that overflow an area of mangrove forest rather than a targeted nutrient addition for individual trees (Feller et al. 2003, Whigham et al. 2009). However, this delivery method may require a long-term enrichment for measurable results within slow-turnover biomass. Floodwater application of nutrient enrichment in a temperate salt marsh had a lag period of at least 2 years before system-wide effects were observed (Deegan et al. 2007) Additionally, a wider coverage

area may be required for an observable effect by the mangrove trees. While all trees considered by this study had at least one above-ground root or pneumatophore within the 4 m² experimental plot, nearly all of the studied trees had multiple above-ground roots extending outside of the experiment unit, which may reduce the strength of the nutrient enrichment.

CONCLUSION

The results from this study suggest that within a short encounter (two years) of nutrient enrichment, high N:P fertilization can enhance litter production. However, fertilizer with the same amount of N but greater P appeared to have little overall effect on litter production, though a one-year spike in reproductive components was observed. This differential effect of N:P input requires further examination to understand the mechanisms involved. In contrast, above-ground biomass composed of wood and foliage did not respond to nutrient enrichment within two years. It is possible that this slow-turnover biomass component requires a longer duration of nutrient amendment before a measurable response is found.

Mangrove system response to nutrient enrichment can depend on geographic location, environmental setting (riverine, fringe, scrub), nutritional status of the mangrove (N- or P-limited), and other environmental factors (e.g., soil salinity). Much of our current knowledge on mangroves and added nutrients is based on work that focused on stunted mangrove trees, which are likely to be strongly nutrient limited and/or salt-stressed (Lovelock et al. 2009) and may have a more profound or rapid respond to nutrient treatment. For a more complete understanding of a rapid and continuing trend in

tropical coastal wetlands, I recommend additional field-based manipulation studies of nutrient enrichment in mangrove systems within different ecosystem settings on a multi-year time scale, as well as research on mangrove production along a nutrient gradient (e.g., southern to northern Jobos Bay).

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TABLES AND FIGURES

Figure 2-1. Satellite image of Jobos Bay, located in southeastern Puerto Rico. The boundaries of the Jobos Bay National Estuarine Research Reserve are outlined in red. A white arrow indicates the location of the nutrient enrichment experiment at offshore keys, approximately 3 km from the mainland (image credits: Zitello et al. 2008; NOAA-NERR 2015).

Table 2-1. Stand characterization of the fringe mangrove site in this study measured at the start (October, 2011) and end (October, 2013) of the experiment. There was no change of stem density for mature trees. Three blocks were established within the stand, at least 100 m apart, for a complete randomized block design with three levels of nutrient treatment. Edaphic characterization of each block is presented in Chapter 1.

Block	Stem density (count m ⁻²)	Basal area (m ⁻² m ⁻²)	
	2011-2013	2011	2013
1	1.1	31.6	32.7
2	0.9	17.1	17.9
3	1.2	19.7	23.0

Table 2-2. Tree characterization (height, stem diameter at 1.3 m, above-ground dry biomass) of the fringe mangrove site in this study measured at the start (October, 2011) and end (October, 2013) of the experiment. Above-ground biomass was calculated from species-specific allometric relationships based on stem diameter (Smith and Whelan 2006). There was no effect of nutrient treatment nor year on above-ground biomass values ($p = 0.5$). No statistical test of tree height was performed.

Treatment	Block	Tree height (m)		Stem diameter (cm ²)		Biomass (kg DW m ⁻²)	
		2011	2013	2011	2013	2011	2013
Control	1	4.8 (0.3)	5.1 (0.4)	6.1 (0.6)	6.2 (0.6)	14.7 (3.6)	15.4 (3.5)
	2	5.4 (0.5)	5.1 (0.3)	4.7 (0.5)	4.8 (0.6)	6.6 (1.6)	7.0 (1.7)
	3	3.3 (0.5)	3.1 (0.6)	3.5 (0.7)	3.7 (0.7)	5.2 (3.4)	5.9 (3.7)
Agriculture	1	3.9 (0.5)	4.2 (0.5)	5.2 (0.8)	5.4 (0.8)	6.9 (1.5)	7.4 (1.5)
	2	4.3 (0.2)	4.4 (0.2)	3.7 (0.4)	3.8 (0.5)	4.2 (1.2)	4.5 (1.3)
	3	3.1 (0.6)	3.2 (0.7)	4.7 (1.2)	5.0 (1.2)	13.1 (6.8)	14.4 (7.0)
Urban	1	5.1 (0.9)	5.0 (1.0)	5.2 (0.6)	5.4 (0.7)	8.3 (1.8)	9.8 (2.1)
	2	5.5 (0.4)	4.7 (0.3)	5.1 (0.6)	5.3 (0.6)	8.3 (2.1)	9.1 (2.4)
	3	3.6 (0.6)	3.8 (0.6)	3.4 (0.6)	3.7 (0.6)	3.9 (6.9)	4.8 (4.5)

Figure 2-2. Above-ground mangrove production (wood and leaves; kg dry weight m⁻¹ y⁻¹) under three nutrient enrichment scenarios within three experimental blocks of a fringe forest. Production rate was calculated using an allometric equation for *R. mangle* or *L. racemosa* based on stem diameter at 1.3 m above the floor. There was no significant difference of biomass growth among nutrient treatment levels ($p = 0.4$). An assumption was made that the growth rate was constant during the two-year enrichment experiment (October 2011 to October 2013). Error bars are ± 1 S.E.

Figure 2-3. Total litter production in a fringe mangrove over two years of nutrient enrichment (Oct. 2011 to Oct. 2013) averaged across three blocks for three nutrient treatments: Control (closed black circles), Agriculture/high N:P (closed grey circles), Urban/intermediate N:P (open circles).

* Significant differences ($p < 0.5$); ° Slight differences ($p \leq 0.7$)

Figure 2-4. Total and component average litterfall (g dry weight m^{-2} day $^{-1}$) by study year (year 1 = Oct. 2011 to Sept. 2012; year 2 = Oct. 2011 to Sept. 2013). A = total litterfall; B = leaf fall; C = propagule and flower fall; D = stipule fall. Litterfall was collected every two weeks during the experimental period in duplicate 0.25 m^2 baskets per unit (see Methods). Averages are across all 3 blocks by nutrient treatment. Note different y-axis values. Error bars are ± 1 S. E.

Table 2-3. Results of two-factor repeated measures analyses of variance with blocking and interaction for total and component annual litterfall. Treatments are control (local channel water), agriculture (N:P ratio 50:1) and urban (N:P ratio 16:1). Litterfall was collected every-other week for two years in duplicate 0.25 m² baskets per experimental unit (3 units within 3 blocks). Total and component litterfall values have been averaged over an experimental year (Oct. 2011 to Sept. 2012/Oct. 2012 to Sept. 2013). *n* = 36.

Litterfall component	Factor	Model <i>df</i>	Error <i>df</i>	<i>F</i>	<i>P</i>
Total litterfall	Treatment	2	26	0.55	0.5836
	Year	1	2	0.69	0.4949
	Treatment*year	2	26	6.92	0.0039 **
Leaves	Treatment	2	26	3.57	0.0426 *
	Year	1	2	1.68	0.3239
	Treatment*year	2	26	0.13	0.8747
Stipules	Treatment	2	26	4.16	0.0271 *
	Year	1	2	0.11	0.7741
	Treatment*year	2	26	3.18	0.0581 °
Propagules & flowers	Treatment	2	26	0.32	0.7319
	Year	1	2	0.24	0.6748
	Treatment*year	2	26	7.85	0.0021 **

°P < 0.06; * P < 0.05; ** P < 0.01

Figure 2-5. Cumulative stipule fall (count m⁻²) measured over two years of nutrient enrichment (Oct. 2011 to Oct. 2013) at three levels: Control (closed black circles), Agriculture/50:1 N:P (closed grey circles), Urban/16:1 N:P (open circles). Stipule fall was averaged across three blocks within the forest. The rate of stipule fall under agriculture treatment was significantly different than control ($p = 0.00002$) and urban ($p = 3.3E-05$) treatments. No significant difference of stipule fall rate was found between urban and control treatments ($p = 1.0$).

Figure 2-6. Litter production components over the two-year nutrient enrichment experiment (Oct. 2011 to Oct. 2013) averaged across three blocks for three nutrient treatments: (A) Control; (B) Agriculture/high N:P; (C) Urban/intermediate N:P. Litter components are: *R. mangle* and *L. racemosa* leaves (light blue); propagules and flowers (red); stipules (yellow); wood (tan); unidentified material (dark blue). Litter production was collected and measured every-other week.

Table 2-4. Litter production rates (g dry mass m⁻² y⁻¹) from studies conducted in Neotropical mangrove systems (Caribbean, Latin America, and northern South America). Forest type is based on Lugo and Snedaker (1974) classification.

Location	Forest type	Species composition	Litter production (g DW m ⁻² y ⁻¹)	Reference
Northeast Mexico	Dwarf	<i>A. germinans</i>	175	Arreola-Lizárraga et al. 2004
Southwest Florida	Basin	<i>R. mangle</i> , <i>A. germinans</i> , <i>L. racemosa</i>	810	Twilley et al. 1986
Southwest Florida	Basin	<i>A. germinans</i>	444	Twilley et al. 1986
Southwest Puerto Rico	Fringe	<i>R. mangle</i>	480	Golley et al. 1962
South Florida	Fringe	<i>R. mangle</i> , <i>A. germinans</i> , <i>L. racemosa</i>	758	Pool et al. 1975
Southeast Mexico	Fringe	<i>R. mangle</i> , <i>L. racemosa</i>	835	Day et al. 1987
Southeast Mexico	Fringe	<i>R. mangle</i> , <i>A. germinans</i> , <i>L. racemosa</i>	1116	Aké-Castillo et al. 2006
Southeast Puerto Rico	Fringe	<i>R. mangle</i>	1690	Lugo et al. 2007
Southeast Mexico	Fringe	<i>R. mangle</i> , <i>A. germinans</i> , <i>L. racemosa</i>	880	Adame et al. 2012
Southeast Puerto Rico	Fringe	<i>R. mangle</i> , <i>L. racemosa</i>	1061 to 1217	This study
South Florida	Overwash	<i>R. mangle</i> , <i>L. racemosa</i>	786	Pool et al. 1975
South Florida	Riverine	<i>R. mangle</i> , <i>A. germinans</i> , <i>L. racemosa</i>	818 to 918	Pool et al. 1975
Southeast Mexico	Riverine	<i>R. mangle</i> , <i>A. germinans</i> , <i>L. racemosa</i>	1252	Day et al. 1987
Southern Ecuador	Riverine	<i>Rhizophora</i> spp.	647 to 1064	Twilley et al. 1997

Table 2-5. Past field studies of experimental nutrient enrichment in mangroves. Mangrove responses to fertilizer input related to production (biomass change, litter production, photosynthesis rate, mortality rate) are briefly described.

Location	Species/forest type	Nutrients applied	Fertilizer type	Fertilization rate* (mol m ⁻² y ⁻¹)	Duration	N-only	Effects P-only	N & P	Reference
Hitchinbrook Island, Australia	Rhizophoraceae family, fringe/overwash	NH ₄ ; P ₂ O ₅	P buried (solid); N subsurface injection (liquid)	0.7 (N); 0.3 (P)	1 year	Enhanced stipule production (edge site)	No effect at edge; Enhanced stipule production (interior site)	--	Boto and Wellington 1983
China	<i>Aegiceras comiculatum</i> ; <i>Kandelia candel</i>	N and P; ionic state unknown	Wastewater	19.6 (N); 0.9 (P)	2 years	--	--	No effect on litter production	Tam et al. 1998
Twin Cays, Belize	<i>R. mangle</i> , dwarf	NH ₄ ; P ₂ O ₅ ; N&P	Buried (solid)	15.0 (N only); 1.9 (P only); 3.3 (N) & 0.6 (P)	2 years	No effect observed	Greater tree height, stem elongation, leaf production; Lower leaf sclerophylly	Same results as P-only	Feller 1995
Indian River Lagoon, Florida	<i>R. mangle</i> , fringe; <i>A. germinans</i> , transition/dwarf	CH ₄ N ₂ O; P ₂ O ₅	Buried (solid)	9.0 (N); 1.9 (P)	2 years	Greater leaf production and stem elongation; Enhanced photosynthesis rate	No effect observed	--	Feller et al. 2003
Indian River Lagoon, Florida	<i>A. germinans</i> , dwarf	NO ₃	Monthly spray (liquid)	0.7 (N)	2 years	Enhanced branching; no effect on shoot growth or leaf production	--	--	Whigham et al. 2009
Multiple sites within Caribbean and Indo- Pacific regions	Multiple, fringe/scrub	CH ₄ N ₂ O; P ₂ O ₅	Buried (solid)	9.0 to 15.0 (N); 1.9 (P)†	3 to 12 years	Scrub: Increased mortality under drought conditions; Fringe: no effect on mortality	No effect on mortality	--	Lovelock et al. 2009
Jobos Bay, Puerto Rico	Fringe	NH ₄ ; KH ₂ PO ₄	3i-weekly spray (liquid)	5.0 (N) & 3.1 (P); 5.0 (N) & 9.7 (P)	2 years	--	--	Higher leaf and stipule production (high N:P only); no effect on standing biomass	This study

*I assume buried fertilizer broadcast area is 1 m²

†Uncertain from literature

Chapter 3

NUTRIENT UPTAKE AND RETENTION WITHIN A FRINGE MANGROVE STAND UNDER DIFFERENT NUTRIENT LOADS

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NUTRIENT UPTAKE AND RETENTION WITHIN A FRINGE MANGROVE STAND UNDER DIFFERENT NUTRIENT LOADS

ABSTRACT

A one-time spike of ^{15}N stable isotope tracer was added to ambient (receiving local channel water) and chronically nutrient enriched (receiving $70 \text{ g N m}^{-2} \text{ y}^{-1}$ and $9.7 \text{ g P m}^{-2} \text{ y}^{-1}$ for 21 to 24 months) sites within a coastal fringe mangrove forest in southeastern Puerto Rico to determine if nutrient enrichment was being retained in the mangrove ecosystem, and to identify mangrove N sinks. Measurements for ^{15}N retention occurred at 1 month, 3 months, and 10 months after the initial spike. ^{15}N tracer was recovered in all components (mangrove foliage, standing litter, surface sediment, and fine roots) within ambient and fertilized sites. The highest proportion of tracer retention (28 to 59% under ambient conditions and 14 to 28% under nutrient enriched conditions) occurred in the organic layer of the forest floor (standing litter, surface sediment, and surficial fine roots). ^{15}N retention within the mangrove canopy represented the smallest N sink, although foliar $\delta^{15}\text{N}$ continued to increase throughout the measurement period. Tracer retention within the organic layer of the forest floor indicates strong recycling and retention of nutrients that supports a highly-productive system in an oligotrophic marine environment. Chronically nutrient enriched sites retained more ^{15}N tracer than ambient sites, but a smaller proportion of the applied ^{15}N fertilizer, suggesting the capacity of nutrient retention had been exceeded by the added nutrient load.

INTRODUCTION

Coastal mangrove wetlands are encountering an unprecedented input of cultural nutrient enrichment to tropical coastlines (Corredor et al. 1999; Deegan et al. 2012), which may alter nutrient cycling and related functions within the mangrove stand and material exchange with other systems. Several studies have examined the effect of targeted nutrient addition (nitrogen, N and phosphorus, P) on mangrove tree production and physiology (Feller et al. 1999, 2003, Whigham et al. 2009). Functional changes by mangroves under nutrient enrichment include higher production rates (Boto and Wellington 1983; Feller 1995; Chen and Twilley 1999), a decrease in the nutrient retranslocation efficiency (Feller et al. 2003) and a reduction of above-ground (shoot) to below-ground (root) biomass ratios (Naidoo 2009), which can increase mortality under drought conditions (Lovelock et al. 2009). However, other studies have found no strong link between nutrient enrichment and mangrove production (Whigham et al. 2009, Tam et al. 1998), which suggests these results depend upon environmental, floristic, and experimental design contexts.

Changes to mangrove production and nutrient use under chronic nutrient enrichment conditions has the potential to affect ecosystem services such as carbon (C) sequestration (Donato et al. 2011) and/or nutrient retention or exchange with adjacent marine systems (Rivera-Monroy and Twilley 1996; Valiela and Cole 2002). Nutrient enrichment may promote atmospheric C capture if the enhanced ecosystem component has a large C:N ratio, such as mangrove trees (C:N ~ 200; Alongi 2009). Therefore a more clear understanding of the fate of nutrient enrichment will allow better prediction and management of mangroves as C sinks. Additionally, mangrove nutrient retention or

exchange with adjacent marine systems may be influenced by chronic nutrient enrichment if the capacity to retain added nutrients has reached a threshold level (Verhoeven et al. 2006). The magnitude of this proposed threshold level (nutrient loading rates and duration), as well as influencing factors, are currently unknown.

In previous work (Chapters 1 and 2), I examined mangrove above-ground production and benthic C remineralization within a fringe mangrove system under experimental nutrient loading. At 18 months of fertilization, there was no observable effect on benthic C remineralization rates (sediment respiration and organic material decomposition), and a small increase of mangrove litter production under enriched conditions. These results encouraged the following questions concerning fate of the added N and implications for the C cycle:

- 1) For mangrove sites that have received chronic nutrient loading, are added nutrients continually taken up by the mangrove system? If so, what is the relative sink strength between main ecosystem components (mangrove foliage, standing litter, surface sediment, and fine roots)?
- 2) Does the amount of N addition affect the distribution of N retention into the ecosystem components?
- 3) Is there a threshold of N uptake capacity?
- 4) Will added N be retained within the system for months after enrichment?

In this work, I attempt to address these questions with the use of ^{15}N stable isotope tracer, an effective tool to observe and quantify N movement and retention between main organic and inorganic pools of an ecosystem (Nadelhoffer et al. 1999; Drake et al. 2009). A one-time spike of ^{15}N -ammonium sulfate was applied to ambient and nutrient enriched

fringe mangrove sites in southeastern Puerto Rico that had received pulsing aqueous nutrient enrichment or ambient channel water for 21 months prior to the ^{15}N spike and continued for 3 more months. Main biomass pools (mangrove leaves, standing litter, top sediment, below-ground fine roots) were measured for ^{15}N retention at repeated intervals (1, 3, 10 months) following ^{15}N tracer addition to estimate nutrient enrichment uptake and retention within these ecosystem N pools.

METHODS

Study site

Jobos Bay is a coastal plain estuary located in southeastern Puerto Rico ($17^{\circ} 56'\text{N}$, $66^{\circ} 13'\text{W}$). The mouth of the bay is mainly enclosed by mangrove-fringed limestone cays extending from a barrier coral reef. Caribbean surface seawater flows northward into the bay through channels between the cays. The local tidal cycle is mixed diurnal and ranges from 17 to 36 cm, with the largest tides in October (Field 2008).

The location of this study is a fringe (*sensu* Lugo and Snedaker 1976) mangrove wetland positioned at the most southeastern channel of the bay, within the domain of the Aguirre State Forest. We selected this location as the least anthropogenically affected site within Jobos Bay, having the greatest distance from the bay-area residential, commercial, and agricultural land uses, and the mangrove-lined seawater channel flows from the low-nutrient Caribbean Sea to the bay. Additionally, stable isotope work by Bowen and Valiela (2008) has demonstrated that rooted vegetation at sites within Jobos Bay are disconnected from anthropogenic nitrogen sources. The coastal edge zone of the fringe mangrove forest (within 10-15 m upland of the coastline) is predominantly

composed of red mangrove (*Rhizophora mangle* L.) with intermittent white mangrove (*Laguncularia racemosa* (L.) c.f. Gaertn.). The average canopy height is 4.24 m (range 0.76 to 7.09 m) and the average diameter at breast height (1.3 m above the forest floor) is 5.26 cm (maximum 21.7 cm). Greater detail of the experimental site forest structure is presented in Chapter 2.

Chronic nutrient addition

Three replicate blocks were established within the mangrove forest with at least 100 m spacing. The blocks were positioned parallel to the coastline and 5 m inland from the coastal edge. Each block contained three 4 m² quadrats (“experimental units”) with at least 3 m of buffer space between the units. The experimental units were randomly assigned a nutrient treatment (ambient; high nitrogen/low phosphorus fertilization; high nitrogen/moderate phosphorus fertilization) which was applied every-other week for two years beginning October 2011. While the complete block is considered for biomass estimates (described below), for the purpose of this stable isotope study, only the ambient and high nitrogen/moderate phosphorus treatments will be considered (herein referred to as “ambient” and “fertilized,” respectively). The treatments were applied by hand with a pressurized sprayer, with care taken to ensure that the spray was applied evenly within the quadrat and positioned close to the forest floor to limit volatilization. When possible, treatments were scheduled to coincide with low tides. Ambient treatment was 1 L of offshore channel water collected at the time of fertilization. Fertilized treatment was 1 L of locally-collected channel water with dissolved ammonium chloride and potassium phosphate (44.6 g NH₄Cl and 7 g KH₂PO₄ per dose within the 4m² unit), for an annual fertilization of 70 g N m⁻² and 9.7 g P m⁻².

¹⁵N tracer addition

In August 2013 (21 months after the start of the experiment) ¹⁵N-ammonium sulfate (95.2% isotope enrichment) was applied as a one-time spike divided over two concurrent days. The ¹⁵N-enriched application followed the fertilization procedure described above, with designated hand sprayers to prevent subsequent isotopic contamination. For the fertilized sites, we applied the standard amount of N and P with 80% of the N in the form of (¹⁵NH₄)₂SO₄ and 20% as un-enriched NH₄Cl. To calculate ¹⁵N input for ambient sites, we assumed a 15 cm water depth over the 4 m² plot for a total of 600 L overflowing (tidal) water and increased the background level to 100 μM N in the form of (¹⁵NH₄)₂SO₄. Our purpose of increasing the ambient N concentration above the background level (2 to 14 μM channel water DIN) was to make certain that the ¹⁵N-NH₄ dominated the isotopic signal of new N input for this one-time addition. Our assumption is that the N spike did not significantly fertilize the ambient units to produce noticeable biochemical or physiological changes over the time period (weeks to months) of this study. The total amount of N and P (mols m⁻²) added to fertilized and ambient sites in early August 2013 is listed below.

	Nutrient load (g m ⁻²)		
	Total N	¹⁵ N	P
Fertilized	3.08	2.38	0.41
Ambient	0.45	0.43	--

Sampling

Ecosystem component pools within the fringe mangrove system were separated into the following categories: living mature mangrove leaves; standing leaf litter forming the

organic layer of the forest floor surface; surface sediment (0 to 2 cm); fine to small below-ground roots and decomposed organic material at 0-15 cm depth. It was assumed that external organic C input was minimal in this micro-tidal, semi-arid system, and that these components represent much of the major organic C pools in this system, although above-ground woody biomass and large roots were not sampled.

Foliage

Each mangrove tree with at least one aerial root or set of pneumatophores located within an experimental unit was considered part of the experiment and assigned an ID. These trees were periodically measured for diameter at breast height (DBH; 1.3 m above the forest floor) and canopy height. The measurements were then used to determine above-ground biomass using allometric relationships (described below).

Leaf collection was performed just before ^{15}N enrichment (July 2013), and at three intervals after ^{15}N enrichment: late August 2013, mid-October 2013, and late May, 2014 (1, 2.5, and 6 months after the ^{15}N enrichment event). All leaves were collected by hand in the lower part of the canopy; thus, only shade leaves were collected. Mature green leaves and senescent leaves still attached to the branch were collected and labeled with a permanent marker. Some experimental units did not contain trees with attached senescent leaves and some trees had leaves that were impossible to reach by climbing, particularly in block 2. When possible, 3 green or senescent leaves were collected for each tree. The collected leaves were stored in a dark cooler for transport from the field to the laboratory.

Leaves were rinsed with distilled water and air-dried overnight before weighing ("fresh weight"). Leaves were then dried at 45° C until a constant weight was reached

(“dry weight”). Replicate leaves collected for the same tree were combined for elemental and isotopic analyses. To minimize confounding factors such as leaf size and age, mid-ribs were removed from each leaf before analyses were conducted. The dried leaf tissue was ground using a Wiley-Mill with a #20 sieve and stored at room temperature with a desiccant until laboratory analysis.

Leaves collected in July 2013 were immediately pressed and copied at 100% aspect ratio. The images were uploaded to an image processing program (Image-J, v. 1.46, NIH Image, <http://imagej.nih.gov/ij/>), which was used to determine the surface area of each leaf without the petiole area. A hand-drawn 1 cm² square was used to calibrate each measurement. Specific leaf area (area/dry weight) was calculated and averaged by block for biomass estimates.

Standing litter

The litter decomposition bag method (Karberg et al. 2008) was used to analyze N uptake and processing within the standing litter pool. Fiberglass mesh litter bags (1 mm² pore size) containing locally-sourced newly fallen senescent leaves (5 per bag, approximately 3 g fresh weight) were deployed in July 2013 and collected periodically through a three-month period at 9, 32, 60, and 90 days. The litterbag method is described in greater detail in Chapter 1. Additional fallen leaves were collected within a 1 m perimeter of each block to obtain a fresh weight to dry weight conversion ratio for whole senescent leaves. The contents of the recovered litter bags were submerged in distilled water and carefully cleaned with a soft-bristled paintbrush to remove sediment. The contents were dried at 45°C until a constant weight was reached. The dry material was ground, stored, and analyzed by the same method as the collected mangrove leaves.

Sediment

Surface sediment cores were collected for each experimental unit at the same time intervals as mangrove leaf collection (pre-enriched; 1, 2.5, and 6 months after the ^{15}N enrichment event). Core locations were haphazardly selected with consideration to avoid benthic macro-algae cover, crab burrows, large surface roots or pneumatophores, or a location with a previous coring event. Any recent standing litter that had not become integrated with the sediment matrix was carefully removed before coring. Three 2.5 cm diameter replicate cores were collected from the top 2 cm of the sediment. The cores were segregated by depth (0-1 cm, 1-2 cm) and replicates within each unit were combined. The core sections were dried at 45° C, ground with a mortar and pestle, and sieved through a (200 μm) mesh to remove fine roots.

Using the same siting criteria, duplicate cores were collected with a commercial film canister (4.6 cm depth, 35.3 cm^3). The cores were immediately weighed (“wet weight”) and then dried at 45° C until a constant weight was reached (“dry weight”). The ratio of dry weight to volume is the bulk density of the sediment and small root matrix. Roots were then sieved and the dry core was re-weighed for the bulk density of the sediment without the root volume.

Below-ground fine roots

For each experimental unit, one below-ground leaf litter bag (5 cm x 10 cm, 3 leaves per bag) that had incubated for 22 months was collected May 2014, 6 months after the end of fertilization and 10 months after the ^{15}N spike. The components of the below-ground decomposition bag had fully integrated with ingrown roots. There were some

small (≤ 0.5 cm) pieces of leaf material, but these were inseparable from the mat of fine roots. Thus these samples were considered below-ground fine root material.

Biomass and N pool estimates

The mass of ecosystem pool components (mangrove foliage, standing litter, sediment) was estimated by direct measurement, biometric-based allometry, or published literature values derived from a comparable mangrove system. For all components, the N pool was determined by elemental measurement of N (described below) and scaled to the ecosystem component mass.

Above-ground dry biomass was calculated using the following allometric relationship of dry biomass and DBH of *R. mangle* and *L. racemosa* provided in Smith and Wheland (2006):

$$\log_{10}y = a \log_{10}(\text{DBH}) + b$$

where y = aboveground dry biomass in kg and DBH is in cm

The following constants were used with the above equations (Smith and Whelan 2006):

Species	Slope constant (a)	Interept constant (b)
<i>R. mangle</i>	1.731	-0.112
<i>L. racemosa</i>	1.930	-0.441

The calculated above-ground biomass was summed and divided by the total area of the experimental unit for an estimation of total stand biomass for each experimental block.

Mangrove leaf biomass was estimated from average DBH per experimental unit using equations in Smith and Whelan (2006). Leaf area and dry weight of at least 10 leaves per experimental unit were measured for a specific leaf weight (g/cm^2). The

specific leaf weight was used with the calculated canopy biomass for an estimate of total leaf area. The canopy leaf area was normalized by stem density (# trees m⁻²) to obtain the leaf area index (LAI; leaf area (m²)/plot area (m²)).

Standing litter on the forest floor was estimated from the average annual litter production measured by litter catch baskets (two 0.25m² per experimental unit, collected bi-weekly) and a turnover rate of 1.5 y⁻¹ reported for a Florida fringe mangrove system (Pool et al. 1975).

The sediment bulk density of each experimental unit was multiplied by 2 cm (the assumed depth of ¹⁵N tracer penetration) and scaled for a value of g DW m⁻². Below-ground fine root mass was estimated as 40% of the sediment bulk density (Corredor and Morell 1994).

Elemental and $\delta^{15}\text{N}$ analysis

Nomenclature and equations

Nitrogen isotopic composition was expressed using delta notation ($\delta^{15}\text{N}$), which is parts per thousand (‰) deviation from the ¹⁵N:¹⁴N molar ratio of the atmospheric standard (R_{standard}) as expressed in the following equation:

$$\delta^{15}\text{N} = [(R_{\text{sample}} - R_{\text{standard}}) / R_{\text{standard}}] \times 1000$$

Where R is the molar ratio of ¹⁵N:¹⁴N and $R_{\text{standard}} = 0.0036765$.

For calculating percent retention (described below), $\delta^{15}\text{N}$ notation was converted to atom percent using the following equation (Fry 2006):

$$\text{Atom percent (AP) of } ^{15}\text{N} = [100 * (\delta^{15}\text{N} + 1000)] / [\delta^{15}\text{N} + 1000 + (1000 / R_{\text{standard}})]$$

Laboratory analysis

To determine isotopic composition and elemental content, approximately 5-7 mg of dry leaf sample or 12-15 mg of dry and sieved sediment sample were weighed into tin vials and measured with an Isoprime 100 Isotope Ratio Mass Spectrometer interfaced with a Micro Vario Elemental Analyzer (Elementar Americas, Mt. Laurel, NJ). The sample weights were recorded to the nearest microgram. The majority of the samples were run in duplicate to check for instrument precision. Only duplicate samples with $\leq 20\%$ isotopic discrepancy were accepted and averaged for a final value.

Initial runs indicated a possible “carry-over effect” for samples with low $\delta^{15}\text{N}$ enrichment immediately following samples with a high $\delta^{15}\text{N}$ enrichment value. Samples that were identified as potentially affected by carry-over were re-run without highly-enriched $\delta^{15}\text{N}$ samples, and the lowest consistent $\delta^{15}\text{N}$ value was considered true. Subsequent runs were structured so that potentially low-enriched $\delta^{15}\text{N}$ samples were run first within a set, with increasing likelihood of $\delta^{15}\text{N}$ enrichment presenting later in the sample set. Samples with natural abundance ^{15}N content (i.e., samples collected before ^{15}N enrichment) were run in a separate group.

Laboratory standards were periodically used throughout each run (approximately every 24 samples) to identify potential instrument drift and to correct for measurement offset error. Elemental content (%N or %C) was calculated by comparing the peak area of each unknown sample to a standard curve of peak area vs. known %N content

$\delta^{15}\text{N}$ mass balance

^{15}N tracer uptake within the ecosystem component pools was calculated from the N pool mass estimates and the difference in ^{15}N concentration within each ecosystem

components following the tracer addition, and was described as a proportion of the total ^{15}N tracer applied for a retention value (Nadelhoffer et al. 1999):

$$^{15}\text{N}_{\text{recovered}} = [m_{\text{pool}} (\text{AP } ^{15}\text{N}_{\text{pool}} - \text{AP } ^{15}\text{N}_{\text{reference}})] / (\text{AP } ^{15}\text{N}_{\text{tracer}} - \text{AP } ^{15}\text{N}_{\text{reference}})$$

where $^{15}\text{N}_{\text{recovered}}$ is the mass of ^{15}N tracer contained in the labeled N pool (g N m^{-2}); m_{pool} is the total N mass of the component pool (g N m^{-2}); $\text{AP } ^{15}\text{N}_{\text{pool}}$ is the ^{15}N atom percent of the labeled (enriched) component; $\text{AP } ^{15}\text{N}_{\text{reference}}$ is the natural abundance ^{15}N atom percent of the component pool (sampled before labelling or from an adjacent unlabeled plot); $\text{AP } ^{15}\text{N}_{\text{tracer}}$ is the ^{15}N atom percent of the ^{15}N -enriched fertilizer.

It was assumed that the ^{15}N was processed through the N pools at the same rate as ^{14}N , and that fractionation effects, which are typically on the order of 2 to 3 ‰ (Fry and Cormier 2011), were negligible compared with the ^{15}N tracer signal added. To estimate the percent of tracer recovery and its associated variability in each ecosystem component (green leaves, standing litter, fine roots and sediment), the following assumptions were made: (1) The mass of the N pools remained constant through the study period; (2) Reference (pre-labeled or non-labeled) ^{15}N values do not change during the study period. Therefore any change in ^{15}N values of sampled material after recovery is assumed to be a result of ^{15}N tracer uptake.

Values of mangrove leaf $\delta^{15}\text{N}$ within reference pools that had been sampled in adjacent sites following ^{15}N tracer addition ranged from 0.5 to 83‰, which presented a higher upper limit than was expected based on previous isotopic studies conducted in the mangroves of Jobos Bay. Demopolous et al. (2007) and Bowen and Valiela (2008) reported natural abundance ranges of 1 to 7 and -6 to 2‰, respectively. Based on these

previous works, reference samples with $\delta^{15}\text{N}$ values higher than 20 ‰ were considered contaminated by ^{15}N tracer and were not included in the reference pool $\delta^{15}\text{N}$ value for tracer retention calculations.

Statistical analyses

A two-factor ANOVA with a blocking term was used to evaluate differences in N mass pools of each ecosystem component under ambient or enriched nutrient treatments. C:N ratios of foliage, standing litter, and surface sediment were evaluated with a three-factor ANOVA with interaction term (treatment, time, treatment*time) and block effect. The same test was used for $\delta^{15}\text{N}$ analyses of each ecosystem component. To account for high variability, all $\delta^{15}\text{N}$ values were $\log_{10}$ transformed. Although other studies have arcsine transformed C:N ratios (e.g., Twilley et al. 1997), I did not alter the data as residuals were normally distributed. All tests included confirmation of variance homogeneity (Levene's test) and normality of the residuals (Shapiro-Wilk). A post-hoc Tukey's test was performed for pair-wise analysis for variables that were significantly different from each other.

RESULTS

Natural ^{15}N abundances

The upper limit of reference pool $\delta^{15}\text{N}$ values sampled from nearby (non- ^{15}N enriched) sites following ^{15}N tracer addition suggested tracer contamination (foliage, 0.5 to 146‰; litter, 2 to 127‰; sediment, 0 to 24‰; Table 3-1) . For tracer retention calculations, all reference samples with $\delta^{15}\text{N}$ values greater than 20‰ were discarded. The discarded samples represented 18% of the total reference sample pool for foliage ($n = 30$), 50% of standing litter ($n = 12$), and 13% of the sediment samples ($n = 8$). The

highest value of discarded $\delta^{15}\text{N}$ reference material represented less than 2% retention of ambient (low concentration) ^{15}N tracer addition; thus the contamination effect was not strong. A 20‰ cut-off value is higher than natural $\delta^{15}\text{N}$ abundances reported for Jobos Bay vegetation (1 to 7 ‰, Demopoulos et al., 2007; -6 to 2 ‰, Bowen and Valiela, 2008) and has the potential to underestimate the amount of ^{15}N tracer uptake by the labeled pools, but the majority of labeled component $\delta^{15}\text{N}$ values were orders of magnitude greater than this cut-off value.

In contrast, $\delta^{15}\text{N}$ of reference fine root samples collected before tracer addition ranged from -0.2 to 7‰.

Ecosystem N pools

A sum across components gives the total N pool range from 64 to 115 g m⁻² under ambient treatment and 60 to 108 g m⁻² under enriched treatment (Tables 3-2 and 3-3). Fine roots constituted the greatest proportion of total N mass at 10 months after tracer addition (ambient: 41 to 74 g m⁻²; enriched: 33 to 61 g m⁻²), followed in descending order by surface sediment ambient: 12 to 23 g m⁻²; enriched: 16 to 30 g m⁻², green leaves (ambient: 9 to 13 g m⁻²; enriched: 9 to 12 g m⁻²), and standing litter (ambient: 2 to 4 g m⁻²; enriched: 2 to 5 g m⁻²). Nutrient enrichment treatment enhanced foliar N mass ($p = 0.01$), but did not affect standing litter nor sediment N mass ($p = 0.8$ and 0.2 , respectively).

Initial standing litter had the highest C:N content (ambient: 107 to 136; enriched: 112 to 128; Tables 3-2 and 3-3), which declined by 50 to 60% within three months of incubation on the forest floor, as time was a significant factor for litter C:N values ($p < 0.001$). Nutrient enrichment had a significant effect on foliar C:N values ($p = 0.05$), and

a small significant effect on standing litter C:N ($p = 0.07$) but no significant effect on the C:N values of surface sediment ($p = 0.2$). Of the components measured, C:N values decreased along the following pattern: initial standing litter < fine roots < standing litter, three months < green foliage < sediment. This pattern differs from component N pool size ranking (described above), demonstrating that total mass and C:N values present different proportions for the component N pool quantity.

^{15}N tracer retention

^{15}N tracer was recovered in all measured ecosystem components at each observation point (1, 3, and 10 months following tracer addition). There were large ranges of $\delta^{15}\text{N}$ values for all components (Tables 3-2 and 3-3), with foliar values spanning three orders of magnitude. Standing leaf litter presented the highest $\delta^{15}\text{N}$ value under both ambient and nutrient enriched conditions by an order of magnitude above the other ecosystem components at early (1 month) measurements. Fine roots represented the next highest average $\delta^{15}\text{N}$ values, although the upper range of foliar $\delta^{15}\text{N}$ matched or exceeded these values. Nutrient conditions had a significant effect on sediment and mangrove foliage $\delta^{15}\text{N}$, but there was no nutrient effect on standing litter ^{15}N (Table 3-4).

Mangrove foliage presented large $\delta^{15}\text{N}$ variation within experimental units (Tables 3-2 and 3-3) and between sampling time periods of individual trees (Figure 3-1). For individual trees, there was no clear pattern of $\delta^{15}\text{N}$ change with time following tracer addition; however, the majority of these trees exhibited higher $\delta^{15}\text{N}$ values 10 months after tracer addition compared with initial (1 month after tracer addition) samples. Time since tracer addition had a significant effect on foliar $\delta^{15}\text{N}$ (Table 3-4). The distribution of foliar $\delta^{15}\text{N}$ under ambient and enriched conditions shifted toward higher values during

the 10-month observation period (Figure 3-2). For ambient treatment, the majority of foliar $\delta^{15}\text{N}$ values at 3 months after tracer addition was below 100‰, with a maximum range of 500‰. Under the same conditions at 10 months, the majority of foliar $\delta^{15}\text{N}$ values fell between 100 and 500‰, with one sample above 1000‰. Similarly, the distribution of foliar $\delta^{15}\text{N}$ values consistently shifted higher with time since tracer application in sites that had received chronic nutrient enrichment. All foliar $\delta^{15}\text{N}$ values were above 100‰ at 10 months after the tracer application, with the largest proportion of $\delta^{15}\text{N}$ values above 1000‰ at the enriched site.

This experiment applied different amounts of ^{15}N tracer to ambient (0.43 g m^{-2}) and nutrient enriched (2.38 g m^{-2}) sites; therefore treatment-wise comparisons of absolute tracer retention as well as proportional retention is needed. Total ^{15}N retention within nutrient enriched sites was 2 to 3 times greater than ^{15}N retention under ambient conditions (Table 3-5). For all measurement periods, contribution of foliar ^{15}N was greater for nutrient enriched sites (12 to $72 \text{ mg } ^{15}\text{N m}^{-2}$) compared with ambient sites (1 to $23 \text{ mg } ^{15}\text{N m}^{-2}$). For both treatments, the lowest foliar ^{15}N retention relative to total ^{15}N retention occurred 3 months after tracer addition. The highest foliar ^{15}N contribution under ambient conditions ($16 \pm 7 \text{ mg } ^{15}\text{N m}^{-2}$) occurred 1 month after tracer addition, whereas the highest foliar ^{15}N retention under enriched conditions ($58.1 \pm 13.5 \text{ mg } ^{15}\text{N m}^{-2}$) was measured 10 months after tracer addition. Average values of standing leaf litter accounted for 57 to 61% of total average ^{15}N retention under ambient conditions and 49 to 61% of ^{15}N retention under enriched conditions within 1 to 3 months after tracer addition. Factoring in fine root ^{15}N retention at 10 months following tracer application (with the assumption that standing litter ^{15}N retention was conserved), the

organic layer of the forest floor (standing litter, top sediment, and surficial fine roots) accounted for 92% of ^{15}N retention under ambient conditions and 77 % of ^{15}N retention under nutrient enriched conditions.

The proportional retention of applied ^{15}N tracer was higher under ambient treatment (low tracer addition) compared with nutrient enrichment treatment (high tracer addition) for all ecosystem components across all sampling periods (Table 3-6; Figure 3-3). With the assumption that the fine root value is the same measured at 10 months after tracer addition, the sum of all component (foliage, standing litter, sediment, fine roots) proportional ^{15}N retention was calculated to be 28 to 59% (ambient) and 14 to 28% (nutrient enriched) at 3 months after tracer addition. The fine roots component was equal to or greater than the sum of all other components. While a greater proportion of total tracer addition was retained by ambient sites, mangrove foliage ^{15}N retention displayed a reverse pattern: foliar ^{15}N uptake was greater under nutrient enrichment conditions (0.7 to 3% of high tracer addition) compared with ambient conditions (0.2 to 5% of low tracer addition).

DISCUSSION

The purpose of this study was to determine (1) if nutrient addition in a fringe mangrove forest was retained within some of the main ecosystem N pools (mangrove leaves, standing litter, sediment, and fine roots); (2) whether chronic enrichment affects the uptake capacity or distribution of additional nutrients within the system; (3) the fate of added N over a 10-month period following application. Following a one-time spike, ^{15}N tracer was recovered within all measured ecosystem components of both chronically

fertilized and ambient sites throughout the 10 month observation period. The locations and quantity of tracer recovery enables preliminary insight for the above questions.

Mangrove N pools

The largest pools of ^{15}N retention were contained within the organic layer (measured as the upper 2 cm) of the forest floor, which is a matrix of standing litter, sediment, and fine roots (Table 3-6 and Figure 3-3). Nutrient immobilization and re-use within the sediment matrix are considered to be important mechanisms of nutrient retention in the mangrove systems (Alongi 2009; Reef et al., 2010). Previous work has described rapid turnover (hours to days) of mineralized N within the mangrove sediment matrix, mainly due to high rates of ammonification and subsequent biological uptake of NH_4^+ (Nedwell et al. 1994, Morell and Corredor 1993). Alongi et al. (1992) described efficient uptake of N solute at the soil-water interface as well as fast N turnover in the sediment in a north Queensland mangrove. They determined that the capacity to rapidly capture and recycle N inputs accounted for the high productivity of the mangroves, which would not be sustained by water-borne N input alone.

While foliar ^{15}N retention was low compared with the sediment matrix, the proportion of foliar ^{15}N retention increased during the observation period (1 to 10 months) in nutrient enriched plots (Figure 3-3B). This small but relatively greater importance of foliage as an N sink for nutrient enriched compared with ambient conditions may be explained by the lower C:N ratio of leaves from nutrient enriched sites compared with ambient sites (Tables 3-2 and 3-3). Previous work has demonstrated that nutrient limitation relief in mangrove systems will decrease foliar nutrient use efficiency and nutrient reabsorption before leaf abscission (Feller et al. 2009, Reef et al. 2010). It

may be more energetically favorable for mangrove trees to take up a greater quantity of N from the surrounding environment rather than reabsorb the nutrient before leaf senescence. Lastly, it is possible that the enhanced N availability reduced “competition” for nutrients between mangrove trees, the sediment microbial community, and sediment sorption of ionic N.

As the purpose of this study was not focused on a complete N budget, there are significant unknown fates of the ^{15}N tracer. Several N pools were not sampled, including above-ground roots and stems, coarse below-ground root material, and deeper (mineral) sediment cores. It is possible a significant portion of the “lost” ^{15}N tracer could be recovered in these N sinks. A small contamination of nearby (at least 3 m away) “reference” sites suggests that some horizontal mixing of the surface layer occurs, although further work would be needed to determine if the exchange occurred naturally, or was enabled by our actions in the field. Other forms of N loss may include dissolved or particulate exchange via tidal flow, burial, denitrification, and NH_4^+ volatilization (Alongi et al. 1992), which can vary according to the environmental conditions of a mangrove site (Alongi 2009).

Effect of nutrient enrichment on N retention

Chronically nutrient enriched treatment sites retained greater ^{15}N tracer than ambient sites, but a lower proportion of the original ^{15}N tracer amount (Tables 3-5 and 3-6). There does not appear to be a strong difference of N pools between the treatments (assuming that the unmeasured N pools were equally proportioned within ambient and enriched sites), so the lower proportional retention suggests a difference in uptake capacity or efficiency. One possibility is that first-order kinetics plays a factor, where the

chance for encounter and uptake of the less concentrated ^{15}N tracer before loss via tidal flushing or sorption to sediment particles was a constraint under ambient treatment. For nutrient enriched sites, lower proportional ^{15}N tracer uptake but higher ^{15}N retention values suggests that there was no encounter constraint and that ^{15}N supply exceeded the system uptake capacity. This effect was also found by Drake et al. (2008) for a nutrient enriched salt marsh, with the conclusion that N loading exceeded uptake capacity by the marsh system.

The apparent threshold of N retention capacity by chronically nutrient enriched coastal wetlands may affect ecosystem service valuation and management. Mangroves and salt marshes have been suggested as sites of nutrient depuration and mitigation of eutrophic conditions that could otherwise promote negative effects for coral reefs and seagrass systems (e.g., Tam and Wong 1995; Corredor and Morell 1994; Valiela and Cole 2002). However, a “nutrient threshold” may define the potential of mangrove systems to effectively retain chronic nutrient input through hydrologic channels to the coastal marine ecosystem. This work demonstrates that the N retention threshold of a fringe mangrove is between 9.7 and 70 g N m⁻² y⁻¹, but further work will be needed to refine this wide range.

The high recovery of ^{15}N tracer within the fine root pool at 10 months past tracer application demonstrates long-term N recycling and storage mechanisms by the mangrove system. The long-term trend of ecosystem-scale turnover rates for recycled nutrients and final fate of added nutrients is still unknown. A periodic return to these sites for ^{15}N sampling of the ecosystem components is highly recommended.

N loading and the carbon cycle

Greater retention of N within the mangrove system may enhance the ecosystem value as a C sink. N retention within sinks that have a high C:N ratio would also conserve C. However, this study demonstrates the majority of mangrove N retention is dominated by the surface sediment components (standing litter, soil, and fine roots), which have a much lower C:N value (30 to 100; Appendix) compared with mangrove tissue (~ 200; Alongi 2009). Thus the capacity for mangrove C sequestration would be greater if the mangrove trees were the major sinks of N rather than the surface sediment matrix. However, chronic nutrient enrichment has resulted in enhanced above-ground mangrove production (Chapter 2), and a long-term analysis of mangrove tree growth under enriched nutrient conditions is recommended.

Variance and study design

Tracer retention estimates were confounded by large variations of biomass estimates and $\delta^{15}\text{N}$ values for each N pool component within experimental units and between experimental blocks. High variability implicates the heterogeneity and spatial complexity within a stand dominated by red and white mangrove trees. The topography of the forest floor, determined in part by a tangle of above-ground roots, pneumatophores, and crab burrows, is likely an important factor in variations of sediment bulk density, standing litter turnover rates, and fine root growth.

For mangrove trees, large spatial distribution of above- and below-ground roots further complicates a field enrichment study. This study design was based on 4 m² quadrats that do not fully encompass the spatial reach of each tree studied, and it was impossible to normalize for the proportion of each mangrove tree that encountered nutrient enrichment (especially if there were horizontal flow of added nutrients). This

may account for some of the high variability of foliar $\delta^{15}\text{N}$. Ideally, a future stable isotope tracer in a mangrove setting would encompass wider study areas.

CONCLUSION

While chronic nutrient loading results in greater N uptake within some of the main ecosystem N pools (foliage, standing litter, sediment, fine roots), the proportional loss of ^{15}N tracer compared with ambient treatment retention suggests that the capacity for N retention has been exceeded by this loading rate ($70 \text{ g N m}^{-2} \text{ y}^{-1}$). The recovery of ^{15}N tracer within all ecosystem pools at 10 months following a one-time spike indicates efficient nutrient recycling between mangrove trees and the sediment matrix. A long-term (decadal) study of these sites may elucidate the longevity of added nutrient retention and cycling, and may be able to assess the terminal fate of added N.

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TABLES AND FIGURES

Table 3-1. Reference ^{15}N abundances (means $\pm$ 1 S.E.) in mangrove leaves, standing litter on the forest floor, surface sediment (0 to 2 cm), and fine roots. Root samples were collected prior to the ^{15}N tracer experiment; all other components were measured after the tracer addition, but in nearby plots that were not enriched with tracer. $\delta^{15}\text{N}$ values are expressed as deviation from the atmospheric standard (0.3663 atom% ^{15}N). $\delta^{15}\text{N}$ values greater than 20‰ were discarded (see Methods).

Ecosystem pool	$\delta^{15}\text{N}$ (‰)	S.E.	<i>n</i>
Green leaves	4.5	0.7	23
Standing litter	7.7	2.8	6
Surface sediment (0-2 cm)	11.5	3.0	4
Fine roots	0.5	0.3	7

Table 3-2. Mass and N content of measured ecosystem components in fringe mangrove plots receiving ambient treatment (1 L local channel water every-other week for 21 months), with one dose of $(^{15}\text{NH}_4)_2\text{SO}_4$ tracer (0.057 moles $^{15}\text{N m}^{-2}$) at the beginning of August, 2013. Low mass/fast turnover and high mass/slow turnover estimates were based on literature data (see Methods). Mass and C:N values are means (+/-1 S.E.).

Component	n	Post tracer (months)	Ambient Treatment					
			Mass (kg DW m^{-2})	Molar C:N	N mass (g m^{-2})	$\delta^{15}\text{N}$		
						min	max	mean
Green leaves	6	1	1.24 (0.196)	58.8 (2.9)	10.9 (1.9)	7.2	1296	507
	14	3	1.27 (0.121)	64.7 (3.4)	10.4 (1.3)	3.7	394	55.1
	8	10	1.27 (0.171)	56.5 (1.3)	11.0 (1.5)	18.4	1152	337
Standing litter	3	1 week	0.43 (0.014)	126.6 (9.8)	1.8 (0.2)	1107	14156	6519
	3	1	0.43 (0.014)	88.0 (2.2)	2.6 (0.04)	1021	11348	4918
	3	3	0.43 (0.014)	64.1 (5.5)	3.9 (0.1)	1033	5794	4013
Sediment	3	1	6.39 (1.53)	31.8 (1.2)	14.5 (2.6)	30.8	1246	520
	3	3	5.59 (1.23)	30.5 (0.8)	22.1 (1.2)	81.2	1077	504
Fine roots	3	10	8.53 (2.67)	74.1 (3.4)	57.7 (16.6)	263	554	392
Range of total mass			11.7 to 21.0		64 to 115			

Table 3-3. Mass and N content of measured ecosystem components in fringe mangrove plots receiving nutrient enrichment treatment (1 L local channel water with 0.209 moles NH_4Cl every-other week for 21 months), with one dose of $(^{15}\text{NH}_4)_2\text{SO}_4$ tracer (0.159 moles $^{15}\text{N m}^{-2}$) at the beginning of August, 2013. Low mass/fast turnover and high mass/slow turnover estimates were based on literature data (see Methods). The $\delta^{15}\text{N}$ values hold for either mass estimate. Mass and C:N values are means (1 S.E.).

Component	<i>n</i>	Post tracer (months)	Enriched Treatment			$\delta^{15}\text{N}$		
			Mass (kg DW m^{-2})	Molar C:N	N mass (g m^{-2})	min	max	mean
Green leaves	8	1	1.10 (0.07)	52.1 (1.8)	11.2 (1.0)	10.4	3628	666
	16	3	1.11 (0.05)	57.7 (3.6)	10.4 (0.8)	8.5	2338	571
	13	10	1.01 (0.05)	55.1 (2.7)	9.6 (0.9)	161	7245	1647
Standing litter	3	1 week	0.45 (0.02)	117.8 (5.2)	2.0 (0.03)	6122	18998	13966
	3	1	0.45 (0.02)	73.9 (10.0)	3.2 (0.2)	9591	12689	11154
	3	3	0.45 (0.02)	52.3 (1.5)	4.3 (0.4)	3277	5765	4404
Sediment	2	1	6.91 (1.81)	33.1 (1.0)	19.1 (2.8)	327	1387	877
	3	3	6.94 (1.15)	33.7 (1.7)	27.4 (2.3)	283	2332	900
Fine roots	4	10	7.70 (1.48)	87.6 (12.5)	47.3 (13.9)	611	3128	1801
Range of total mass			12.7 to 18.9		60 to 108			

Table 3-4. Analysis of variance results for $\delta^{15}\text{N}$ values in measured main N pools of a fringe mangrove. Factors are nutrient treatment (ambient, fertilized) and time since ^{15}N tracer was added (foliage and sediment: 1, 3, 10 months; standing litter: 1 week, 1 month, 3 months), with a randomized blocking effect. Fine roots were only sampled at 10 months following tracer addition. $\delta^{15}\text{N}$ were $\log_{10}$ -transformed to account for high variability of $\delta^{15}\text{N}$ values.

N pool component	Factor	df	Sum Sq.	Mean Sq.	F	P
Foliage	Treatment	2	4.605	4.605	10.08	0.0024 **
	Time	2	7.417	3.709	8.12	0.0008 ***
	Treatment*Time	2	1.611	0.805	1.76	0.1808
Standing litter	Treatment	1	0.427	0.427	4.02	0.0680
	Time	4	0.517	0.129	1.22	0.3535
	Treatment*Time	3	0.131	0.044	0.41	0.7478
Sediment	Treatment	1	0.905	0.905	7.36	0.0134 *
	Time	2	0.031	0.016	0.13	0.8814
	Treatment*Time	2	0.253	0.127	1.03	0.3756
Fine roots	Treatment	1	0.652	0.652	10.18	0.0242 *

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Figure 3-1. Values of $\delta^{15}\text{N}$ of individual tree foliage at three sampling intervals after ^{15}N tracer was applied. (A) Ambient nutrient conditions, receiving 1 L channel water every-other week for 21 months before ^{15}N tracer; (B) Chronically enriched nutrient conditions, receiving 1 L channel water with NH_4Cl fertilizer (loading rate 70 g N m^{-2}) before ^{15}N tracer. Individual trees were located within experimental blocks separated at least 100 m apart. Note log scale of y-axis.

Figure 3-2. Frequency of $\delta^{15}\text{N}$ value categories from tree foliage at three sampling intervals after ^{15}N tracer was applied. (A) Ambient nutrient conditions, receiving 1 L channel water every-other week for 21 months before ^{15}N tracer; (B) Chronically enriched nutrient conditions, receiving 1 L channel water with NH_4Cl fertilizer (loading rate 70 g N m^{-2}) before ^{15}N tracer. Experimental blocks were combined by treatment.

Table 3-5. ^{15}N tracer retention (mg m^{-2}) within measured ecosystem components in fringe mangrove plots receiving ambient treatment (1 L local channel water) or nutrient enrichment (1 L local channel water with 0.209 moles NH_4Cl) every-other week for 21 to 24 months, with one dose of $(^{15}\text{NH}_4)_2\text{SO}_4$ tracer (ambient: $0.43 \text{ g } ^{15}\text{N m}^{-2}$; enriched: $2.38 \text{ g } ^{15}\text{N m}^{-2}$) at the beginning of August, 2013. Nutrient enrichment ended October 2013. Recovery values are means (± 1 S.E.). The sum of components for May 2014 (italicized) assumed standing litter and top sediment ^{15}N recovery was equivalent to samples from October 2013.

Ecosystem component	Aug. 2013		Oct. 2013		May 2014	
	1 month post ^{15}N addition		3 months post ^{15}N addition		10 months post ^{15}N additon	
	Ambient	Enriched	Ambient	Enriched	Ambient	Enriched
Green leaves	16.0 (6.7)	39.4 (27.9)	1.3 (0.5)	27.8 (11.1)	11.4 (3.4)	58.1 (13.5)
Standing litter	46.7 (30.1)	151.4 (12.6)	59.5 (22.5)	80.2 (13.6)	ND	ND
Top sediment (0-2 cm)	19.9 (6.7)	71.5 (27.2)	38.5 (9.1)	102.0 (35.5)	ND	ND
Fine roots	ND	ND	ND	ND	20.4 (8.1)	12.1 (1.8)
Sum of components	82.6 (43.5)	262.3 (67.7)	99.3 (32.1)	210.0 (60.2)	<i>129.8 (43.1)</i>	<i>252.4 (64.4)</i>

Table 3-6. Percent recovery of applied ^{15}N within measured ecosystem components in fringe mangrove plots receiving ambient treatment (1 L local channel water) or nutrient enrichment (1 L local channel water with 0.209 moles NH_4Cl) every-other week for 21 to 24 months, with one dose of $(^{15}\text{NH}_4)_2\text{SO}_4$ tracer (ambient: $0.43 \text{ g } ^{15}\text{N m}^{-2}$; enriched: $2.38 \text{ g } ^{15}\text{N m}^{-2}$) at the beginning of August, 2013. Nutrient enrichment ended October 2013. Recovery values are means (± 1 S.E.). The sum of components for May 2014 (italicized) assumed standing litter and top sediment ^{15}N recovery was equivalent to samples from October 2013.

Ecosystem component	Aug. 2013		Oct. 2013		May 2014	
	1 month post ^{15}N addition		3 months post ^{15}N addition		10 months post ^{15}N additon	
	Control	Fertilized	Control	Fertilized	Control	Fertilized
Green leaves	3.7 (1.6)	1.7 (1.2)	0.3 (0.1)	1.2 (0.5)	2.7 (0.8)	2.4 (0.6)
Standing litter	10.9 (7.0)	6.4 (0.5)	13.8 (5.2)	3.4 (0.5)	ND	ND
Top sediment (0-2 cm)	4.6 (1.6)	3.0 (1.1)	8.9 (2.1)	4.3 (1.5)	ND	ND
Fine roots	ND	ND	ND	ND	20.4 (8.1)	12.1 (1.8)
Sum of components	19.2 (10.2)	11.1 (2.8)	23.0 (7.4)	8.9 (2.5)	<i>45.8 (16.2)</i>	<i>22.2 (4.4)</i>

Figure 3-3. Percent ^{15}N tracer retention at 1, 3, and 10 month time points after ^{15}N tracer addition. (A) Ambient nutrient conditions, receiving 1 L channel water every-other week for 21 months before ^{15}N tracer; (B) Chronically enriched nutrient conditions, receiving 1 L channel water with NH_4Cl fertilizer (loading rate 70 g N m^{-2}) before ^{15}N tracer. Fine roots were only measured at 10 months following ^{15}N tracer addition. Standing litter and top sediment were not measured at the 10 month sampling point; the values from the 3 month period was used for comparison among all components.

Appendix A: Supplemental tables and figures

Figure A.1 Monthly total precipitation (mm) during the experimental time period (October 2011 to 2013). Source: Jobos Bay National Estuarine Research Reserve; NOAA Centralized Data Management Office; <http://cdmo.baruch.sc.edu>

Figure A.2 Monthly average temperature (average, minimum, and maximum) at the Jobos Bay National Estuarine Research Reserve from 2007 to 2014. Data source: NOAA-NERR Centralized Data Management Office; <http://cdmo.baruch.sc.edu>

Figure A.3 Topography measurements for sections 1, 2, and 3, with experimental unit locations within each section. Two east-west transects were measured along the southern and northern boundaries of each section using two graduated poles and a hand level. Note that “0” is a relative point within a section (the starting height of the first pole location) and not necessarily the same absolute height between sections. The sections were located parallel to the coastline, approximately 5 m inland.

Figure A.4 Average high water levels of each quadrat in (A) March and (B) October, 2012, which represent the lowest and highest tidal ranges within a year (Field, 2008). High water levels were measured using water-based dye and glue and graduated poles.

Figure A.5 Average monthly DIN concentrations during the first year of the experiment (October 2011 to October 2012) at Station 20, located at the southeastern mouth of Jobos Bay and upstream of the mangrove nutrient enrichment sites. Data source: NOAA Centralized Data Management Office; <http://cdmo.baruch.sc.edu>

Figure A.6 Inorganic nutrient measurements from samples collected at Jobos Bay National Estuarine Research Reserve monitoring stations in January, 2013. Samples were collected in acid-washed opaque bottles and immediately frozen until analysis.

Treatment	Sample	NH ₄ ⁺	NO ₂ & NO ₃	Total DIN	Ortho-PO ₄	N:P
Control	1	6.42	3.85	10.27	2.86	3.59
	2	7.22	3.03	10.25	4.45	2.30
	3	9.02	1.08	10.10	4.79	2.11
Average (S.E.)		7.55 (0.77)	2.65 (0.82)	10.21 (0.05)	4.03 (0.59)	2.67 (0.47)
Urban	1	15.60	3.52	19.12	15.60	1.23
	2	11.61	2.91	14.52	11.61	1.25
	3	18.40	1.27	19.67	18.40	1.07
Average (S.E.)		15.20 (1.97)	2.57 (0.67)	17.77 (1.63)	15.20 (1.97)	1.18 (0.06)

Figure A.7 Inorganic nutrient concentrations in flood waters that are overlying the control and urban nutrient enriched quadrats at block 2. These samples were taken at slack high tide in January, 2012, 14 days after the previous nutrient spray. Samples were frozen until analyzed.

Figure A.8 Fresh-to-dry weight ratios of standing leaf litter collected in areas closely surrounding the experimental sites. Approximately 50 leaves were collected per block, rinsed with distilled water, air dried, and weighed (“fresh weight”) before drying at 45 C° for a final “dry weight.” A linear regression was used to determine the fresh-to-dry ratio for calculating final dry mass of collected decomposed litter into fresh weight for a comparison with initial mass (See Ch. 1, Methods).

Figure A.9 Sediment respiration rates ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) compared with (A) surface sediment (1 to 2 cm) temperature and (B) crab burrow area of the quadrat. Sediment respiration was measured with an infra-red gas analyzer. Soil temperature was measured with a temperature probe. Crab burrows were measured by counting and measuring the diameter of all crab burrows within a 20x20 cm quadrat, and scaling to the quadrat area (4 m^2).

Appendix B: Litterfall data

Litterfall collection and processing is described in the Methods section of Chapter 2. Briefly, two litter collection baskets (0.25 m^2) per quadrat were harvested every-other week during the study period. Recovered litter was sorted into components (leaves, propagules and flowers, stipules, wood, miscellaneous), dried, and weighed. All values reported here are $\text{g dry mass m}^{-2} \text{ d}^{-1}$.

Date	Block	Treatment	Basket	Propagules &		Stipules	Wood	Misc	Total litterfall
				Leaves	Flowers				
10/6/2011	1	Agriculture	1	1.44	0.31	0.24	0.00	0.32	2.31
10/6/2011	1	Agriculture	2	1.00	0.17	0.46	0.00	0.38	2.01
10/6/2011	2	Agriculture	1	1.49	0.16	0.28	0.00	0.11	2.03
10/6/2011	2	Agriculture	2	1.84	0.29	0.20	0.00	0.15	2.48
10/6/2011	3	Agriculture	1	3.09	0.00	0.00	0.00	0.00	3.09
10/6/2011	3	Agriculture	2	4.30	0.93	0.22	0.16	0.07	5.67
10/6/2011	1	Control	1	1.58	0.18	0.26	0.00	0.08	2.10
10/6/2011	1	Control	2	1.44	0.00	0.14	0.00	0.00	1.59
10/6/2011	2	Control	1	1.95	0.44	0.25	0.00	0.26	2.90
10/6/2011	2	Control	2	1.80	0.27	0.23	0.00	0.24	2.54
10/6/2011	3	Control	1	2.53	1.51	0.21	0.00	0.07	4.31
10/6/2011	3	Control	2	1.50	3.23	0.23	0.00	0.14	5.10
10/6/2011	1	Urban	1	1.68	0.96	0.09	0.27	0.10	3.09
10/6/2011	1	Urban	2	0.16	0.18	0.00	0.00	0.16	0.50
10/6/2011	2	Urban	1	1.15	0.49	0.23	0.00	0.20	2.07
10/6/2011	2	Urban	2	1.69	0.52	0.22	0.00	0.70	3.12
10/6/2011	3	Urban	1	2.02	0.45	0.06	0.00	0.22	2.75
10/6/2011	3	Urban	2	1.89	1.01	0.25	0.00	0.23	3.38
10/27/2011	1	Agriculture	1	3.22	0.06	0.29	0.00	0.15	3.73
10/27/2011	1	Agriculture	2	2.02	0.19	0.08	0.07	0.07	2.42
10/27/2011	2	Agriculture	1	1.51	0.17	0.10	0.00	0.12	1.89
10/27/2011	2	Agriculture	2						
10/27/2011	3	Agriculture	1	1.55	0.49	0.28	0.00	0.12	2.44
10/27/2011	3	Agriculture	2	2.11	0.32	0.24	0.29	0.27	3.24
10/27/2011	1	Control	1	1.84	0.32	0.13	0.00	0.04	2.33
10/27/2011	1	Control	2						
10/27/2011	2	Control	1						
10/27/2011	2	Control	2	2.23	0.12	0.11	0.00	0.13	2.58
10/27/2011	3	Control	1	1.20	0.09	0.21	0.00	0.06	1.56
10/27/2011	3	Control	2	1.23	0.17	0.17	0.00	0.10	1.68
10/27/2011	1	Urban	1						
10/27/2011	1	Urban	2	1.34	0.14	0.27	0.03	0.16	1.94
10/27/2011	2	Urban	1	1.64	0.55	0.14	0.00	0.27	2.60
10/27/2011	2	Urban	2	1.46	0.44	0.14	0.00	0.26	2.30
10/27/2011	3	Urban	1	1.54	0.08	0.10	1.20	0.08	3.00
10/27/2011	3	Urban	2	1.16	0.19	0.19	1.13	0.12	2.79
11/10/2011	1	Agriculture	1	4.55	1.04	0.29	0.00	0.14	6.03
11/10/2011	1	Agriculture	2	1.85	0.00	0.27	0.00	0.03	2.15
11/10/2011	2	Agriculture	1	1.02	0.04	0.08	0.04	0.04	1.22
11/10/2011	2	Agriculture	2	1.76	0.05	0.19	0.00	0.16	2.15
11/10/2011	3	Agriculture	1	1.83	0.11	0.23	0.00	0.19	2.35

Date	Block	Treatment	Basket	Propagules &					Total
				Leaves	Flowers	Stipules	Wood	Misc	
11/10/2011	3	Agriculture	2	2.86	0.21	0.17	0.00	0.38	3.62
11/10/2011	1	Control	1	1.63	0.04	0.26	0.00	0.07	1.99
11/10/2011	1	Control	2	1.79	0.21	0.42	0.02	0.10	2.54
11/10/2011	2	Control	1						
11/10/2011	2	Control	2	1.15	0.10	0.17	0.00	0.14	1.56
11/10/2011	3	Control	1	2.86	0.03	0.04	0.00	0.02	2.94
11/10/2011	3	Control	2	2.03	0.21	0.36	0.02	0.23	2.85
11/10/2011	1	Urban	1						
11/10/2011	1	Urban	2	1.23	0.07	0.24	0.03	0.09	1.66
11/10/2011	2	Urban	1	1.47	0.43	0.10	0.03	0.18	2.20
11/10/2011	2	Urban	2	1.62	0.47	0.10	0.00	0.33	2.52
11/10/2011	3	Urban	1	2.53	0.00	0.15	0.00	0.24	2.91
11/10/2011	3	Urban	2	1.51	0.04	0.24	0.00	0.07	1.86
12/6/2011	1	Agriculture	1	0.59	0.09	0.12	0.00	0.07	0.88
12/6/2011	1	Agriculture	2	0.33	0.02	0.04	0.00	0.05	0.45
12/6/2011	2	Agriculture	1	0.31	0.00	0.10	0.00	0.01	0.42
12/6/2011	2	Agriculture	2	0.40	0.10	0.08	0.00	0.05	0.62
12/6/2011	3	Agriculture	1	1.33	0.08	0.12	0.00	0.13	1.66
12/6/2011	3	Agriculture	2	1.31	0.07	0.13	0.00	0.16	1.68
12/6/2011	1	Control	1	1.06	0.01	0.06	0.00	0.05	1.17
12/6/2011	1	Control	2	0.49	0.04	0.05	0.00	0.04	0.63
12/6/2011	2	Control	1	0.85	0.15	0.08	0.00	0.33	1.40
12/6/2011	2	Control	2	0.53	0.18	0.11	0.00	0.14	0.96
12/6/2011	3	Control	1	0.69	0.00	0.05	0.00	0.03	0.77
12/6/2011	3	Control	2	0.63	0.02	0.16	0.00	0.07	0.88
12/6/2011	1	Urban	1	0.41	0.00	0.18	0.00	0.07	0.66
12/6/2011	1	Urban	2	0.41	0.02	0.09	0.02	0.07	0.60
12/6/2011	2	Urban	1	0.87	0.05	0.13	0.00	0.12	1.17
12/6/2011	2	Urban	2	0.38	0.06	0.10	0.00	0.11	0.64
12/6/2011	3	Urban	1	0.51	0.12	0.03	0.18	0.07	0.91
12/6/2011	3	Urban	2	0.28	0.06	0.13	0.03	0.04	0.54
12/22/2011	1	Agriculture	1	1.59	0.15	0.13	0.00	0.12	1.98
12/22/2011	1	Agriculture	2	1.21	0.00	0.02	0.01	0.12	1.36
12/22/2011	2	Agriculture	1	1.12	0.14	0.14	0.00	0.04	1.44
12/22/2011	2	Agriculture	2						
12/22/2011	3	Agriculture	1	1.58	0.46	0.12	0.01	0.16	2.33
12/22/2011	3	Agriculture	2	2.22	0.88	0.12	0.00	0.15	3.37
12/22/2011	1	Control	1	0.56	0.00	0.13	0.06	0.05	0.80
12/22/2011	1	Control	2						
12/22/2011	2	Control	1	1.96	0.10	0.08	0.02	0.08	2.24

Date	Block	Treatment	Basket	Propagules &					Total
				Leaves	Flowers	Stipules	Wood	Misc	
12/22/2011	2	Control	2	1.80	0.11	0.06	0.00	0.07	2.03
12/22/2011	3	Control	1	1.64	0.00	0.16	0.08	0.14	2.01
12/22/2011	3	Control	2	1.94	0.21	0.08	0.00	0.17	2.39
12/22/2011	1	Urban	1	0.85	0.26	0.14	0.00	0.14	1.40
12/22/2011	1	Urban	2	1.03	0.14	0.15	0.00	0.13	1.45
12/22/2011	2	Urban	1	1.39	0.05	0.12	0.00	0.02	1.58
12/22/2011	2	Urban	2	0.83	0.33	0.02	0.00	0.10	1.27
12/22/2011	3	Urban	1	0.33	0.00	0.02	0.00	0.06	0.40
12/22/2011	3	Urban	2	1.31	0.23	0.04	0.00	0.03	1.60
3/10/2012	1	Agriculture	1	0.58	0.00	0.13	0.00	0.00	0.71
3/10/2012	1	Agriculture	2	2.70	0.14	0.20	0.00	0.11	3.15
3/10/2012	2	Agriculture	1	0.97	0.50	0.13	0.00	0.05	1.65
3/10/2012	2	Agriculture	2	1.06	0.02	0.11	0.00	0.05	1.23
3/10/2012	3	Agriculture	1	2.20	0.17	0.20	0.00	0.08	2.64
3/10/2012	3	Agriculture	2	1.80	0.03	0.01	0.00	0.03	1.87
3/10/2012	1	Control	1	1.35	0.02	0.22	0.01	0.02	1.61
3/10/2012	1	Control	2	0.89	0.06	0.21	0.34	0.12	1.61
3/10/2012	2	Control	1	1.24	0.19	0.06	0.00	0.11	1.60
3/10/2012	2	Control	2	1.06	0.00	0.00	0.00	0.00	1.06
3/10/2012	3	Control	1	2.13	0.47	0.04	0.15	0.07	2.85
3/10/2012	3	Control	2	1.57	0.06	0.01	0.00	0.04	1.68
3/10/2012	1	Urban	1	2.05	0.00	0.11	0.04	0.03	2.23
3/10/2012	1	Urban	2	1.99	0.00	0.06	0.00	0.04	2.09
3/10/2012	2	Urban	1	1.14	0.06	0.03	0.19	0.07	1.50
3/10/2012	2	Urban	2	1.44	0.37	0.06	0.01	0.10	1.98
3/10/2012	3	Urban	1	3.23	0.02	0.07	0.05	0.04	3.42
3/10/2012	3	Urban	2	1.26	0.18	0.03	0.00	0.01	1.48
3/15/2012	1	Agriculture	1	0.66	0.07	0.09	0.02	0.08	0.93
3/15/2012	1	Agriculture	2	0.92	0.00	0.10	0.00	0.22	1.24
3/15/2012	2	Agriculture	1	0.62	0.00	0.06	0.00	0.03	0.71
3/15/2012	2	Agriculture	2	0.31	0.00	0.03	2.03	0.13	2.50
3/15/2012	3	Agriculture	1	1.48	0.25	0.06	0.00	0.06	1.85
3/15/2012	3	Agriculture	2	1.40	0.08	0.00	0.00	0.16	1.64
3/15/2012	1	Control	1	2.72	0.00	0.00	0.00	0.02	2.74
3/15/2012	1	Control	2	1.46	0.10	0.00	0.04	0.10	1.70
3/15/2012	2	Control	1	1.14	0.00	0.00	0.00	0.41	1.54
3/15/2012	2	Control	2	2.14	0.00	0.14	0.00	0.24	2.51
3/15/2012	3	Control	1	0.91	0.00	0.00	0.00	0.07	0.98
3/15/2012	3	Control	2	0.88	0.00	0.09	0.23	0.00	1.20
3/15/2012	1	Urban	1	0.26	0.00	0.00	0.01	0.12	0.39
3/15/2012	1	Urban	2	1.99	0.00	0.15	0.66	0.10	2.90

Date	Block	Treatment	Basket	Propagules &					Total
				Leaves	Flowers	Stipules	Wood	Misc	
3/15/2012	2	Urban	1	2.00	0.00	0.21	0.00	0.05	2.26
3/15/2012	2	Urban	2	3.18	0.00	0.17	0.00	0.34	3.69
3/15/2012	3	Urban	1	3.40	0.00	0.00	0.00	0.02	3.42
3/15/2012	3	Urban	2	0.98	0.00	0.12	0.00	0.10	1.21
3/29/2012	1	Agriculture	1	1.19	0.09	0.20	0.00	0.03	1.51
3/29/2012	1	Agriculture	2	1.62	0.17	0.04	0.00	0.05	1.87
3/29/2012	2	Agriculture	1	0.43	0.01	0.09	0.00	0.01	0.54
3/29/2012	2	Agriculture	2	0.79	0.00	0.05	0.00	0.00	0.83
3/29/2012	3	Agriculture	1	3.01	0.01	0.04	0.00	0.04	3.10
3/29/2012	3	Agriculture	2	2.13	0.14	0.23	0.00	0.00	2.50
3/29/2012	1	Control	1	0.48	0.44	0.00	0.00	0.05	0.97
3/29/2012	1	Control	2	0.97	0.11	0.02	0.00	0.07	1.17
3/29/2012	2	Control	1	1.64	0.04	0.04	0.00	0.03	1.75
3/29/2012	2	Control	2	1.06	0.45	0.09	0.00	0.01	1.62
3/29/2012	3	Control	1	0.57	0.00	0.16	0.00	0.11	0.84
3/29/2012	3	Control	2	1.36	0.42	0.05	0.00	0.09	1.92
3/29/2012	1	Urban	1	1.03	0.05	0.09	0.66	0.04	1.87
3/29/2012	1	Urban	2	1.53	0.03	0.06	0.01	0.00	1.63
3/29/2012	2	Urban	1	0.80	0.00	0.09	0.00	0.00	0.90
3/29/2012	2	Urban	2	0.95	0.00	0.07	0.00	0.02	1.04
3/29/2012	3	Urban	1	0.55	0.95	0.08	0.00	0.08	1.65
3/29/2012	3	Urban	2	1.06	0.02	0.15	0.00	0.00	1.23
4/12/2012	1	Agriculture	1	1.64	0.31	0.27	0.01	0.02	2.25
4/12/2012	1	Agriculture	2	1.38	0.09	0.07	0.00	0.19	1.73
4/12/2012	2	Agriculture	1	1.40	0.00	0.12	0.00	0.00	1.52
4/12/2012	2	Agriculture	2	1.25	0.00	0.34	0.00	0.00	1.58
4/12/2012	3	Agriculture	1	0.79	0.00	0.24	0.00	0.09	1.13
4/12/2012	3	Agriculture	2	3.43	0.00	0.40	0.00	0.09	3.91
4/12/2012	1	Control	1	0.77	0.03	0.01	0.00	0.00	0.81
4/12/2012	1	Control	2	0.66	0.02	0.05	0.01	0.00	0.73
4/12/2012	2	Control	1	1.59	0.00	0.07	0.78	0.00	2.44
4/12/2012	2	Control	2	2.51	0.27	0.11	0.00	0.07	2.96
4/12/2012	3	Control	1	0.95	0.00	0.33	0.03	0.01	1.33
4/12/2012	3	Control	2	1.12	0.07	0.22	0.01	0.22	1.64
4/12/2012	1	Urban	1	2.68	0.01	0.13	0.00	0.02	2.84
4/12/2012	1	Urban	2	1.69	0.00	0.07	0.00	0.00	1.76
4/12/2012	2	Urban	1	1.08	0.00	0.15	0.00	0.02	1.24
4/12/2012	2	Urban	2	1.43	0.06	0.26	0.00	0.05	1.80
4/12/2012	3	Urban	1	1.13	0.00	0.13	0.07	0.10	1.43
4/12/2012	3	Urban	2	0.69	0.00	0.16	0.00	0.04	0.88
4/25/2012	1	Agriculture	1	2.58	0.04	0.21	0.00	0.03	2.86

Date	Block	Treatment	Basket	Propagules &					Total
				Leaves	Flowers	Stipules	Wood	Misc	
4/25/2012	1	Agriculture	2	2.81	0.00	0.19	0.33	0.03	3.36
4/25/2012	2	Agriculture	1	2.51	0.00	0.30	0.00	0.04	2.84
4/25/2012	2	Agriculture	2	2.76	0.07	0.11	0.00	0.11	3.06
4/25/2012	3	Agriculture	1	3.38	0.24	0.27	0.00	0.10	3.99
4/25/2012	3	Agriculture	2	2.95	0.03	0.32	0.00	0.10	3.41
4/25/2012	1	Control	1	1.25	0.02	0.04	0.00	0.05	1.36
4/25/2012	1	Control	2	2.34	0.00	0.00	0.03	0.02	2.39
4/25/2012	2	Control	1	2.01	0.91	0.08	0.50	0.15	3.65
4/25/2012	2	Control	2	3.53	0.02	0.20	0.00	0.09	3.83
4/25/2012	3	Control	1	1.49	0.00	0.08	0.00	0.07	1.64
4/25/2012	3	Control	2	1.30	1.26	0.05	0.00	0.23	2.84
4/25/2012	1	Urban	1	1.43	0.96	0.06	0.03	0.08	2.57
4/25/2012	1	Urban	2	1.22	0.00	0.24	0.00	0.05	1.51
4/25/2012	2	Urban	1	2.54	0.03	0.20	0.00	0.17	2.94
4/25/2012	2	Urban	2	1.30	1.16	0.22	1.61	0.10	4.39
4/25/2012	3	Urban	1	3.83	0.00	0.09	0.10	0.34	4.36
4/25/2012	3	Urban	2	1.75	0.00	0.13	0.00	0.09	1.97
5/17/2012	1	Agriculture	1	3.43	0.00	0.65	0.00	0.11	4.19
5/17/2012	1	Agriculture	2	2.22	0.00	0.34	0.95	0.13	3.64
5/17/2012	2	Agriculture	1	2.51	0.00	0.33	0.00	0.04	2.88
5/17/2012	2	Agriculture	2	2.32	0.04	0.54	0.00	0.11	3.01
5/17/2012	3	Agriculture	1	4.78	0.03	0.63	0.08	0.17	5.69
5/17/2012	3	Agriculture	2	2.39	0.09	0.37	0.07	0.04	2.96
5/17/2012	1	Control	1	1.86	0.00	0.64	0.00	0.05	2.56
5/17/2012	1	Control	2	3.14	0.05	0.51	0.83	0.07	4.60
5/17/2012	2	Control	1	2.97	2.29	0.44	0.11	0.21	6.01
5/17/2012	2	Control	2	4.06	0.00	0.22	0.00	0.07	4.35
5/17/2012	3	Control	1	2.92	0.25	0.27	0.00	0.04	3.48
5/17/2012	3	Control	2	2.83	0.55	0.38	0.00	0.16	3.92
5/17/2012	1	Urban	1	2.11	0.00	0.34	0.00	0.12	2.57
5/17/2012	1	Urban	2	2.22	0.00	0.43	0.00	0.14	2.79
5/17/2012	2	Urban	1	2.24	0.02	0.55	0.00	0.14	2.95
5/17/2012	2	Urban	2	2.09	0.06	0.47	0.00	0.25	2.87
5/17/2012	3	Urban	1	4.47	0.00	0.27	0.07	0.09	4.88
5/17/2012	3	Urban	2	2.72	0.01	0.39	0.00	0.08	3.20
5/31/2012	1	Agriculture	1	2.79	0.03	0.37	0.16	0.04	3.38
5/31/2012	1	Agriculture	2	3.00	0.02	0.14	0.00	0.10	3.26
5/31/2012	2	Agriculture	1	1.50	0.40	0.32	0.00	0.12	2.34
5/31/2012	2	Agriculture	2	1.81	0.00	0.32	0.63	0.10	2.85
5/31/2012	3	Agriculture	1	3.26	0.28	0.45	0.02	0.38	4.38
5/31/2012	3	Agriculture	2	2.80	0.17	0.49	0.06	0.29	3.81

Date	Block	Treatment	Basket	Propagules &					Total
				Leaves	Flowers	Stipules	Wood	Misc	
5/31/2012	1	Control	1	0.75	0.00	0.53	0.00	0.05	1.33
5/31/2012	1	Control	2	1.81	2.22	0.49	0.19	0.10	4.81
5/31/2012	2	Control	1	3.25	1.03	0.31	0.00	0.47	5.07
5/31/2012	2	Control	2	2.04	0.01	0.16	0.00	0.23	2.43
5/31/2012	3	Control	1	1.88	0.43	0.14	0.26	0.25	2.95
5/31/2012	3	Control	2	1.79	0.00	0.26	0.00	0.13	2.18
5/31/2012	1	Urban	1	2.73	0.00	0.23	0.00	0.08	3.04
5/31/2012	1	Urban	2	3.66	2.76	0.25	0.00	0.13	6.79
5/31/2012	2	Urban	1	1.72	0.00	0.30	0.00	0.05	2.07
5/31/2012	2	Urban	2	3.49	0.01	0.37	0.00	0.07	3.95
5/31/2012	3	Urban	1	7.31	0.02	0.17	0.00	0.39	7.90
5/31/2012	3	Urban	2	3.85	0.05	0.27	0.00	0.18	4.35
6/13/2012	1	Agriculture	1	4.90	0.95	0.18	0.00	0.05	6.08
6/13/2012	1	Agriculture	2	2.92	0.00	0.23	0.00	0.05	3.20
6/13/2012	2	Agriculture	1	3.16	0.00	0.14	0.00	0.00	3.30
6/13/2012	2	Agriculture	2	1.94	0.00	0.32	0.04	0.00	2.30
6/13/2012	3	Agriculture	1						
6/13/2012	3	Agriculture	2	3.39	0.17	0.42	0.00	0.00	3.98
6/13/2012	1	Control	1	1.79	0.00	0.00	0.00	0.00	1.79
6/13/2012	1	Control	2	1.86	1.55	0.15	0.00	0.06	3.62
6/13/2012	2	Control	1	3.66	7.75	0.15	0.09	0.18	11.83
6/13/2012	2	Control	2	3.63	0.00	0.13	0.00	0.05	3.82
6/13/2012	3	Control	1	1.86	0.00	0.12	0.00	0.19	2.17
6/13/2012	3	Control	2	2.21	0.86	0.27	0.00	0.00	3.34
6/13/2012	1	Urban	1	2.78	0.81	0.21	0.00	0.09	3.89
6/13/2012	1	Urban	2	2.91	0.07	0.22	0.00	0.00	3.20
6/13/2012	2	Urban	1	2.18	0.00	0.10	0.05	0.11	2.45
6/13/2012	2	Urban	2	2.02	0.04	0.18	0.00	0.08	2.32
6/13/2012	3	Urban	1	5.37	0.00	0.02	4.62	0.00	10.01
6/13/2012	3	Urban	2	3.42	0.03	0.21	0.04	0.02	3.72
6/27/2012	1	Agriculture	1	4.20	0.80	0.54	0.00	0.25	5.79
6/27/2012	1	Agriculture	2	4.41	0.00	0.33	0.03	0.40	5.17
6/27/2012	2	Agriculture	1	2.63	0.43	0.33	0.00	0.03	3.43
6/27/2012	2	Agriculture	2	3.13	2.00	0.53	0.00	0.04	5.70
6/27/2012	3	Agriculture	1	2.80	0.18	0.31	0.00	0.30	3.60
6/27/2012	3	Agriculture	2	5.15	0.55	0.51	0.00	0.35	6.55
6/27/2012	1	Control	1	1.94	0.00	0.26	0.00	0.05	2.25
6/27/2012	1	Control	2	3.97	0.03	0.28	0.02	0.12	4.42
6/27/2012	2	Control	1	2.31	11.87	0.09	0.00	0.52	14.79
6/27/2012	2	Control	2	2.58	2.14	0.11	0.00	0.27	5.09
6/27/2012	3	Control	1	2.71	0.00	0.35	0.01	0.03	3.10

Date	Block	Treatment	Basket	Propagules &					Total
				Leaves	Flowers	Stipules	Wood	Misc	
6/27/2012	3	Control	2	3.50	0.38	0.28	0.00	0.04	4.20
6/27/2012	1	Urban	1	2.97	0.93	0.18	0.27	0.15	4.50
6/27/2012	1	Urban	2	3.32	2.67	0.19	0.02	0.15	6.35
6/27/2012	2	Urban	1	2.81	1.73	0.20	0.01	0.04	4.79
6/27/2012	2	Urban	2	3.36	2.67	0.28	0.00	0.11	6.41
6/27/2012	3	Urban	1	4.65	0.73	0.10	0.03	0.16	5.66
6/27/2012	3	Urban	2	2.99	0.03	0.24	0.00	0.29	3.54
7/13/2012	1	Agriculture	1	4.66	0.27	0.40	0.06	0.21	5.59
7/13/2012	1	Agriculture	2	5.18	0.03	0.14	0.00	0.12	5.46
7/13/2012	2	Agriculture	1	3.37	2.31	0.40	0.06	0.02	6.15
7/13/2012	2	Agriculture	2	3.52	3.51	0.33	0.00	0.11	7.47
7/13/2012	3	Agriculture	1	2.91	1.30	0.32	1.23	0.33	6.09
7/13/2012	3	Agriculture	2	2.09	1.43	0.37	0.00	0.25	4.13
7/13/2012	1	Control	1	2.28	0.00	0.17	0.00	0.04	2.49
7/13/2012	1	Control	2	4.29	0.48	0.21	0.02	0.19	5.18
7/13/2012	2	Control	1	2.84	5.70	0.23	0.26	0.25	9.27
7/13/2012	2	Control	2	4.24	0.89	0.19	0.00	0.08	5.39
7/13/2012	3	Control	1	0.57	0.09	0.05	0.00	0.07	0.78
7/13/2012	3	Control	2						
7/13/2012	1	Urban	1						
7/13/2012	1	Urban	2	3.99	6.05	0.17	1.26	0.16	11.63
7/13/2012	2	Urban	1	2.63	1.31	0.13	0.00	0.27	4.34
7/13/2012	2	Urban	2	2.30	3.59	0.18	0.00	0.12	6.19
7/13/2012	3	Urban	1	2.49	0.03	0.09	0.06	0.06	2.72
7/13/2012	3	Urban	2	2.15	2.92	0.31	0.00	0.16	5.53
7/26/2012	1	Agriculture	1	4.11	0.39	0.25	0.00	0.72	5.47
7/26/2012	1	Agriculture	2	4.86	0.00	0.36	0.06	0.56	5.84
7/26/2012	2	Agriculture	1	1.85	0.54	0.21	0.00	0.33	2.92
7/26/2012	2	Agriculture	2	3.34	0.43	0.19	0.00	0.62	4.58
7/26/2012	3	Agriculture	1	3.23	0.35	0.28	0.30	0.69	4.85
7/26/2012	3	Agriculture	2	5.31	4.05	0.15	0.00	2.51	12.02
7/26/2012	1	Control	1	1.70	0.76	0.06	0.00	0.57	3.10
7/26/2012	1	Control	2	5.07	1.33	0.15	0.00	0.75	7.30
7/26/2012	2	Control	1	3.63	6.30	0.05	0.10	0.97	11.06
7/26/2012	2	Control	2	2.06	5.18	0.14	0.00	0.31	7.69
7/26/2012	3	Control	1	2.46	2.92	0.18	0.00	0.26	5.84
7/26/2012	3	Control	2	4.37	1.13	0.21	0.00	0.59	6.29
7/26/2012	1	Urban	1	2.80	6.83	0.07	0.00	0.44	10.14
7/26/2012	1	Urban	2	2.64	3.42	0.07	0.00	0.68	6.81
7/26/2012	2	Urban	1	1.78	6.06	0.06	0.10	0.34	8.33
7/26/2012	2	Urban	2	3.13	15.78	0.07	0.00	0.73	19.71

Date	Block	Treatment	Basket	Propagules &					Total
				Leaves	Flowers	Stipules	Wood	Misc	
7/26/2012	3	Urban	1	1.34	0.25	0.23	0.00	0.54	2.36
7/26/2012	3	Urban	2	3.52	0.03	0.03	0.00	0.67	4.25
8/9/2012	1	Agriculture	1	2.99	0.42	0.31	0.00	0.31	4.03
8/9/2012	1	Agriculture	2	3.83	0.12	0.22	0.00	0.18	4.36
8/9/2012	2	Agriculture	1	2.09	0.33	0.28	0.73	0.10	3.53
8/9/2012	2	Agriculture	2	1.71	2.56	0.21	0.00	0.08	4.57
8/9/2012	3	Agriculture	1	2.83	1.23	0.50	0.15	0.18	4.88
8/9/2012	3	Agriculture	2	3.87	0.74	0.50	0.15	0.75	6.00
8/9/2012	1	Control	1	3.65	0.05	0.45	0.00	0.11	4.26
8/9/2012	1	Control	2	3.51	1.42	0.19	0.00	0.31	5.44
8/9/2012	2	Control	1	2.57	12.50	0.24	0.00	0.55	15.85
8/9/2012	2	Control	2	2.40	2.22	0.21	0.00	0.17	5.00
8/9/2012	3	Control	1	0.37	0.19	0.15	0.00	0.11	0.82
8/9/2012	3	Control	2	3.29	0.74	0.11	0.00	0.15	4.29
8/9/2012	1	Urban	1	2.27	0.96	0.17	0.00	0.14	3.53
8/9/2012	1	Urban	2	2.59	4.70	0.16	0.00	0.18	7.63
8/9/2012	2	Urban	1	3.12	14.24	0.16	0.37	0.55	18.44
8/9/2012	2	Urban	2	1.72	12.01	0.22	0.00	0.54	14.49
8/9/2012	3	Urban	1	1.59	0.02	0.12	0.00	0.12	1.86
8/9/2012	3	Urban	2	1.31	0.23	0.15	0.43	0.22	2.33
8/21/2012	1	Agriculture	1	4.10	0.41	0.19	0.00	0.29	4.98
8/21/2012	1	Agriculture	2	4.85	0.16	0.29	0.00	0.14	5.44
8/21/2012	2	Agriculture	1	2.21	0.11	0.22	0.00	0.11	2.65
8/21/2012	2	Agriculture	2	3.33	0.61	0.28	2.82	0.11	7.15
8/21/2012	3	Agriculture	1	2.99	0.56	0.64	0.00	0.15	4.35
8/21/2012	3	Agriculture	2	2.90	1.21	0.39	0.00	0.95	5.45
8/21/2012	1	Control	1	3.27	3.63	0.40	0.00	0.04	7.33
8/21/2012	1	Control	2	2.04	2.01	0.17	0.06	0.39	4.66
8/21/2012	2	Control	1	2.92	9.64	0.29	0.00	0.70	13.55
8/21/2012	2	Control	2	2.36	0.04	0.25	0.00	0.17	2.82
8/21/2012	3	Control	1	1.36	0.10	0.20	0.00	0.12	1.79
8/21/2012	3	Control	2	1.97	0.29	0.32	0.00	0.22	2.81
8/21/2012	1	Urban	1	1.83	0.88	0.20	0.39	0.25	3.54
8/21/2012	1	Urban	2	1.21	3.01	0.18	0.00	0.14	4.53
8/21/2012	2	Urban	1	2.31	16.92	0.19	0.00	0.35	19.77
8/21/2012	2	Urban	2	2.47	19.30	0.18	0.00	0.48	22.42
8/21/2012	3	Urban	1	1.54	0.02	0.12	0.04	0.15	1.86
8/21/2012	3	Urban	2	2.07	0.31	0.50	0.00	0.12	3.01
9/10/2012	1	Agriculture	1	3.48	3.47	0.17	0.99	0.56	8.67
9/10/2012	1	Agriculture	2	3.84	0.22	0.32	0.87	0.40	5.64
9/10/2012	2	Agriculture	1	1.50	0.35	0.28	0.12	0.40	2.66

Date	Block	Treatment	Basket	Propagules &					Total
				Leaves	Flowers	Stipules	Wood	Misc	
9/10/2012	2	Agriculture	2	2.11	0.26	0.29	0.00	0.38	3.04
9/10/2012	3	Agriculture	1	1.94	0.41	0.15	0.02	0.34	2.86
9/10/2012	3	Agriculture	2	2.52	1.31	0.29	0.00	0.68	4.81
9/10/2012	1	Control	1	1.74	0.15	0.27	0.00	0.29	2.45
9/10/2012	1	Control	2	2.75	0.60	0.16	0.45	0.57	4.53
9/10/2012	2	Control	1	2.19	5.92	0.29	0.21	0.63	9.24
9/10/2012	2	Control	2	2.33	0.91	0.28	0.07	0.28	3.87
9/10/2012	3	Control	1	1.64	0.13	0.14	0.00	0.26	2.16
9/10/2012	3	Control	2	1.46	0.15	0.29	1.81	0.66	4.37
9/10/2012	1	Urban	1	2.22	10.51	0.25	1.01	0.34	14.33
9/10/2012	1	Urban	2	2.46	0.04	0.23	0.26	0.43	3.42
9/10/2012	2	Urban	1	3.49	10.28	0.27	0.00	0.47	14.51
9/10/2012	2	Urban	2	2.58	11.59	0.19	2.92	0.45	17.73
9/10/2012	3	Urban	1	1.48	0.11	0.15	0.03	0.35	2.12
9/10/2012	3	Urban	2	2.89	0.15	0.26	3.40	0.41	7.11
9/24/2012	1	Agriculture	1	3.30	0.66	0.24	1.13	0.35	5.67
9/24/2012	1	Agriculture	2	1.91	0.07	0.13	0.00	0.11	2.23
9/24/2012	2	Agriculture	1	1.01	0.49	0.30	0.00	0.14	1.93
9/24/2012	2	Agriculture	2	2.74	0.27	0.36	0.00	0.11	3.49
9/24/2012	3	Agriculture	1	2.62	0.32	0.23	0.00	0.15	3.32
9/24/2012	3	Agriculture	2	2.36	0.33	0.39	0.00	0.15	3.22
9/24/2012	1	Control	1	1.71	0.78	0.32	0.00	0.10	2.92
9/24/2012	1	Control	2	1.65	4.44	0.37	0.62	0.23	7.31
9/24/2012	2	Control	1	3.53	3.85	0.08	0.00	0.02	7.48
9/24/2012	2	Control	2	2.44	0.50	0.21	0.00	0.11	3.26
9/24/2012	3	Control	1	1.35	0.07	0.07	0.00	0.07	1.56
9/24/2012	3	Control	2	1.65	0.68	0.29	0.00	0.19	2.80
9/24/2012	1	Urban	1	0.79	0.39	0.26	0.00	0.12	1.55
9/24/2012	1	Urban	2	1.65	0.06	0.23	0.00	0.17	2.11
9/24/2012	2	Urban	1	1.16	2.21	0.23	0.00	0.12	3.72
9/24/2012	2	Urban	2	2.11	1.10	0.40	0.00	0.11	3.73
9/24/2012	3	Urban	1	1.13	0.00	0.07	0.56	0.18	1.93
9/24/2012	3	Urban	2	1.33	0.21	0.20	0.00	0.20	1.94
10/8/2012	1	Agriculture	1	3.03	6.06	0.25	0.13	0.54	10.02
10/8/2012	1	Agriculture	2	1.90	0.21	0.11	0.00	0.28	2.50
10/8/2012	2	Agriculture	1	1.81	0.42	0.24	0.00	0.13	2.61
10/8/2012	2	Agriculture	2	1.19	0.28	0.16	0.00	0.21	1.84
10/8/2012	3	Agriculture	1	1.49	0.65	0.09	0.00	0.23	2.46
10/8/2012	3	Agriculture	2	1.56	0.71	0.20	0.00	0.25	2.73
10/8/2012	1	Control	1	1.89	3.49	0.07	0.00	0.16	5.62
10/8/2012	1	Control	2	1.78	3.00	0.12	0.22	0.52	5.63

Date	Block	Treatment	Basket	Propagules &		Stipules	Wood	Misc	Total
				Leaves	Flowers				
10/8/2012	2	Control	1	1.23	0.00	0.18	0.00	0.04	1.45
10/8/2012	2	Control	2	2.05	0.09	0.18	0.00	0.14	2.45
10/8/2012	3	Control	1	0.86	0.08	0.00	0.00	0.00	0.94
10/8/2012	3	Control	2	2.15	0.23	0.13	0.00	0.07	2.57
10/8/2012	1	Urban	1	1.49	1.84	0.36	0.00	0.28	3.97
10/8/2012	1	Urban	2	0.95	0.18	0.21	0.00	0.06	1.40
10/8/2012	2	Urban	1	1.33	4.31	0.06	0.00	0.33	6.03
10/8/2012	2	Urban	2	1.70	0.63	0.20	0.00	0.17	2.69
10/8/2012	3	Urban	1	1.65	0.00	0.04	0.00	0.15	1.85
10/8/2012	3	Urban	2	1.79	0.22	0.09	0.00	0.19	2.29
10/22/2012	1	Agriculture	1	1.63	4.78	0.27	0.00	0.55	7.23
10/22/2012	1	Agriculture	2	1.04	4.72	0.00	0.06	0.13	5.94
10/22/2012	2	Agriculture	1	2.31	0.29	0.06	0.00	0.11	2.77
10/22/2012	2	Agriculture	2	0.64	0.24	0.11	0.00	0.12	1.11
10/22/2012	3	Agriculture	1	1.55	1.09	0.23	0.00	0.26	3.12
10/22/2012	3	Agriculture	2	2.01	1.11	0.09	0.00	0.28	3.48
10/22/2012	1	Control	1	1.37	0.31	0.07	0.00	0.13	1.87
10/22/2012	1	Control	2	2.31	3.28	0.14	0.11	0.29	6.13
10/22/2012	2	Control	1	1.01	0.05	0.20	0.00	0.07	1.32
10/22/2012	2	Control	2	2.49	0.09	0.11	0.00	0.05	2.74
10/22/2012	3	Control	1	1.39	0.00	0.04	0.00	0.09	1.52
10/22/2012	3	Control	2	2.02	0.15	0.14	0.00	0.19	2.49
10/22/2012	1	Urban	1	2.05	1.44	0.17	0.00	0.19	3.84
10/22/2012	1	Urban	2	1.14	0.09	0.20	0.00	0.20	1.63
10/22/2012	2	Urban	1	1.29	0.01	0.30	0.00	0.07	1.68
10/22/2012	2	Urban	2	0.84	0.05	0.13	0.00	0.10	1.13
10/22/2012	3	Urban	1	1.88	0.10	0.04	0.00	0.25	2.27
10/22/2012	3	Urban	2	1.52	0.14	0.12	0.00	0.10	1.89
11/5/2012	1	Agriculture	1	2.24	0.76	0.12	0.49	0.30	3.91
11/5/2012	1	Agriculture	2	0.87	0.16	0.11	0.00	0.04	1.19
11/5/2012	2	Agriculture	1	0.97	0.28	0.13	0.00	0.14	1.52
11/5/2012	2	Agriculture	2	1.00	0.12	0.22	0.00	0.08	1.42
11/5/2012	3	Agriculture	1	1.43	1.82	0.15	0.00	0.17	3.57
11/5/2012	3	Agriculture	2	2.51	0.77	0.19	3.37	0.49	7.32
11/5/2012	1	Control	1	0.80	1.77	0.13	0.00	0.24	2.94
11/5/2012	1	Control	2	0.63	1.33	0.16	0.17	0.28	2.57
11/5/2012	2	Control	1	2.08	0.05	0.17	0.00	0.05	2.35
11/5/2012	2	Control	2	1.31	0.32	0.19	0.00	0.01	1.83
11/5/2012	3	Control	1	1.05	0.03	0.03	0.00	0.03	1.15
11/5/2012	3	Control	2	1.41	0.27	0.18	0.03	0.08	1.98
11/5/2012	1	Urban	1	0.83	0.30	0.21	0.00	0.18	1.52

Date	Block	Treatment	Basket	Propagules &					Total
				Leaves	Flowers	Stipules	Wood	Misc	
11/5/2012	1	Urban	2	0.56	0.36	0.13	0.00	0.09	1.13
11/5/2012	2	Urban	1	1.25	0.00	0.06	0.00	0.03	1.33
11/5/2012	2	Urban	2	1.71	0.33	0.14	1.01	0.14	3.33
11/5/2012	3	Urban	1	1.86	0.11	0.00	0.00	0.31	2.27
11/5/2012	3	Urban	2	1.47	0.06	0.19	0.00	0.04	1.76
11/26/2012	1	Agriculture	1	1.25	2.03	0.17	0.12	0.21	3.78
11/26/2012	1	Agriculture	2	0.68	2.81	0.14	0.00	0.02	3.65
11/26/2012	2	Agriculture	1	1.34	0.14	0.28	0.00	0.14	1.90
11/26/2012	2	Agriculture	2	0.77	0.23	0.19	0.00	0.04	1.23
11/26/2012	3	Agriculture	1	1.46	1.78	0.21	0.00	0.13	3.57
11/26/2012	3	Agriculture	2	0.52	3.57	0.37	0.00	2.22	6.68
11/26/2012	1	Control	1	0.99	0.26	0.25	0.00	0.03	1.53
11/26/2012	1	Control	2	1.38	1.62	0.24	0.00	0.18	3.44
11/26/2012	2	Control	1	0.94	0.05	0.24	0.00	0.06	1.30
11/26/2012	2	Control	2	1.04	0.03	0.14	0.12	0.06	1.39
11/26/2012	3	Control	1	1.05	0.00	0.16	0.00	0.00	1.21
11/26/2012	3	Control	2	1.00	0.14	0.18	0.00	0.22	1.54
11/26/2012	1	Urban	1	1.20	0.09	0.16	0.00	0.16	1.61
11/26/2012	1	Urban	2	0.83	0.20	0.20	0.00	0.11	1.34
11/26/2012	2	Urban	1	0.99	0.03	0.22	0.00	0.08	1.33
11/26/2012	2	Urban	2	1.09	0.04	0.23	0.00	0.07	1.43
11/26/2012	3	Urban	1	0.86	0.02	0.25	0.00	0.05	1.18
11/26/2012	3	Urban	2	0.90	0.00	0.05	0.00	0.08	1.03
12/8/2012	1	Agriculture	1	0.99	0.54	0.22	0.00	0.27	2.01
12/8/2012	1	Agriculture	2	0.71	0.24	0.02	0.10	0.21	1.28
12/8/2012	2	Agriculture	1	0.79	0.58	0.21	0.00	0.16	1.73
12/8/2012	2	Agriculture	2	1.36	1.67	0.25	0.10	0.16	3.53
12/8/2012	3	Agriculture	1	1.13	0.51	0.22	0.00	0.15	2.01
12/8/2012	3	Agriculture	2	1.03	1.04	0.23	0.16	0.19	2.65
12/8/2012	1	Control	1	1.36	0.27	0.16	0.52	0.13	2.45
12/8/2012	1	Control	2	0.94	0.41	0.23	0.00	0.11	1.70
12/8/2012	2	Control	1	1.11	0.05	0.19	0.00	0.12	1.47
12/8/2012	2	Control	2	0.60	0.05	0.14	0.00	0.18	0.97
12/8/2012	3	Control	1	0.39	0.03	0.13	0.00	0.01	0.56
12/8/2012	3	Control	2	1.29	0.15	0.16	0.00	0.21	1.81
12/8/2012	1	Urban	1	1.43	0.09	0.26	0.00	0.14	1.92
12/8/2012	1	Urban	2	1.25	0.05	0.10	0.00	0.15	1.55
12/8/2012	2	Urban	1	0.49	0.00	0.11	0.00	0.13	0.73
12/8/2012	2	Urban	2	0.53	0.03	0.25	0.00	0.07	0.88
12/8/2012	3	Urban	1	0.75	0.05	0.06	0.00	0.01	0.88
12/8/2012	3	Urban	2	1.28	0.00	0.15	0.00	0.08	1.51

Date	Block	Treatment	Basket	Propagules &					Total
				Leaves	Flowers	Stipules	Wood	Misc	
12/24/2012	1	Agriculture	1	1.08	1.58	0.24	0.04	0.10	3.03
12/24/2012	1	Agriculture	2	0.46	0.02	0.12	0.00	0.01	0.60
12/24/2012	2	Agriculture	1	0.69	0.03	0.13	0.00	0.08	0.93
12/24/2012	2	Agriculture	2	0.38	0.10	0.24	0.00	0.02	0.74
12/24/2012	3	Agriculture	1	1.36	1.62	0.43	0.12	0.05	3.57
12/24/2012	3	Agriculture	2						
12/24/2012	1	Control	1	0.28	0.16	0.16	0.00	0.01	0.60
12/24/2012	1	Control	2	0.52	0.17	0.08	0.00	0.19	0.95
12/24/2012	2	Control	1	0.89	0.03	0.12	0.00	0.07	1.11
12/24/2012	2	Control	2						
12/24/2012	3	Control	1	0.40	0.00	0.06	0.00	0.06	0.51
12/24/2012	3	Control	2	1.05	0.08	0.21	0.00	0.09	1.43
12/24/2012	1	Urban	1	0.84	0.09	0.13	0.00	0.08	1.14
12/24/2012	1	Urban	2	0.96	0.03	0.12	0.00	0.08	1.18
12/24/2012	2	Urban	1	1.24	0.23	0.21	0.00	0.04	1.72
12/24/2012	2	Urban	2	0.61	0.31	0.23	0.00	0.03	1.19
12/24/2012	3	Urban	1	0.54	0.00	0.05	0.00	0.04	0.63
12/24/2012	3	Urban	2	0.63	0.00	0.03	0.00	0.04	0.70
1/10/2013	1	Agriculture	1	0.52	0.37	0.18	0.32	0.14	1.53
1/10/2013	1	Agriculture	2	1.36	0.02	0.04	0.00	0.19	1.60
1/10/2013	2	Agriculture	1	0.15	0.04	0.03	0.84	0.16	1.22
1/10/2013	2	Agriculture	2	1.23	0.16	0.06	0.34	0.16	1.95
1/10/2013	3	Agriculture	1	1.14	0.09	0.13	0.00	0.15	1.52
1/10/2013	3	Agriculture	2	0.73	0.32	0.12	0.00	0.99	2.17
1/10/2013	1	Control	1	0.47	0.03	0.08	0.09	0.07	0.74
1/10/2013	1	Control	2	0.37	0.33	0.08	0.00	0.17	0.95
1/10/2013	2	Control	1	0.63	0.00	0.07	0.00	0.09	0.79
1/10/2013	2	Control	2	0.84	0.05	0.09	0.56	0.06	1.60
1/10/2013	3	Control	1	0.16	0.00	0.00	0.00	0.14	0.29
1/10/2013	3	Control	2	1.04	0.05	0.27	0.00	0.17	1.54
1/10/2013	1	Urban	1	1.17	0.26	0.15	0.00	0.18	1.76
1/10/2013	1	Urban	2	0.72	0.12	0.12	0.00	0.27	1.23
1/10/2013	2	Urban	1	0.42	0.00	0.05	0.00	0.10	0.58
1/10/2013	2	Urban	2	1.22	0.03	0.14	3.08	0.19	4.67
1/10/2013	3	Urban	1	0.39	0.28	0.02	0.00	0.17	0.86
1/10/2013	3	Urban	2	1.06	0.00	0.11	0.00	0.13	1.30
1/24/2013	1	Agriculture	1	1.70	0.13	0.11	0.00	0.09	2.03
1/24/2013	1	Agriculture	2	0.15	0.05	0.06	0.00	0.06	0.31
1/24/2013	2	Agriculture	1	0.43	0.34	0.08	0.00	0.05	0.91
1/24/2013	2	Agriculture	2	1.18	0.10	0.09	0.07	0.15	1.60
1/24/2013	3	Agriculture	1	0.60	0.05	0.08	0.00	0.03	0.75

Date	Block	Treatment	Basket	Propagules &					Total
				Leaves	Flowers	Stipules	Wood	Misc	
1/24/2013	3	Agriculture	2	1.59	0.15	0.05	0.00	0.10	1.90
1/24/2013	1	Control	1	0.69	0.15	0.02	0.00	0.03	0.89
1/24/2013	1	Control	2	0.94	0.00	0.09	0.00	0.11	1.14
1/24/2013	2	Control	1	0.65	0.03	0.01	0.00	0.19	0.88
1/24/2013	2	Control	2	0.89	0.00	0.06	0.00	0.05	1.00
1/24/2013	3	Control	1	0.71	0.03	0.05	0.00	0.01	0.81
1/24/2013	3	Control	2	1.37	0.05	0.11	0.03	0.06	1.61
1/24/2013	1	Urban	1	0.58	0.00	0.00	0.00	0.09	0.67
1/24/2013	1	Urban	2	1.37	0.03	0.04	0.00	0.02	1.47
1/24/2013	2	Urban	1	1.00	0.05	0.10	0.00	0.05	1.20
1/24/2013	2	Urban	2	0.97	0.05	0.05	0.00	0.10	1.17
1/24/2013	3	Urban	1	0.52	0.00	0.00	0.00	0.03	0.55
1/24/2013	3	Urban	2	1.28	0.05	0.05	0.00	0.06	1.44
2/8/2013	1	Agriculture	1	1.06	0.68	0.07	0.00	0.08	1.90
2/8/2013	1	Agriculture	2	1.07	0.00	0.00	0.00	0.05	1.12
2/8/2013	2	Agriculture	1	0.74	0.03	0.07	0.00	0.05	0.89
2/8/2013	2	Agriculture	2	0.29	0.10	0.03	0.00	0.20	0.62
2/8/2013	3	Agriculture	1	0.85	0.29	0.16	0.00	0.14	1.44
2/8/2013	3	Agriculture	2	0.86	0.26	0.05	0.00	0.13	1.30
2/8/2013	1	Control	1	0.37	0.00	0.03	0.00	0.03	0.43
2/8/2013	1	Control	2	0.83	0.08	0.07	0.06	0.14	1.18
2/8/2013	2	Control	1	0.85	0.03	0.04	0.00	0.05	0.97
2/8/2013	2	Control	2	0.77	0.05	0.09	0.00	0.07	0.97
2/8/2013	3	Control	1	0.34	0.00	0.03	0.00	0.01	0.38
2/8/2013	3	Control	2	1.19	0.10	0.02	0.83	0.11	2.25
2/8/2013	1	Urban	1	0.38	0.11	0.04	0.09	0.17	0.78
2/8/2013	1	Urban	2	1.39	0.09	0.05	0.00	0.06	1.58
2/8/2013	2	Urban	1	0.44	0.05	0.05	0.00	0.09	0.62
2/8/2013	2	Urban	2	0.42	0.05	0.02	0.00	0.14	0.62
2/8/2013	3	Urban	1	0.44	0.00	0.02	0.00	0.13	0.59
2/8/2013	3	Urban	2	0.37	0.00	0.15	0.00	0.15	0.67
2/22/2013	1	Agriculture	1	1.13	0.37	0.18	0.00	0.05	1.73
2/22/2013	1	Agriculture	2	1.15	0.00	0.15	0.00	0.11	1.41
2/22/2013	2	Agriculture	1	0.29	0.00	0.05	0.00	0.03	0.38
2/22/2013	2	Agriculture	2	1.29	0.06	0.15	0.00	0.09	1.58
2/22/2013	3	Agriculture	1	1.22	0.05	0.04	0.00	0.07	1.38
2/22/2013	3	Agriculture	2	2.69	0.09	0.10	0.00	0.07	2.95
2/22/2013	1	Control	1	0.40	0.02	0.27	0.00	0.01	0.69
2/22/2013	1	Control	2	0.51	0.15	0.15	0.06	0.07	0.94
2/22/2013	2	Control	1	0.54	0.10	0.13	0.00	0.03	0.79
2/22/2013	2	Control	2	0.27	0.05	0.04	0.00	0.07	0.43

Date	Block	Treatment	Basket	Propagules &					Total
				Leaves	Flowers	Stipules	Wood	Misc	
2/22/2013	3	Control	1	0.73	0.04	0.03	0.00	0.04	0.83
2/22/2013	3	Control	2	1.20	0.20	0.07	0.00	0.13	1.59
2/22/2013	1	Urban	1	0.95	0.09	0.08	0.00	0.09	1.22
2/22/2013	1	Urban	2	0.43	0.11	0.02	0.00	0.02	0.59
2/22/2013	2	Urban	1	1.05	0.07	0.13	0.00	0.02	1.27
2/22/2013	2	Urban	2	1.35	0.14	0.14	0.00	0.17	1.80
2/22/2013	3	Urban	1	0.61	0.00	0.00	0.00	0.02	0.63
2/22/2013	3	Urban	2	0.84	0.00	0.29	0.00	0.08	1.22
3/12/2013	1	Agriculture	1	0.41	0.32	0.13	0.00	0.03	0.89
3/12/2013	1	Agriculture	2	1.40	0.00	0.07	0.00	0.06	1.52
3/12/2013	2	Agriculture	1	0.67	0.04	0.08	0.00	0.04	0.83
3/12/2013	2	Agriculture	2	0.56	0.03	0.15	0.00	0.16	0.90
3/12/2013	3	Agriculture	1	1.60	0.10	0.06	0.00	0.10	1.87
3/12/2013	3	Agriculture	2	1.34	0.26	0.10	0.00	0.15	1.85
3/12/2013	1	Control	1	0.84	0.03	0.07	0.08	0.09	1.11
3/12/2013	1	Control	2	1.11	0.01	0.06	0.00	0.05	1.23
3/12/2013	2	Control	1	2.27	0.02	0.10	0.00	0.12	2.51
3/12/2013	2	Control	2	0.45	0.00	0.04	0.00	0.08	0.57
3/12/2013	3	Control	1	0.43	0.06	0.04	0.00	0.00	0.53
3/12/2013	3	Control	2	0.46	0.11	0.04	0.00	0.13	0.75
3/12/2013	1	Urban	1	1.38	0.02	0.14	0.00	0.04	1.58
3/12/2013	1	Urban	2	0.76	0.00	0.03	0.00	0.02	0.82
3/12/2013	2	Urban	1	0.98	0.06	0.10	0.00	0.08	1.21
3/12/2013	2	Urban	2	0.43	0.03	0.08	0.00	0.11	0.65
3/12/2013	3	Urban	1	0.89	0.00	0.03	0.04	0.06	1.02
3/12/2013	3	Urban	2	0.87	0.13	0.13	0.00	0.08	1.21
4/1/2013	1	Agriculture	1	1.78	0.24	0.15	0.01	0.06	2.24
4/1/2013	1	Agriculture	2	0.87	0.00	0.02	0.17	0.04	1.10
4/1/2013	2	Agriculture	1	0.80	0.02	0.10	0.18	0.07	1.17
4/1/2013	2	Agriculture	2	0.32	0.21	0.10	0.00	0.08	0.71
4/1/2013	3	Agriculture	1	2.26	0.12	0.16	0.00	0.08	2.63
4/1/2013	3	Agriculture	2	2.10	0.30	0.17	0.00	0.14	2.70
4/1/2013	1	Control	1	1.70	0.00	0.12	0.00	0.07	1.89
4/1/2013	1	Control	2	1.48	0.01	0.02	0.01	0.02	1.54
4/1/2013	2	Control	1	0.62	0.06	0.20	0.00	0.08	0.95
4/1/2013	2	Control	2	0.51	0.01	0.11	0.00	0.02	0.66
4/1/2013	3	Control	1	0.52	0.02	0.10	0.00	0.03	0.67
4/1/2013	3	Control	2	1.00	0.13	0.10	0.13	0.08	1.43
4/1/2013	1	Urban	1	1.89	0.00	0.14	0.01	0.05	2.09
4/1/2013	1	Urban	2	1.52	0.00	0.04	0.00	0.03	1.59
4/1/2013	2	Urban	1	0.89	0.11	0.19	0.00	0.03	1.22

Date	Block	Treatment	Basket	Propagules &					Total
				Leaves	Flowers	Stipules	Wood	Misc	
4/1/2013	2	Urban	2	0.79	0.08	0.08	0.00	0.03	0.98
4/1/2013	3	Urban	1	1.90	0.00	0.05	0.00	0.01	1.96
4/1/2013	3	Urban	2	0.64	0.36	0.15	0.00	0.05	1.19
4/18/2013	1	Agriculture	1	1.96	0.05	0.11	0.00	0.09	2.21
4/18/2013	1	Agriculture	2	0.82	0.00	0.06	0.00	0.19	1.07
4/18/2013	2	Agriculture	1	1.47	0.01	0.03	0.03	0.06	1.60
4/18/2013	2	Agriculture	2	1.67	0.00	0.03	0.00	0.18	1.88
4/18/2013	3	Agriculture	1	2.83	0.15	0.11	0.00	0.09	3.18
4/18/2013	3	Agriculture	2	1.70	0.27	0.13	0.00	0.29	2.39
4/18/2013	1	Control	1	0.89	0.00	0.01	0.00	0.02	0.92
4/18/2013	1	Control	2	1.93	0.00	0.04	0.00	0.04	2.01
4/18/2013	2	Control	1	1.54	0.00	0.07	0.00	0.03	1.64
4/18/2013	2	Control	2	0.85	0.00	0.06	0.00	0.10	1.01
4/18/2013	3	Control	1	1.87	0.00	0.13	0.00	0.00	2.00
4/18/2013	3	Control	2	1.36	0.08	0.03	0.56	0.11	2.15
4/18/2013	1	Urban	1	0.85	0.05	0.06	0.00	0.20	1.17
4/18/2013	1	Urban	2	1.27	0.12	0.02	0.01	0.08	1.49
4/18/2013	2	Urban	1	0.97	0.01	0.02	0.00	0.04	1.04
4/18/2013	2	Urban	2	1.10	0.02	0.08	0.00	0.07	1.26
4/18/2013	3	Urban	1	1.80	0.00	0.02	0.00	0.05	1.87
4/18/2013	3	Urban	2	1.67	0.05	0.07	0.02	0.10	1.91
5/3/2013	1	Agriculture	1	2.10	0.02	0.27	0.00	0.08	2.47
5/3/2013	1	Agriculture	2	1.51	0.00	0.11	0.00	0.15	1.77
5/3/2013	2	Agriculture	1	1.50	0.29	0.29	0.00	0.05	2.13
5/3/2013	2	Agriculture	2	1.52	0.00	0.30	0.00	0.22	2.05
5/3/2013	3	Agriculture	1	1.85	0.00	0.03	0.00	0.04	1.93
5/3/2013	3	Agriculture	2	1.11	0.00	0.07	0.16	0.05	1.39
5/3/2013	1	Control	1	1.30	0.02	0.03	0.00	0.05	1.40
5/3/2013	1	Control	2	0.99	0.02	0.06	0.15	0.02	1.24
5/3/2013	2	Control	1	2.33	0.00	0.25	0.59	0.22	3.39
5/3/2013	2	Control	2	1.38	0.00	0.11	0.34	0.15	1.99
5/3/2013	3	Control	1	2.61	0.00	0.13	0.00	0.01	2.74
5/3/2013	3	Control	2	1.51	0.03	0.20	0.00	0.10	1.84
5/3/2013	1	Urban	1	2.10	0.02	0.07	0.00	0.11	2.30
5/3/2013	1	Urban	2	1.18	1.19	0.15	0.00	0.06	2.58
5/3/2013	2	Urban	1	2.12	0.00	0.25	0.00	0.04	2.41
5/3/2013	2	Urban	2	2.03	0.02	0.39	0.00	0.04	2.48
5/3/2013	3	Urban	1	2.58	0.04	0.17	0.00	0.07	2.86
5/3/2013	3	Urban	2	1.85	0.15	0.40	0.02	0.14	2.57
5/30/2013	1	Agriculture	1	1.56	0.09	0.36	0.06	0.16	2.23
5/30/2013	1	Agriculture	2	2.99	0.00	0.31	0.05	0.47	3.82

Date	Block	Treatment	Basket	Propagules &					Total
				Leaves	Flowers	Stipules	Wood	Misc	
5/30/2013	2	Agriculture	1	2.43	0.51	0.47	0.00	0.16	3.56
5/30/2013	2	Agriculture	2	1.53	1.23	0.48	0.00	0.58	3.82
5/30/2013	3	Agriculture	1	2.76	0.04	0.62	0.00	0.21	3.62
5/30/2013	3	Agriculture	2	0.99	0.05	0.63	0.00	0.18	1.85
5/30/2013	1	Control	1	2.16	0.70	0.12	0.00	0.12	3.11
5/30/2013	1	Control	2	3.62	0.60	0.38	0.23	0.08	4.91
5/30/2013	2	Control	1	1.45	0.01	0.45	0.02	0.73	2.66
5/30/2013	2	Control	2	1.61	0.01	0.22	0.00	0.12	1.97
5/30/2013	3	Control	1	1.81	0.00	0.12	0.00	0.32	2.25
5/30/2013	3	Control	2	2.44	0.12	0.36	0.00	0.15	3.07
5/30/2013	1	Urban	1	2.43	0.00	0.56	0.00	0.37	3.36
5/30/2013	1	Urban	2	2.42	1.58	0.37	0.04	0.09	4.50
5/30/2013	2	Urban	1	1.72	0.00	0.41	0.00	0.07	2.20
5/30/2013	2	Urban	2	1.82	0.02	0.33	0.00	0.17	2.34
5/30/2013	3	Urban	1	3.67	0.00	0.30	0.00	0.37	4.34
5/30/2013	3	Urban	2	2.07	0.02	0.64	0.19	0.14	3.06
6/14/2013	1	Agriculture	1	3.50	0.03	0.35	0.00	0.23	4.11
6/14/2013	1	Agriculture	2	2.71	0.02	0.11	0.03	0.52	3.39
6/14/2013	2	Agriculture	1	2.30	0.00	0.37	0.00	0.18	2.84
6/14/2013	2	Agriculture	2	1.67	0.18	0.33	0.00	0.33	2.52
6/14/2013	3	Agriculture	1	2.84	0.97	0.50	0.00	0.17	4.49
6/14/2013	3	Agriculture	2	0.68	0.42	0.41	0.13	0.16	1.80
6/14/2013	1	Control	1	2.50	1.00	0.40	0.00	0.26	4.15
6/14/2013	1	Control	2	2.55	1.16	0.41	0.05	0.09	4.27
6/14/2013	2	Control	1	2.12	0.02	0.30	0.00	0.21	2.66
6/14/2013	2	Control	2	2.13	0.00	0.26	0.00	0.13	2.52
6/14/2013	3	Control	1	1.53	0.00	0.21	0.00	0.05	1.79
6/14/2013	3	Control	2	2.10	0.00	0.33	0.00	0.07	2.50
6/14/2013	1	Urban	1	1.81	0.00	0.18	0.00	0.32	2.30
6/14/2013	1	Urban	2	1.80	0.03	0.21	0.00	0.11	2.14
6/14/2013	2	Urban	1	2.01	0.01	0.41	0.00	0.06	2.49
6/14/2013	2	Urban	2	2.29	0.00	0.37	0.00	0.15	2.81
6/14/2013	3	Urban	1	3.31	0.00	0.12	0.00	0.43	3.86
6/14/2013	3	Urban	2	1.84	0.02	0.28	0.00	0.16	2.31
6/28/2013	1	Agriculture	1	2.33	0.75	0.23	0.18	0.17	3.66
6/28/2013	1	Agriculture	2	3.61	0.00	0.16	0.03	0.47	4.27
6/28/2013	2	Agriculture	1	2.21	0.03	0.21	0.00	0.08	2.53
6/28/2013	2	Agriculture	2	1.83	0.00	0.27	0.00	0.11	2.21
6/28/2013	3	Agriculture	1	2.12	0.23	0.52	0.00	0.15	3.01
6/28/2013	3	Agriculture	2	4.01	0.32	0.13	0.04	0.16	4.66
6/28/2013	1	Control	1	1.03	1.76	0.35	0.00	0.12	3.26

Date	Block	Treatment	Basket	Propagules &					Total
				Leaves	Flowers	Stipules	Wood	Misc	
6/28/2013	1	Control	2	2.90	0.61	0.22	0.05	0.13	3.90
6/28/2013	2	Control	1	2.03	1.57	0.32	0.51	0.10	4.52
6/28/2013	2	Control	2	2.64	0.04	0.11	0.00	0.11	2.90
6/28/2013	3	Control	1	1.52	0.06	0.15	0.08	0.20	2.01
6/28/2013	3	Control	2	2.33	1.41	0.17	1.34	0.06	5.31
6/28/2013	1	Urban	1	3.09	0.03	0.22	0.00	0.18	3.52
6/28/2013	1	Urban	2	3.25	0.02	0.35	0.00	0.15	3.77
6/28/2013	2	Urban	1	1.67	0.00	0.21	0.00	0.06	1.94
6/28/2013	2	Urban	2	2.08	0.04	0.35	0.00	0.08	2.55
6/28/2013	3	Urban	1						
6/28/2013	3	Urban	2	2.23	0.08	0.28	0.00	0.20	2.79
7/22/2013	1	Agriculture	1	4.49	0.21	0.18	0.00	0.24	5.11
7/22/2013	1	Agriculture	2	5.58	0.31	0.11	0.00	0.54	6.54
7/22/2013	2	Agriculture	1	4.29	0.75	0.28	0.00	0.21	5.53
7/22/2013	2	Agriculture	2	5.06	0.42	0.30	0.00	0.68	6.46
7/22/2013	3	Agriculture	1	3.59	0.44	0.28	1.24	0.36	5.91
7/22/2013	3	Agriculture	2	4.62	0.62	0.31	0.38	0.52	6.45
7/22/2013	1	Control	1	3.00	1.66	0.11	1.01	0.12	5.91
7/22/2013	1	Control	2	5.09	0.39	0.15	0.23	0.26	6.11
7/22/2013	2	Control	1	3.16	0.88	0.27	0.32	0.21	4.84
7/22/2013	2	Control	2	3.94	0.06	0.24	0.09	0.23	4.56
7/22/2013	3	Control	1	2.38	0.19	0.22	0.00	0.11	2.90
7/22/2013	3	Control	2	3.39	1.73	0.23	0.00	0.21	5.55
7/22/2013	1	Urban	1	4.05	1.08	0.28	0.17	0.24	5.82
7/22/2013	1	Urban	2	3.53	0.71	0.24	0.00	0.23	4.70
7/22/2013	2	Urban	1	3.20	0.44	0.41	0.27	0.17	4.48
7/22/2013	2	Urban	2	4.06	0.37	0.54	0.00	0.25	5.21
7/22/2013	3	Urban	1	5.29	0.00	0.10	0.00	0.23	5.62
7/22/2013	3	Urban	2	4.06	0.10	0.28	0.01	0.29	4.73
7/31/2013	1	Agriculture	1	3.88	0.30	0.22	0.25	0.46	5.12
7/31/2013	1	Agriculture	2	5.40	0.08	0.08	10.04	1.43	17.04
7/31/2013	2	Agriculture	1	2.66	0.84	0.36	0.00	0.29	4.16
7/31/2013	2	Agriculture	2	2.77	0.20	0.24	0.00	0.46	3.68
7/31/2013	3	Agriculture	1	5.54	0.66	0.39	0.81	0.77	8.17
7/31/2013	3	Agriculture	2	3.11	1.24	0.37	0.00	0.69	5.40
7/31/2013	1	Control	1	1.98	3.76	0.07	0.00	0.20	6.00
7/31/2013	1	Control	2	2.87	0.26	0.12	0.00	0.23	3.47
7/31/2013	2	Control	1	1.64	0.09	0.23	3.04	0.36	5.37
7/31/2013	2	Control	2	1.96	0.12	0.20	3.75	0.27	6.28
7/31/2013	3	Control	1	1.82	0.17	0.16	0.00	0.06	2.20
7/31/2013	3	Control	2	3.90	0.22	0.08	0.00	0.31	4.51

Date	Block	Treatment	Basket	Propagules &					Total
				Leaves	Flowers	Stipules	Wood	Misc	
7/31/2013	1	Urban	1	2.54	0.15	0.13	0.60	0.48	3.91
7/31/2013	1	Urban	2	3.34	0.07	0.19	0.00	0.10	3.69
7/31/2013	2	Urban	1	3.28	0.08	0.23	0.00	0.12	3.72
7/31/2013	2	Urban	2	4.12	0.06	0.25	0.00	0.19	4.61
7/31/2013	3	Urban	1	5.24	0.03	0.12	0.08	0.13	5.59
7/31/2013	3	Urban	2	3.80	0.12	0.10	0.00	0.25	4.27
8/14/2013	1	Agriculture	1	2.80	8.20	0.26	0.39	0.40	12.06
8/14/2013	1	Agriculture	2	5.54	0.07	0.23	0.16	0.40	6.40
8/14/2013	2	Agriculture	1	1.47	1.96	0.29	0.00	0.21	3.93
8/14/2013	2	Agriculture	2	3.20	0.35	0.29	0.00	0.45	4.29
8/14/2013	3	Agriculture	1	5.05	0.61	0.37	0.00	0.42	6.45
8/14/2013	3	Agriculture	2	2.97	0.99	0.18	0.00	0.67	4.81
8/14/2013	1	Control	1	2.64	0.03	0.17	0.06	0.09	2.99
8/14/2013	1	Control	2	2.43	0.25	0.17	0.05	0.35	3.24
8/14/2013	2	Control	1	2.69	0.14	0.29	0.00	0.15	3.26
8/14/2013	2	Control	2	1.71	0.24	0.33	0.00	0.25	2.53
8/14/2013	3	Control	1	2.11	0.05	0.13	0.00	0.06	2.35
8/14/2013	3	Control	2	7.85	0.84	0.33	0.03	0.32	9.37
8/14/2013	1	Urban	1	1.75	0.29	0.28	2.01	0.57	4.90
8/14/2013	1	Urban	2	2.33	0.32	0.20	0.15	0.42	3.42
8/14/2013	2	Urban	1	3.30	0.25	0.50	0.00	0.20	4.25
8/14/2013	2	Urban	2	2.62	0.25	0.63	0.04	0.32	3.85
8/14/2013	3	Urban	1	2.81	0.02	0.13	0.00	0.32	3.28
8/14/2013	3	Urban	2	2.45	0.31	0.16	0.00	0.39	3.31
8/30/2013	1	Agriculture	1	2.78	0.63	0.11	0.07	0.25	3.84
8/30/2013	1	Agriculture	2	3.90	0.11	0.15	0.08	0.14	4.38
8/30/2013	2	Agriculture	1	2.74	1.35	0.26	0.00	0.22	4.56
8/30/2013	2	Agriculture	2	2.52	0.64	0.25	0.00	0.42	3.82
8/30/2013	3	Agriculture	1	2.81	0.86	0.25	0.00	0.40	4.30
8/30/2013	3	Agriculture	2	2.69	2.03	0.28	0.00	0.54	5.53
8/30/2013	1	Control	1	2.11	0.52	0.11	0.00	0.11	2.85
8/30/2013	1	Control	2	2.38	2.07	0.20	0.00	0.21	4.86
8/30/2013	2	Control	1	2.22	0.20	0.41	0.00	0.20	3.02
8/30/2013	2	Control	2	0.67	0.21	0.24	0.22	0.18	1.51
8/30/2013	3	Control	1	1.25	0.15	0.14	0.00	0.13	1.66
8/30/2013	3	Control	2	1.63	0.29	0.27	0.00	0.18	2.36
8/30/2013	1	Urban	1	1.81	0.33	0.28	0.00	0.31	2.73
8/30/2013	1	Urban	2	2.45	0.43	0.07	0.04	0.26	3.25
8/30/2013	2	Urban	1	0.77	0.35	0.24	0.03	0.16	1.55
8/30/2013	2	Urban	2	2.55	0.29	0.25	0.00	0.17	3.26
8/30/2013	3	Urban	1	3.15	0.13	0.10	0.00	0.10	3.47

Date	Block	Treatment	Basket	Propagules &					Total
				Leaves	Flowers	Stipules	Wood	Misc	
8/30/2013	3	Urban	2	1.57	0.61	0.13	0.06	0.18	2.54
9/13/2013	1	Agriculture	1	2.97	1.53	0.19	3.56	0.43	8.68
9/13/2013	1	Agriculture	2	3.61	2.74	0.13	0.71	1.24	8.43
9/13/2013	2	Agriculture	1	1.92	1.16	0.33	0.00	0.32	3.73
9/13/2013	2	Agriculture	2	2.22	0.80	0.19	0.03	0.85	4.09
9/13/2013	3	Agriculture	1	2.83	2.97	0.17	0.00	0.62	6.59
9/13/2013	3	Agriculture	2	3.52	1.42	0.25	0.21	0.59	5.99
9/13/2013	1	Control	1	2.82	4.72	0.09	0.02	0.38	8.03
9/13/2013	1	Control	2	3.23	2.65	0.10	0.00	0.27	6.24
9/13/2013	2	Control	1	1.53	1.95	0.12	0.00	0.75	4.35
9/13/2013	2	Control	2	0.97	0.25	0.19	0.00	0.44	1.85
9/13/2013	3	Control	1	1.49	0.09	0.13	0.00	0.05	1.77
9/13/2013	3	Control	2	2.23	0.29	0.21	0.00	0.34	3.06
9/13/2013	1	Urban	1	2.40	0.65	0.06	0.00	0.24	3.35
9/13/2013	1	Urban	2	0.93	0.74	0.08	0.00	0.39	2.14
9/13/2013	2	Urban	1	3.49	0.83	0.23	0.00	0.29	4.83
9/13/2013	2	Urban	2	0.91	3.32	0.31	0.00	0.42	4.96
9/13/2013	3	Urban	1	1.75	1.73	0.17	0.00	0.25	3.89
9/13/2013	3	Urban	2	2.19	1.69	0.17	0.00	0.37	4.43
9/27/2013	1	Agriculture	1	3.35	5.04	0.37	0.00	0.25	9.02
9/27/2013	1	Agriculture	2	3.87	1.82	0.18	0.00	0.29	6.16
9/27/2013	2	Agriculture	1	1.41	0.39	0.36	0.00	0.33	2.49
9/27/2013	2	Agriculture	2	2.41	0.49	0.33	0.00	0.37	3.60
9/27/2013	3	Agriculture	1						
9/27/2013	3	Agriculture	2	2.91	1.50	0.33	0.00	0.33	5.08
9/27/2013	1	Control	1	2.55	3.64	0.17	0.10	0.25	6.70
9/27/2013	1	Control	2	3.45	2.79	0.06	0.00	0.31	6.61
9/27/2013	2	Control	1	1.99	2.66	0.53	0.00	0.58	5.75
9/27/2013	2	Control	2	1.85	0.40	0.20	0.00	0.41	2.87
9/27/2013	3	Control	1	1.33	0.08	0.02	0.00	0.13	1.55
9/27/2013	3	Control	2	2.15	0.20	0.14	0.00	0.28	2.77
9/27/2013	1	Urban	1	1.43	4.59	0.21	0.00	0.41	6.65
9/27/2013	1	Urban	2	1.93	3.47	0.12	0.00	0.45	5.96
9/27/2013	2	Urban	1	3.04	0.65	0.21	0.00	0.45	4.36
9/27/2013	2	Urban	2	1.89	3.52	0.42	0.00	0.58	6.41
9/27/2013	3	Urban	1	1.19	2.58	0.02	0.00	0.23	4.03
9/27/2013	3	Urban	2	1.44	2.86	0.14	0.00	0.33	4.77

Appendix C: Stable isotope data

Collection of ecosystem components and stable isotope measurements are described in Chapter 3.

Sample type	Block	Treatment	Tree ID	Date	d15N	Molar C:N	d13C
Green leaves	1	Ambient	56	8/30/2013	7.16	57.3	-30.07
Green leaves	1	Ambient	58	8/30/2013	62.32	56.8	-31.18
Green leaves	2	Ambient	28	8/30/2013	549.96	49.7	-31.01
Green leaves	3	Ambient	3	8/30/2013	1106.33	54.6	-28.39
Green leaves	3	Ambient	6	8/30/2013	1296.07	66.1	-30.20
Green leaves	3	Ambient	9	8/30/2013	21.15	68.5	-30.19
Green leaves	1	Ambient	56	10/13/2013	26.12	56.6	-29.78
Green leaves	1	Ambient	58	10/13/2013	18.62	66.7	-29.68
Green leaves	1	Ambient	59	10/13/2013	31.39	57.2	-29.11
Green leaves	1	Ambient	60	10/13/2013	20.65	43.9	-31.76
Green leaves	1	Ambient	62	10/13/2013	3.72	57.4	-29.86
Green leaves	2	Ambient	38	10/13/2013	11.15	62.1	-31.31
Green leaves	2	Ambient	39	10/13/2013	3.74	67.8	-30.14
Green leaves	2	Ambient	40	10/13/2013	6.85	68.1	-32.33
Green leaves	3	Ambient	3	10/13/2013	101.94	57.6	-29.33
Green leaves	3	Ambient	5	10/13/2013	87.46	60.0	-30.82
Green leaves	3	Ambient	6	10/13/2013	37.27	64.7	-30.74
Green leaves	3	Ambient	7	10/13/2013	17.19	77.5	-30.13
Green leaves	3	Ambient	8	10/13/2013	393.75	99.0	-30.57
Green leaves	3	Ambient	9	10/13/2013	11.25	67.6	-31.07
Green leaves	1	Ambient	56	5/22/2014	208.72	54.1	-30.55
Green leaves	1	Ambient	58	5/22/2014	180.33	55.4	-30.57
Green leaves	1	Ambient	62	5/22/2014	18.40	56.0	-29.26
Green leaves	2	Ambient	38	5/22/2014	173.96	53.6	-30.81
Green leaves	3	Ambient	5	5/22/2014	392.23	61.1	-30.91
Green leaves	3	Ambient	6	5/22/2014	1152.14	58.2	-31.94
Green leaves	3	Ambient	7	5/22/2014	407.50	62.2	-30.75
Green leaves	3	Ambient	10	5/22/2014	160.45	51.7	-32.05

Sample type	Block	Treatment	ID	Date	d15N	Molar C:N	d13C
Green leaves	1	Fertilized	65	8/30/2013	3628.10	43.7	-31.21
Green leaves	1	Fertilized	75	8/30/2013	54.47	51.6	-29.15
Green leaves	2	Fertilized	30	8/30/2013	931.86	50.6	-28.06
Green leaves	2	Fertilized	33	8/30/2013	10.44	50.4	-30.40
Green leaves	2	Fertilized	36	8/30/2013	355.55	52.0	-31.62
Green leaves	3	Fertilized	21	8/30/2013	19.73	50.7	-31.03
Green leaves	3	Fertilized	22	8/30/2013	69.15	57.7	-30.88
Green leaves	3	Fertilized	86	8/30/2013	259.83	60.2	-30.00
Green leaves	1	Fertilized	63	10/13/2013	686.40	46.8	-28.83
Green leaves	1	Fertilized	65	10/13/2013	2337.56	40.8	-31.32
Green leaves	1	Fertilized	66	10/13/2013	40.28	46.8	-31.26
Green leaves	1	Fertilized	67	10/13/2013	2221.77	44.3	-29.07
Green leaves	1	Fertilized	69	10/13/2013	302.10	43.5	-29.88
Green leaves	1	Fertilized	75	10/13/2013	12.80	58.7	-30.60
Green leaves	2	Fertilized	31	10/13/2013	8.54	60.7	-29.89
Green leaves	2	Fertilized	32	10/13/2013	514.74	53.6	-28.16
Green leaves	2	Fertilized	33	10/13/2013	10.04	63.0	-29.86
Green leaves	2	Fertilized	36	10/13/2013	215.44	54.3	-31.48
Green leaves	2	Fertilized	36	10/13/2013	234.83	53.5	-31.64
Green leaves	3	Fertilized	19	10/13/2013	692.01	89.7	-30.31
Green leaves	3	Fertilized	20	10/13/2013	29.96	75.7	-30.19
Green leaves	3	Fertilized	21	10/13/2013	1680.00	89.4	-29.95
Green leaves	3	Fertilized	22	10/13/2013	146.29	57.1	-30.42
Green leaves	3	Fertilized	24	10/13/2013	418.40	55.5	-30.30
Green leaves	3	Fertilized	26	10/13/2013	147.39	46.7	-32.28
Green leaves	1	Fertilized	65	5/22/2014	1039.08	41.9	-31.81
Green leaves	1	Fertilized	66	5/22/2014	549.75	42.8	-30.24
Green leaves	1	Fertilized	68	5/22/2014	816.91	45.0	-30.69
Green leaves	2	Fertilized	33	5/22/2014	160.51	56.5	-31.36
Green leaves	2	Fertilized	36	5/22/2014	1435.36	45.5	-31.83
Green leaves	3	Fertilized	19	5/22/2014	2378.06	69.4	-30.81
Green leaves	3	Fertilized	20	5/22/2014	170.24	66.2	-29.89
Green leaves	3	Fertilized	21	5/22/2014	7244.92	64.6	-31.16
Green leaves	3	Fertilized	22	5/22/2014	1146.88	50.1	-31.03
Green leaves	3	Fertilized	23	5/22/2014	2028.45	54.0	-29.45
Green leaves	3	Fertilized	26	5/22/2014	554.99	52.3	-31.41
Green leaves	3	Fertilized	27	5/22/2014	1949.02	64.6	-29.99
Green leaves	3	Fertilized	86	5/22/2014	1940.45	63.6	-30.06

Sample type	Block	Treatment	ID	Date	d15N	d13C	Molar C:N	N mass g m ⁻²
Litter	1	Ambient	153	8/7/2013	4294.83	-29.10	135.9	1.54
Litter	2	Ambient	33	8/7/2013	1106.58	-28.87	107.0	2.20
Litter	3	Ambient	130	8/7/2013	14155.76	-29.26	136.9	1.58
Litter	1	Ambient	98	8/30/2013	11347.63	-28.22	86.6	2.54
Litter	2	Ambient	176	8/30/2013	1020.82	-28.89	92.3	2.68
Litter	3	Ambient	93	8/30/2013	2386.35	-28.99	85.1	2.57
Litter	1	Ambient	189	9/27/2013	7000.52	-28.88	84.3	3.13
Litter	2	Ambient	24	9/27/2013	943.61	-29.14	60.0	4.21
Litter	3	Ambient	43	9/27/2013	2951.14	-29.51	73.4	3.31
Litter	1	Ambient	124	10/27/2013	5794.11	-28.80	65.7	3.92
Litter	2	Ambient	1	10/27/2013	1032.91	-28.84	72.7	3.75
Litter	3	Ambient	164	10/27/2013	5211.55	-29.78	53.8	3.99
Litter	1	Fertilized	94	8/7/2013	6122.27	-29.74	113.3	1.91
Litter	2	Fertilized	41	8/7/2013	18997.70	-29.49	111.9	2.00
Litter	3	Fertilized	125	8/7/2013	16777.32	-29.41	128.2	2.02
Litter	1	Fertilized	131	8/30/2013	9590.68	-29.27	58.1	3.46
Litter	2	Fertilized	187	8/30/2013	12688.53	-29.78	71.2	3.32
Litter	3	Fertilized	178	8/30/2013	11183.18	-29.19	92.4	2.91
Litter	1	Fertilized	101	9/27/2013	5188.09	-29.36	58.4	3.99
Litter	1	Fertilized	156	10/27/2013	5764.79	-29.69	55.6	4.32
Litter	2	Fertilized	196	10/27/2013	3276.97	-28.19	51.8	5.08
Litter	3	Fertilized	136	10/27/2013	4170.64	-28.82	49.7	3.44

Sample type	Block	Treatment	ID	Date	d15N	d13C	Molar C:N
Fine roots	1	Ambient	118	5/22/2014	262.77	-26.99	76.4
Fine roots	1	Ambient	138	5/22/2014	554.21	-26.53	78.5
Fine roots	2	Ambient	142	5/22/2014	359.12	-27.70	67.5
Fine roots	1	Fertilized	147	5/22/2014	611.24	-27.58	62.1
Fine roots	1	Fertilized	135	5/22/2014	1473.95	-26.59	86.5
Fine roots	2	Fertilized	133	5/22/2014	1988.60	-27.88	80.1
Fine roots	3	Fertilized	154	5/22/2014	3128.24	-27.22	121.7

Sample type	Block	Treatment	ID	Date	d15N	d13C	Molar C:N
Sediment	1	Ambient	0-1 cm	8/14/2013	1072.82	-27.20	37.0
Sediment	1	Ambient	1-2 cm	8/14/2013	217.62	-27.09	31.0
Sediment	2	Ambient	0-1 cm	8/14/2013	187.60	-27.97	30.2
Sediment	2	Ambient	1-2 cm	8/14/2013	30.78	-27.85	31.4
Sediment	3	Ambient	0-1 cm	8/14/2013	1245.51	-27.35	28.4
Sediment	3	Ambient	1-2 cm	8/14/2013	366.25	-27.44	33.0
Sediment	1	Ambient	0-1 cm	10/13/2013	1060.63	-26.85	29.0
Sediment	1	Ambient	1-2 cm	10/13/2013	1077.19	-26.63	30.9
Sediment	2	Ambient	0-1 cm	10/13/2013	207.30	-27.50	31.4
Sediment	2	Ambient	0-1 cm	10/13/2013	265.53	-27.32	28.9
Sediment	2	Ambient	0-1 cm	10/13/2013	308.11	-27.71	31.1
Sediment	2	Ambient	1-2 cm	10/13/2013	81.20	-27.32	30.5
Sediment	3	Ambient	0-1 cm	10/13/2013	654.38	-27.13	27.5
Sediment	3	Ambient	1-2 cm	10/13/2013	374.65	-27.00	34.7
Sediment	2	Ambient	0-1 cm	5/22/2014	163.83	-27.89	29.8
Sediment	2	Ambient	1-2 cm	5/22/2014	69.01	-27.53	31.6
Sediment	1	Fertilized	0-1 cm	8/14/2013	1277.25	-27.32	33.4
Sediment	1	Fertilized	1-2 cm	8/14/2013	517.29	-27.41	33.7
Sediment	2	Fertilized	0-1 cm	8/14/2013	1386.55	-27.51	30.1
Sediment	2	Fertilized	1-2 cm	8/14/2013	327.13	-27.15	34.9
Sediment	1	Fertilized	0-1 cm	10/13/2013	304.84	-27.14	30.8
Sediment	1	Fertilized	1-2 cm	10/13/2013	321.71	-27.19	35.7
Sediment	2	Fertilized	0-1 cm	10/13/2013	837.97	-27.70	30.1
Sediment	2	Fertilized	1-2 cm	10/13/2013	283.23	-27.53	30.4
Sediment	3	Fertilized	0-1 cm	10/13/2013	2331.90	-27.42	34.1
Sediment	3	Fertilized	1-2 cm	10/13/2013	1319.63	-27.42	41.1
Sediment	2	Fertilized	0-1 cm	5/22/2014	496.81	-27.97	29.4
Sediment	2	Fertilized	1-2 cm	5/22/2014	288.74	-27.52	31.6

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