SPECIAL PUBLICATION SJ2008-SP15

ASSESSMENT OF THE EFFECTS OF LAND USE CHANGES ON LOWER ST. JOHNS RIVER BASIN WATERSHED DETRITAL INPUT (PHASE 2)

FINAL REPORT

Assessment of the Effects of Land Use Changes on Lower St. Johns River Basin Watershed Detrital Input (Phase 2)

Final Report – Contract Number SG465RA

Submitted to

Dr. Dean R. Dobberfuhl

Environmental Sciences, Water Resources

St. Johns River Water Management District

by

Arthur C. Benke, Ph.D.

Alexander D. Huryn, Ph.D.

Jonathan P. Benstead, Ph.D.

Michael A. Chadwick, Ph.D.

Heidi S. Wilcox, M.S.

Department of Biological Sciences

University of Alabama

Tuscaloosa, Alabama 35481

31 January 2008

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4. Effects of freshwater tidal flow on litter decomposition and macroinvertebrate community structure in urbanized tributaries of the lower St. Johns River, Florida

General Introduction

Conversion of land use from rural to urban can affect stream ecosystems via multiple pathways, including altered hydrology, water chemistry, channel geomorphology, and trophic resources (Paul and Meyer 2001). Hydrologic changes include increased total runoff, shorter duration and higher volume peak runoff, and altered baseflows (Gordon et al. 1992, Arnolds and Gibbons 1996, Booth and Jackson 1997, Paul and Meyer 2001). Water chemistry is widely acknowledged to be degraded in urbanized streams by both point and non-point sources of contaminants and nutrients (Porcella and Sorenson 1980, Paul and Meyer 2001, Pitt 1995, Hatt et al. 2004). Urbanized streams are also routinely widened and incised due to both altered hydrology and management (Booth 1990, Paul and Meyer 2001), and urban development is likely to result in changes to riparian vegetation which can dramatically alter trophic dynamics (Fisher and Likens 1973, Wallace et. al 1997, Naiman et al. 2005). Clearly, effects of catchment urbanization on stream ecosystems can arise from a myriad of interrelated sources.

The research conducted from September 2003 to August 2005 addressed the central question of what effects changing land use have played in detrital dynamics of small, headwater tributaries to the lower St. Johns River. The work was subdivided into three major tasks: 1) *quantifying detrital inputs along an urban-rural gradient*, 2) *assessing trophic changes in stream food-webs along an urban-rural gradient* and 3) *assessing downstream effects of altered detritus dynmics on stream communities*. In addressing *detrital inputs along an urban-rural gradient*, we quantified inputs of coarse particulate organic matter, estimated export of leaf litter, quantified standing crop of

benthic organic matter, and measured processing rates for coarse detritus. *Trophic changes along an urban-rural gradient* were measured using both functional and structural assessments of benthic invertebrates. These included preliminary measures of whole-stream metabolism and stable isotope analysis. Both methods showed potential to assess the relative importance of autochthonous and allochthonous organic matter. Assessment of *downstream effects* was limited to measure of coarse organic matter export.

The work conducted during the last two years of this funding sought to further understand the implications of catchment-scale land use changes on the structure and function of headwater tributaries of the lower St. Johns River. This work was divided into three areas: 1) metabolism and food web structure in stream reaches with *Hydrilla verticillata*, an invasive macrophyte, 2) ammonium uptakes rates in an urbanized, headwater tributary of the St. Johns River (Mimm's Creek), and 3) litter decomposition and benthic macroinvertebrate structure in streams that experience freshwater tidal flow regimes.

During the course of this work, the southeastern United States (including the greater Jacksonville area) began a period of below normal rainfall. These drought conditions resulted in decreases in stream discharge and required several modifications to the research tasks.

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2. Effects of *Hydrilla verticillata*, an Invasive Aquatic Macrophyte, on Stream Metabolism and Food Web Structure.

2.1 Introduction

Due to urban development, forest vegetation from the riparian zone of many headwater tributaries of the lower St. Johns River Basin has been removed. This alteration has increased the amount of sunlight received by these streams and facilitates the establishment of aquatic macrophytes, particularly *Hydrilla verticillata* (L. f.) Royle. *Hydrilla verticillata* is an invasive macrophyte that was introduced to Florida in the early 1950's (Schmitz et al. 1991). It spread quickly, likely due to vegetative reproduction (i.e., regrowth from stem fragments and tubers) and because aquatic habitats in Florida are excellent for *H. verticillata* growth. For example, the highest rates of photosynthesis and most favorable stem growth occurs at temperatures between 16-24^{o}C (Barko and Smart 1981), which are typical for many northern Florida streams. Under these conditions, stems can grow several meters per year. However, stems do senesce if exposed to colder temperatures (Cook and Luond 1982, Carter et al. 1994, Langland 1996) which can occur for limited periods in the northern St Johns basin. *H. verticillata* can also grow at low light levels relative to other macrophytes and stem elongation (2-6 meters) can occur even when light is near limiting levels (Haller and Sutton 1975, Barko and Smart 1981). Along with favorable conditions for growth, there are only a few herbivores in Florida aquatic systems that are known to feed on live *H. verticillata* stems, and these have been shown to have little effect on its distribution and growth (Langland 1996).

The introduction and spread of *H. verticillata* has had a dramatic effect on headwater tributaries of the St. Johns River. Although the changes brought on by *H. verticillata* in stream ecosystems are many, there are two factors that are of particular concern. First, relatively constant concentrations of dissolved oxygen are changed to widely fluctuating concentrations, from incipient anoxia during early morning to extreme supersaturation during afternoon. The effects of such fluctuations on a fauna adapted to the relatively constant conditions of the originally forested streams have probably been severe. Second, the source of organic carbon to the streams has shifted from a predominantly terrestrial origin (riparian leaf litter and dissolved organic carbon) to net production by autochthonous *H. verticillata* biomass. The shift of carbon sources from allochthonous leaf litter to autochthonous living *H. verticillata* biomass and detritus is likely to have large effects of stream food webs due to differences in food quality and seasonal availability. Given the potentially large amount of *H. verticillata* biomass produced in streams lacking canopy shading, this carbon source may form an important subsidy for detritivores.

The goal of this study was to quantify seasonal changes in metabolism and food web structure in stream reaches with and without *Hydrilla verticillata*. Our first objective was to determine how annual variation in *H. verticillata* affects net ecosystem metabolism. Based on a preliminary study (Fig. 1), we knew that daily patterns in oxygen concentrations change dramatically with the introduction of *H. verticillata*. In the absence of this macrophyte (i.e., shaded streams), dissolved oxygen concentrations show little daily fluctuations. When macrophytes are present (e.g., open canopy streams), dissolved oxygen has wide night- to-day fluctuations and anoxic conditions

can occur. However, the degree of variation of gross primary production (GPP) and community respiration (CR) among streams with differing amounts of *H. verticillata* is unknown. Also, unknown is how seasonal variations in temperature and subsequent *H. verticillata* biomass and detritus affect stream metabolism. Our second objective was to investigate how autochthonous vs. allochthonous resources affect stream food webs using stable isotopes of nitrogen and carbon as tracers. Specifically, we wanted to see if *H. verticillata* carbon is assimilated by consumers. Finally, we investigated how spatial and seasonal changes in *H. verticillata* biomass alters natural abundance nitrogen and carbon isotope signatures of the abundant taxa that comprise stream food webs.

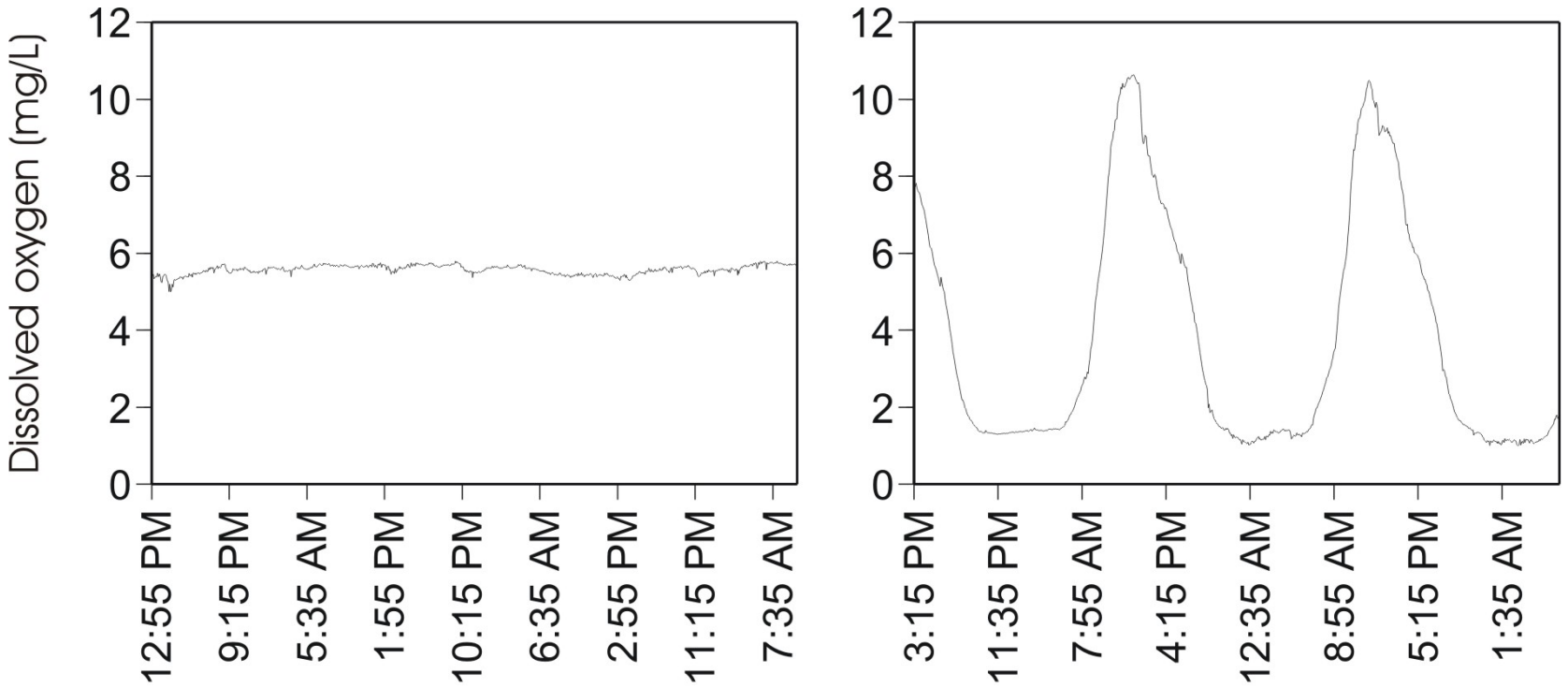

Figure 1. Dissolved oxygen concentrations measured at 5 minute intervals over a 48 hour period (23-26 May 2005) in two headwater tributaries of the St. Johns River (left panel=shaded stream lacking *Hydrilla verticillata* and 65-66% saturation; right panel= open canopy stream with *H. verticillata* present with a range of ~15% saturation during night to122% during day)**.**

2.2 Methods

2.2.1 Study sites

Three streams in the greater Jacksonville, Florida, area were the focus of this study (Fig. 2). Catchment boundaries and estimates of land cover were provided by the St. John's River Water Management District (Fig. 2, Table 1). Total impervious area was calculated using a normalized difference vegetation index (see Chadwick et al. 2006). Monthly water samples were analyzed for alkalinity (ALK), biological oxygen demand (BOD), chlorophyll a (Chla), conductivity (CON), dissolved oxygen (DO), dissolved organic carbon (DOC), ammonium (NH_4), nitrate (NO_3), total Kjeldahl nitrogen (TKN), pH, dissolved phosphate (PO_4), total dissolved phosphorus (TP), total dissolved solids (TDS), total suspended solids (TSS), volatile suspended solids (VSS), and a suite of metals (Al, Cd, Cu, Fe, Mg, Mn, Ni, Pb, Zn). Water was filtered on site and all samples were analyzed within 24 hours of collection. Water temperature, conductivity, and dissolved oxygen data were collected using a YSI DO meter. Both the St. Johns River Water Management District laboratory and contracted laboratories were used for analysis of the array of water quality constituents. All analyses were performed using U.S. EPA and Florida Department of Environmental Protection approved methods (40 CFR 100-149, APHA 1998). Current velocities, water depth, and cross-sectional area were measured in each stream and used to calculate discharge (Q).

In each stream, two 50-meter stream reaches were selected. The upstream reach lacked forested vegetation and dense stands of *H. verticillata* were present during some period of the year. The downstream reach had significant canopy cover and *H. verticillata* was absent. All streams had sandy substrata. Riparian canopies, where

present, were dominated by red maple (*Acer rubrum*), sweetgum (*Liquidambar styraciflua*), and water oak (*Quercus nigra*). Because of the low channel gradients, stream habitats were simple, being composed of runs with occasional coarse woody snags.

2.2.2 Hydrilla verticillata biomass

Benthic samples were collected in early December 2005, February 2006, July 2006, and October 2006 using a modified Hess sampler (0.07 m^2). At each stream, 5 randomly selected locations were selected and a sample was taken in the middle of the stream channel. The grabs were emptied into a 4 gallon bucket. All *H. verticillata* stems were removed by hand and placed in a plastic bag. Samples were either preserved in the field with ~5% formaldehyde or placed on ice and later frozen. Collected material was eventually dried to constant mass (60^o C), and then weighed. A portion from each sample was ashed (550^o C) and the ash weight was combined with dry weight to calculate ash free dry mass (AFDM).

2.2.3 Whole-stream metabolism

Respired (CR) and photosynthetically fixed carbon (GPP) was estimated using the single station dissolved oxygen change technique (Owens 1974, Bott 1996). YSI 600XL Multi-Parameter Water Quality probes were deployed in each reach for at least 24 hours in early December 2005, February 2006, July 2006, and October 2006. Sample periods were chosen such that water levels were stable (i.e., no storm flow). In each stream reach dissolved oxygen and temperature was recorded at one minute

intervals. Mean dissolved oxygen concentrations were then averaged over 15-min intervals (i.e., averaged from 1 minute intervals) and corrected for estimated oxygen reaeration. These records were then analyzed using the single-station night-time regression method to derive GPP and CR for each 15 minute interval (Owens 1974, Bott 1996, Fig. 3)

2.2.4 Natural abundance stable isotopes

The relative importance of *H. verticillata* as a source of carbon and nitrogen to stream food webs was assessed using stable isotope analysis. One to three replicate samples (depending on availability) of putative food sources and abundant consumers were collected quarterly (December 2005, February 2006, June 2006, and October 2006) from the study reaches. *Hydrilla verticillata* stems, coarse particulate matter (CPOM), and oxidized coarse particulate organic matter (OCPOM) were collected by hand. Fine particulate organic matter (FPOM) was collected from depositional area within the stream using a transfer pipette. Epilithon (epil) was scraped from available substrate and also rinsed from *H. verticillata* stems (i.e., epiphyton –epip). Sample were collected on a pre-ashed glass fiber filters. Invertebrates were collected with a kick net and by hand from representative habitats in all the reaches. Specimens were transported to the laboratory on ice and then frozen. Later, specimens were thawed, cleaned of any detached detritus, and their gut contents removed by dissection (with the exception of small chironomids). All material was dried at 50°C and finely ground in a Spex ball mill. Samples were then weighed to ~1 mg for each replicate. Larger taxa were analyzed individually (e.g. snails, clams, crayfish, dragonflies) while several

smaller taxa (e.g., amphipods and midges) were combined to form a single composite sample. Samples were then sent to the Colorado Plateau Stable Isotope Laboratory at Northern Arizona University for analysis.

Figure 2. The lower St. John's River, Florida and locations of the 3 study streams. In each stream, two fifty-meter stream reaches were selected. Upstream reaches lacked riparian forest vegetation and dense stands of *Hydrilla verticillata* were present during some period of the year. The downstream reaches had significant canopy cover and no *H. verticillata*.

Table 1. Summary of the distribution of percent land use, percent total impervious area (PTIA) and catchment area (ha) for the 3 study catchments.

site	agriculture	barren	rangeland	forests	urban	wetlands	PTIA	catchment area
5	0	2	6	6	73	8	26	686.72
11	0	13	1	13	60	9	35	261.57
13	0	1	0	1	85	13	17	63.65

Table 2. Selected physical and chemical conditions in the 3 tributaries on the St. Johns River, Florida. Alk = alkalinity reported in mg L^{-1}, Con = conductivity reported in µmhos cm^{-1}, DOC = dissolved organic carbon reported in mg L^{-1}, Nutrients are reported in mg L^{-1}, Q = discharge reported in L s^{-1}, metal are reported in µg L^{-1}. Values other than Q were collected prior to this study.

site	Alk	Con	DOC	pH	NH_4	NO_x	PO_4	Q
5	77	288	5.60	7.7	0.0133	0.0311	0.0096	55
11	128	383	7.98	7.4	0.0746	0.0601	0.0088	35
13	71	386	9.46	6.9	0.2058	0.6918	0.0064	11

Table 2 cont.

site	Al	Cd	Fe	Mg	Mn	Ni	Pb	Zn
5	274.09	0.18	866	8240	14.06	1.75	0.53	3.67
11	429.91	0.18	1306	6850	26.37	2.49	0.56	3.71
13	38.12	0.26	1028	8720	48.88	2.88	0.79	13.86

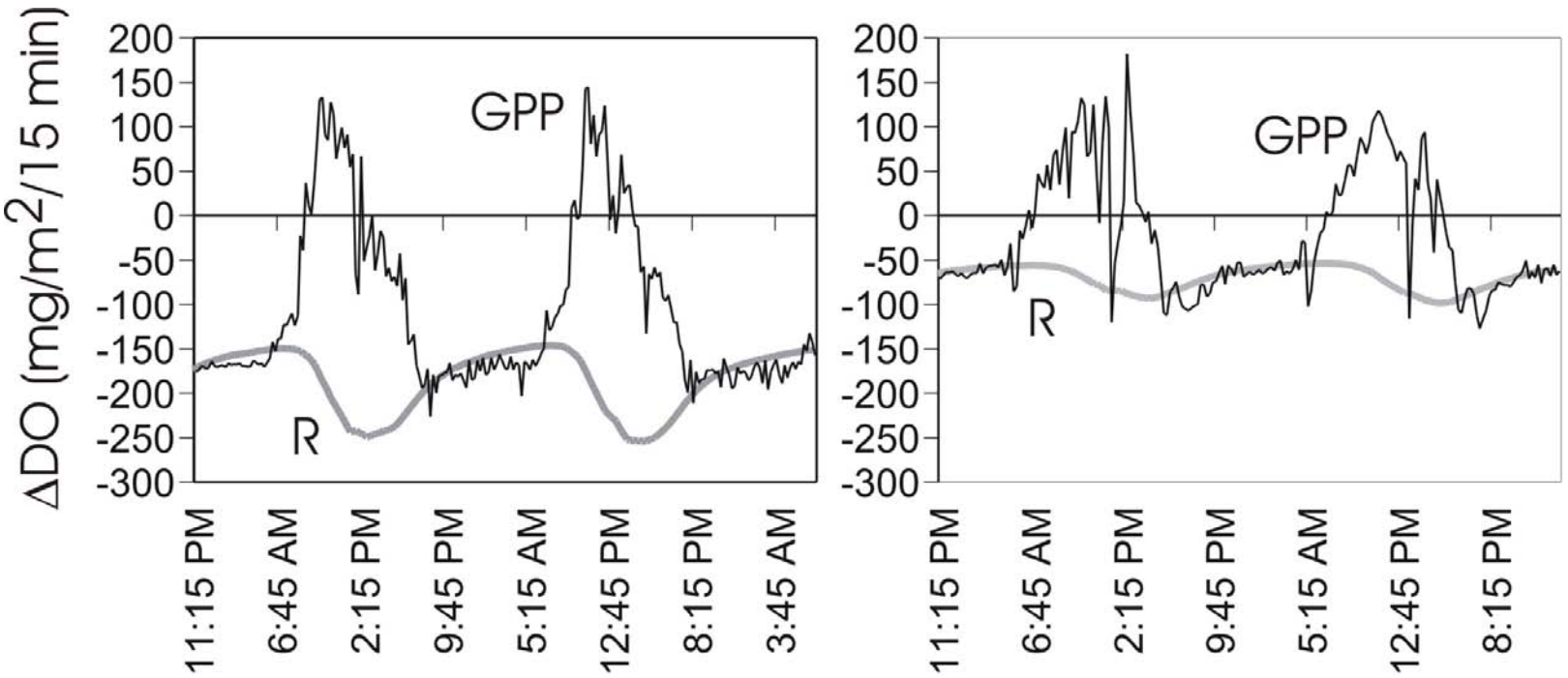

Figure 3. Respired and photosynthetically fixed carbon (i.e., whole-stream metabolism) estimated using the single station dissolved oxygen change technique in two headwater tributaries of the St. Johns River (23-26 May 2005). Gross primary production (GPP, above left) was 5.8 g AFDM m^{-2} d^{-1} and community respiration (R) was 12.7 g AFDM m^{-2} d^{-1}. GPP (above right) was 3.3 g AFDM m^{-2} d^{-1} and R was 4.6 g AFDM m^{-2} d^{-1}.

2.3 Results and Discussion

2.3.1 *Hydrilla verticillata* biomass

Hydrilla biomass among streams was variable (Fig. 4). The open canopy reach in stream 5 had the most consistent biomass of *H. verticillata* (100-200 g AFDM m^{-2}). Unfortunately, macrophytes invaded the closed canopy reach in stream 5 after beginning the study. *H. verticillata* was able to establish in this reach due to an opening in the canopy created by tree fall. By July 2006, average *H. verticillata* biomass reached approximately half the levels found in the open canopy reach. After a summer peak, the plant biomass decreased to very low levels by October. In stream 11, *H. verticillata* biomass was ~200-400 g AFDM m^{-2} during autumn, spring, and summer, but senesced completely during winter. No macrophytes were observed in the closed canopy reach in stream 11. Stream 13 had the lowest plant biomass (<100 g AFDM m^{-2}) and plants were only observed in summer and autumn. No macrophytes were observed in the closed canopy reach in stream 13.

H. verticillata biomass samples were collected on 4 additional occasions (January 2006, March 2006, May 2006, and August 2006). *H. verticillata* biomass for months where samples were not taken were estimated by averaging adjacent monthly values. AFDM of *H. verticillata* stems were converted to C by assuming that AFDM is equivalent to 40% C, Fig. 5). Using all of these values we made rough estimates of the rates of carbon gain or loss (Fig. 6).

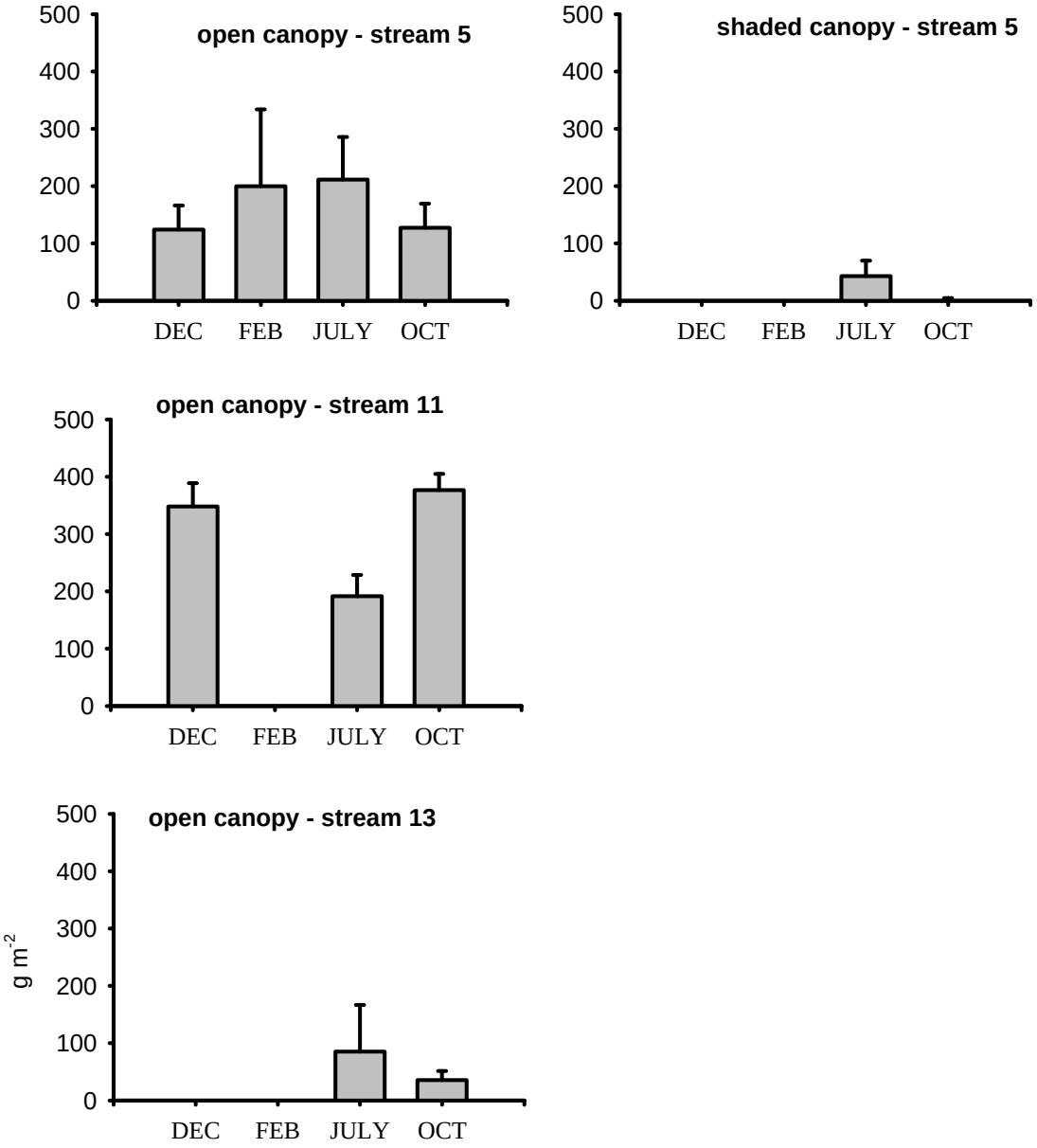

Figure 4. *Hydrilla verticillata* biomass (AFDM) sampled from all stream reaches where macrophyes occurred. Error bars are ±1 SE. No macrophytes occurred in the shaded reaches in streams 11 and 13. A gap in the canopy due to a fallen tree allowed *H. verticillata* to become established in the shade reach in stream 5.

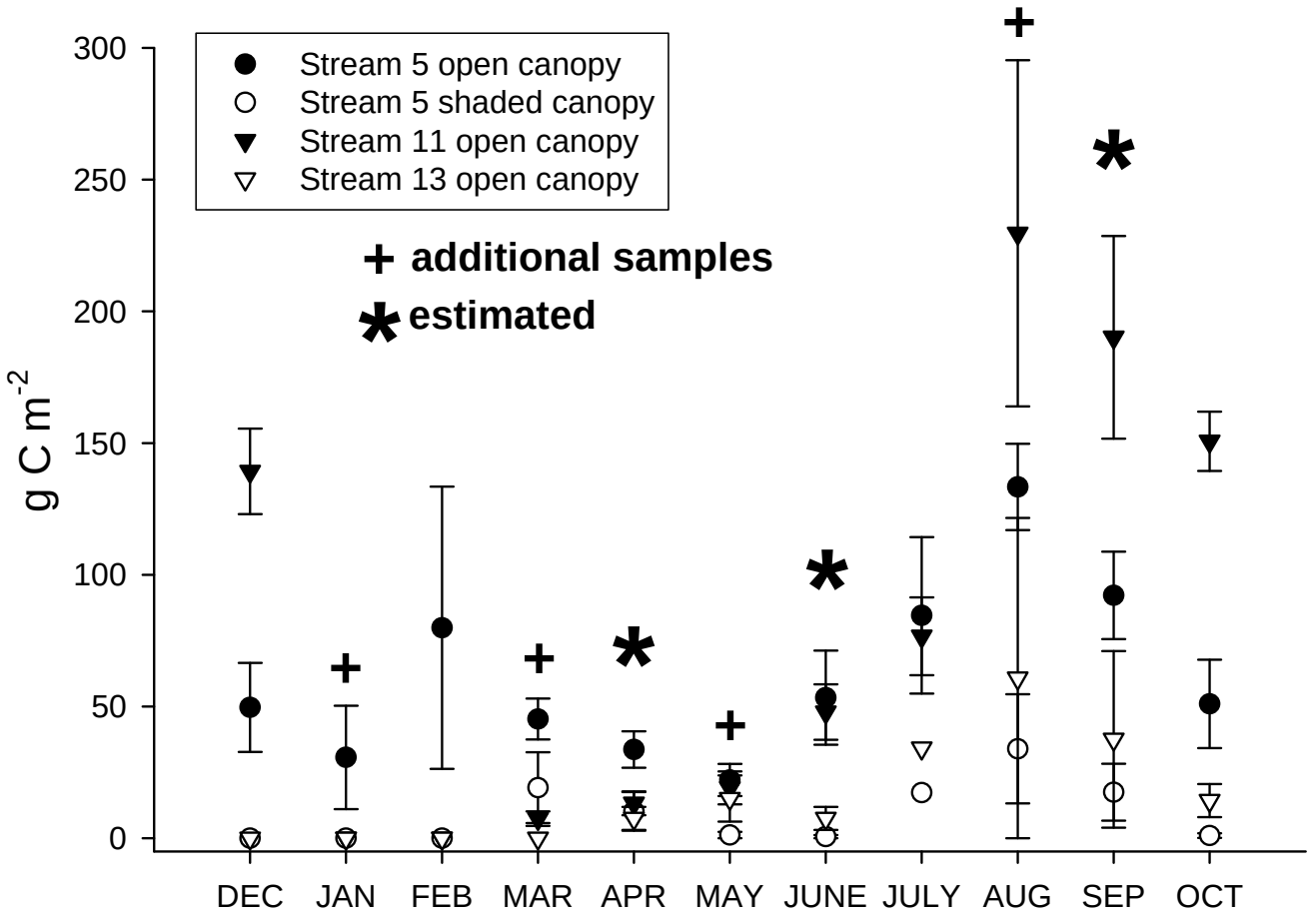

Figure 5. Summary of all *H. verticillata* biomass samples collected (January 2006, March 2006, May 2006, and August 2006) and estimated biomass for months where samples were not taken (April 2006 and June 2006).

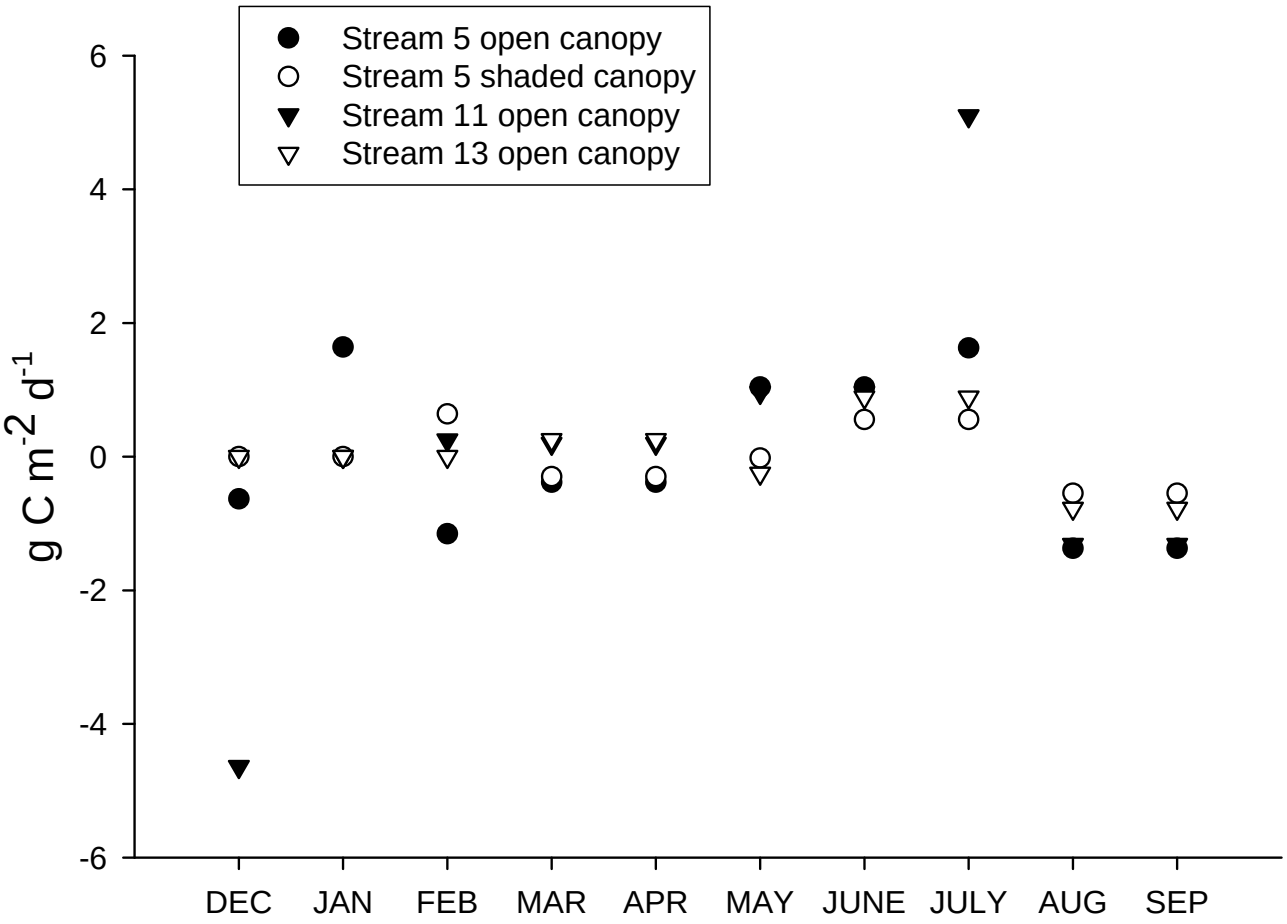

Figure 6. Monthly estimates of carbon gains or losses for *Hydrilla verticillata* biomass from all stream reaches.

Values of carbon gain or loss from all reaches ranged from ~-5 to 5 g C m^{-2} d^{-1}(Fig. 6). During growing periods, average carbon gains were ~1.3 g C m^{-2} d^{-1} (stream 5 - open canopy and stream 11) and ~0.6 g C m^{-2} d^{-1} (Stream 5 - shaded canopy and stream 13). During senescence, average carbon decreases were 0.88 g C m^{-2} d^{-1} (stream 5 –open canopy), 0.34 g C m^{-2} d^{-1} (stream 5 shaded canopy), 2.42 g C m^{-2} d^{-1} (stream 11), and 0.60 g C m^{-2} d^{-1} (stream 13).

2.3.2 Whole-stream metabolism

We were able to generate estimates of GPP and R for most dates when data loggers were deployed (Fig. 7). Gross primary production for the open canopy reach of stream 5 ranged from ~5 to 12 g AFDM m^{-2} d^{-1} while CR was between ~11 and 20 g AFDM $m^{-2}d^{-1}$ (Fig. 7). GPP/CR was ~0.5, except in December 2005 when GPP/CR was 1. For the shaded reach of stream 5, GPP ranged from ~4 to 10 g AFDM $m^{-2}d^{-1}$ and R ranged from 4 to 14 g AFDM m^{-2} d^{-1}. GPP/CR was always below 1 and ranged from 0.45 to 0.86.

The lowest values of GPP and CR for stream 5 (both reaches) occurred in July when temperature and day length were greatest. GPP/CR did not appear to be influenced by season. In the open reach of stream 11, GPP was < 2 g AFDM m^{-2} d^{-1} while R was ~18 g AFDM $m^{-2}d^{-1}$ in December 2005 and 31 g AFDM $m^{-2}d^{-1}$ in February 2006 (Fig. 7). The high R values were likely driven by *H. verticillata* decomposition. Management of this catchment includes periodic application of herbicides which results in *H. verticillata* stem die back. Accordingly, GPP/CR was low at ~0.1.

Metabolism was not estimated in July 2006 and October 2006 in the open reach of stream 11 due to anoxia. GPP during these periods, however, was likely high given the amount of biomass that accrued during these periods. If the maximum rate of *H. verticillata* carbon gain (~5 g C m^{-2} d^{-1} or 13 g AFDM m^{-2} d^{-1}, Fig. 6) is assumed to be equivalent to net primary production (NPP) and GPP = NPP/0.556, then GPP could be as high as ~22 g AFDM m^{-2} d^{-1} for *H. verticillata* alone (e.g., not including epiphytic and epilithic biofilms). In the shaded reach, GPP was also < 2 g AFDM $m^{-2}d^{-1}$, but CR ranged from ~6 to 8 g AFDM m^{-2} d^{-1} (Fig. 7). GPP/CR ranged from 0.1 to 0.3.

In stream 13 both data logger failure and anoxia prevented estimates of ecosystem metabolism for some dates. In the open canopy reach GPP varied from ~5 to 8 g AFDM m^{-2} d^{-1} while CR was from ~6 to 29 g AFDM m^{-2} d^{-1}. GPP/CR ranged from 0.4 to 0.8. In the shaded canopy, GPP was <2 and CR was ~6 g AFDM m^{-2} d^{-1}. GPP/CR was 0.23 in July 2006 and 0.03 in October 2006.

Both GPP and CR tended to be lower in the shaded reaches as would be expected. In the open canopy reaches, metabolism was influenced by the dynamics of *H. verticillata* growth and senescence. The open canopy reaches were autotrophic (i.e., GPP/CR>1) for short periods when photosynthetic rates were maximized. Overall, however, these reaches were highly heterotrophic (except stream 5 in December 2005). For example, respiration in stream 11 in the open canopy reach required 31 g AFDM m^{-2} d^{-1} while the total amount of organic matter produced by photosynthesis was only 2.5 g AFDM m^{-2} d^{-1} . Presumably the greater levels of respiration are related to stores of *H. verticillata* biomass, detritus, and smaller fractions of allochthonous organic matter. The lack of balance between GPP and CR clearly indicates that consumers require

supplemental sources (e.g., particulate or dissolved organic matter) to support their metabolic activity.

Estimates of GPP and CR using whole-system methods are complicated by fluxes of dissolved oxygen to and from the atmosphere (reaeration). The direction of flux is dependant on the level of oxygen saturation in the stream. Our estimates of reaeration using nighttime regression (Fig. 8; 0.001 to 0.092 min^{-1}, Owens 1974) were similar to those calculated using a tracer gas methods (Marzolf et al. 1994) in low gradient streams in southwestern Georgia (Mulholland et al. 2005). We attempted to calculate reaeration using the same technique (Marzolf et al. 1994), but found highly variable levels of tracer gas concentration suggesting that we injected the tracer gas (propane) too close to the study reach resulting in incomplete mixing at the upstream sampling location.

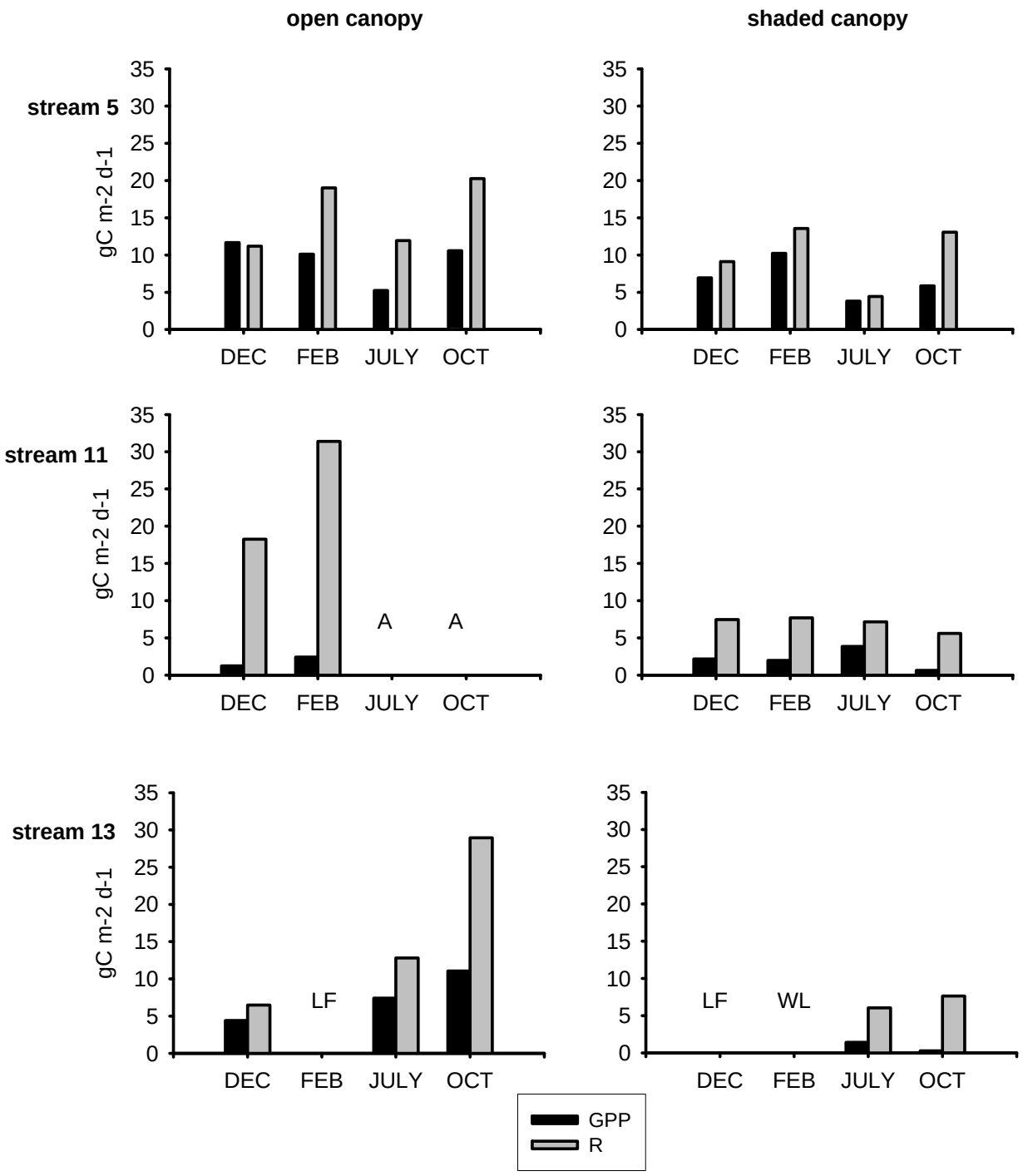

Figure 7. Gross primary production (GPP) and community respiration (R) estimated using the single station dissolved oxygen change technique. A = anoxic conditions, LF = logger failure, WL= unstable water level.

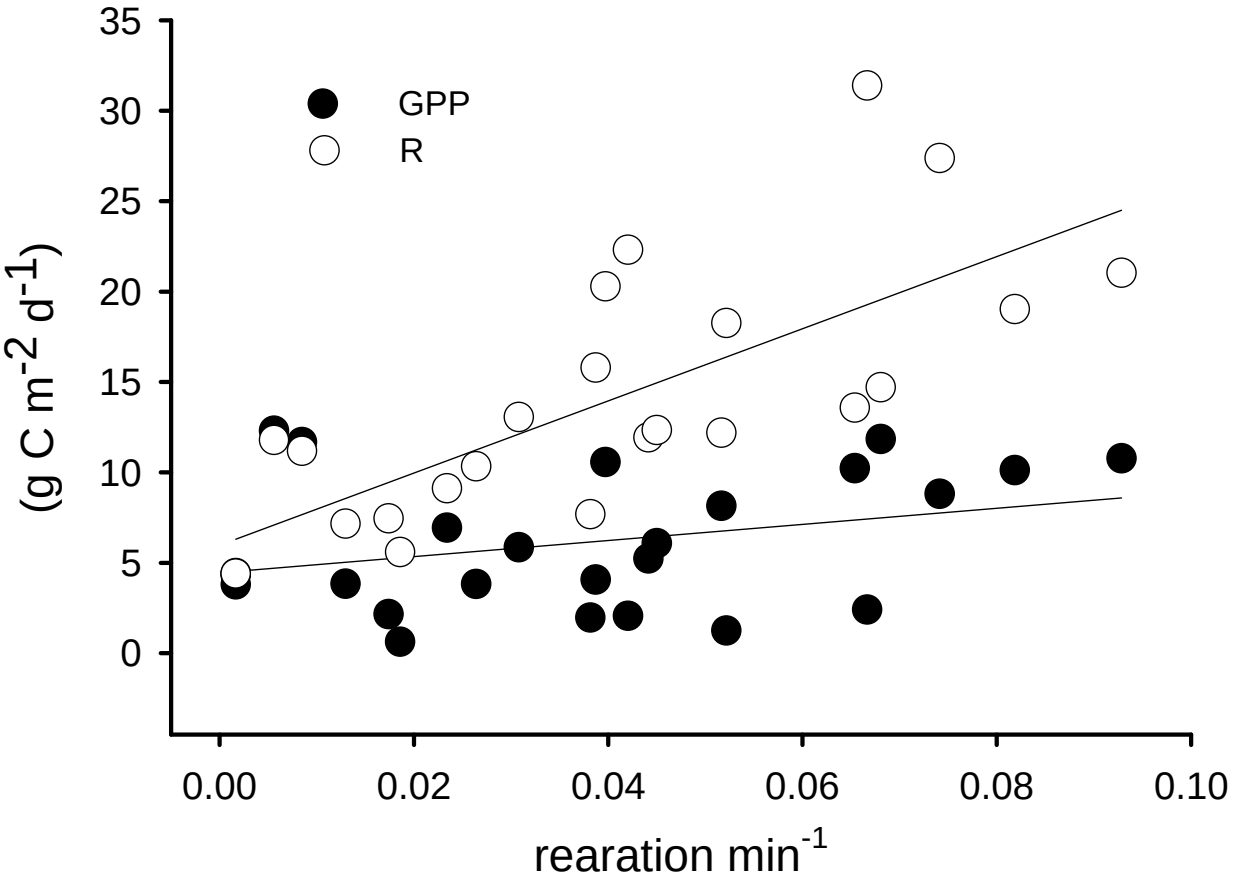

Figure 8. Estimated reaeration using nighttime regression methods.

2.3.4 Natural Abundance stable isotopes

Mean $\delta^{13}C$ values among putative food sources (*Hydrilla verticillata*, epiphyton, epilithon, CPOM, OCPOM, and FBOM) varied both by stream and reach (Fig. 9A-C, appendix). Stream 5 values ranged from -33‰ to -25‰ and there was considerable overlap among food sources regardless of reach location or date (Fig. 9A). This overlap was attributable to the establishment of *H. verticillata* in each reach. Stream 11 values were more variable and ranged from -37‰ to -24‰ (Fig 9b). *Hydrilla verticillata* was more negative than the other food sources. Further, positive shifts in *H. verticillata* in July potentially indicate a change in photosynthetic pathways that have been suggested for this macrophyte (Langland 1996). Stream 13 showed similar patterns to stream 5 with most food sources having overlapping $\delta^{13}C$ values. These values for this stream ranged from -34‰ to -21‰ (Fig 9c). Similar to stream 11, *Hydrilla verticillata* again had the most negative signature (-34‰).

Mean $\delta^{15}N$ values among consumers (*Hydrilla verticillata*, epiphyton, epilithon, CPOM, OCPOM, and FBOM) tended to overlap between the open canopy and shaded reaches, but differed among streams (Fig. 9A-A, appendix). Stream 5 values ranged from 0‰ to 8‰ (Fig. 9a). CPOM values were lowest (0‰) and *H. verticillata* values were the highest (6‰ to 8‰). Stream 11 values were ranged from 0‰ to 5‰. Again CPOM values were ~0‰, but H. *verticillata* values were ~5‰ (Fig 9b). Stream 13 showed a much different pattern than the other streams and signatures were not similar among dates (Fig. 9c). Ranges of $\delta^{15}N$ values were 2‰ to 4‰ in December, 2‰ to 10‰ in February, 0‰ to 15‰ in June, and 2‰ to 14‰ in October. These differences observed among all of the streams and within stream13 throughout the course of the

year are likely related to changes in anthropogenic sources of nitrogen (Mcclelland et al. 1997, Wayland and Hobson 2001, deBruyn and Rasmussen 2002, Ulseth and Hershey, 2005). Sewage and fertilizer are known to have relatively high $\delta^{15}N$ values compared to natural sources and this is likely to be the case for these streams. The increased variation during the course of the year, particularly for stream 13, may suggest that fertilizers applied to maintain growing lawns could be the N source.

In general, patterns in consumer signatures among streams and dates reflect the overlap in putative food sources (Fig 9A-C). However, where *H. verticillata* values differed from other food sources (e.g., stream 11) taxon-specific signatures reflected these differences. For example, in stream 11 (December and June) taxa collected in the open canopy reach had more negative $\delta^{13}C$ signatures than the same taxa collected in the shaded reach. *H. verticillata* may thus be a significant source of carbon for primary consumers. Further, because both detritivores (Cambaridae, *Hyallela*, *Melanoides*) and predators (*Gambusia*, Hirudinea, Zygoptera) had non-overlapping δ13C values, this demonstrates that *H. verticillata* carbon may be important for supporting food webs in these streams.

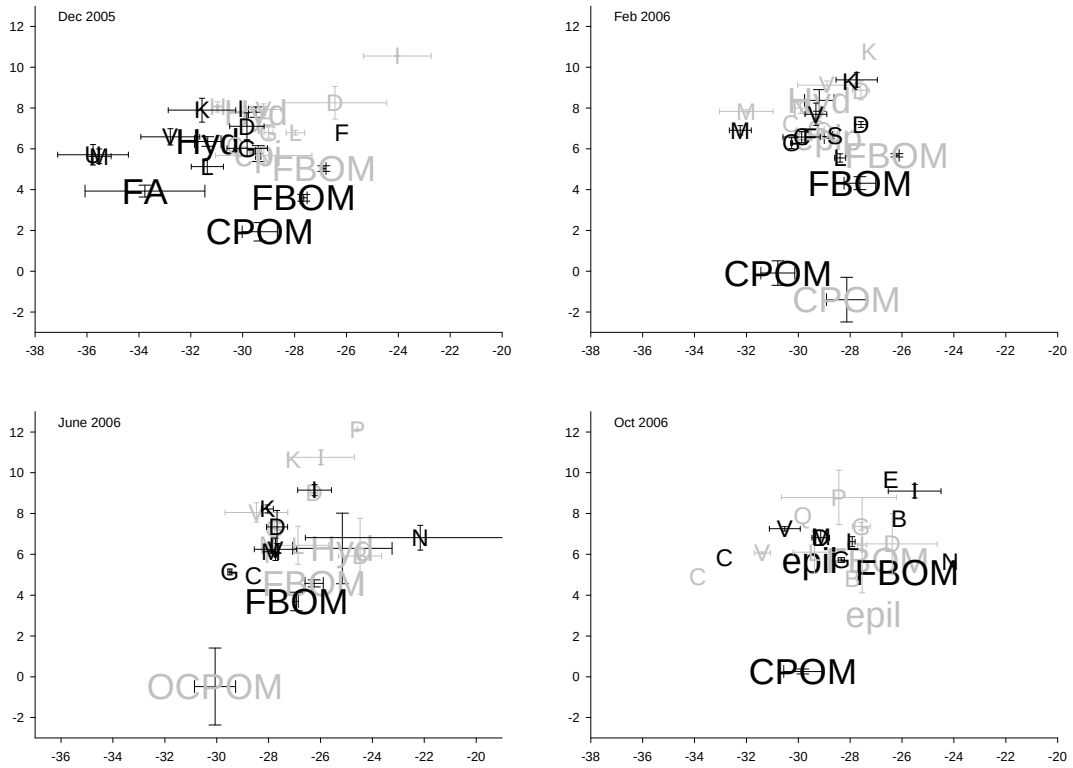

Figure 9a. Average $\delta^{13}C$ and δ^{15} N values for putative food sources and consumers for stream 5 in December 2005, February 2006, June 2006, and October 2006. Error bars are ±1 SE. Taxon names associated with each letter are found in the appendix.

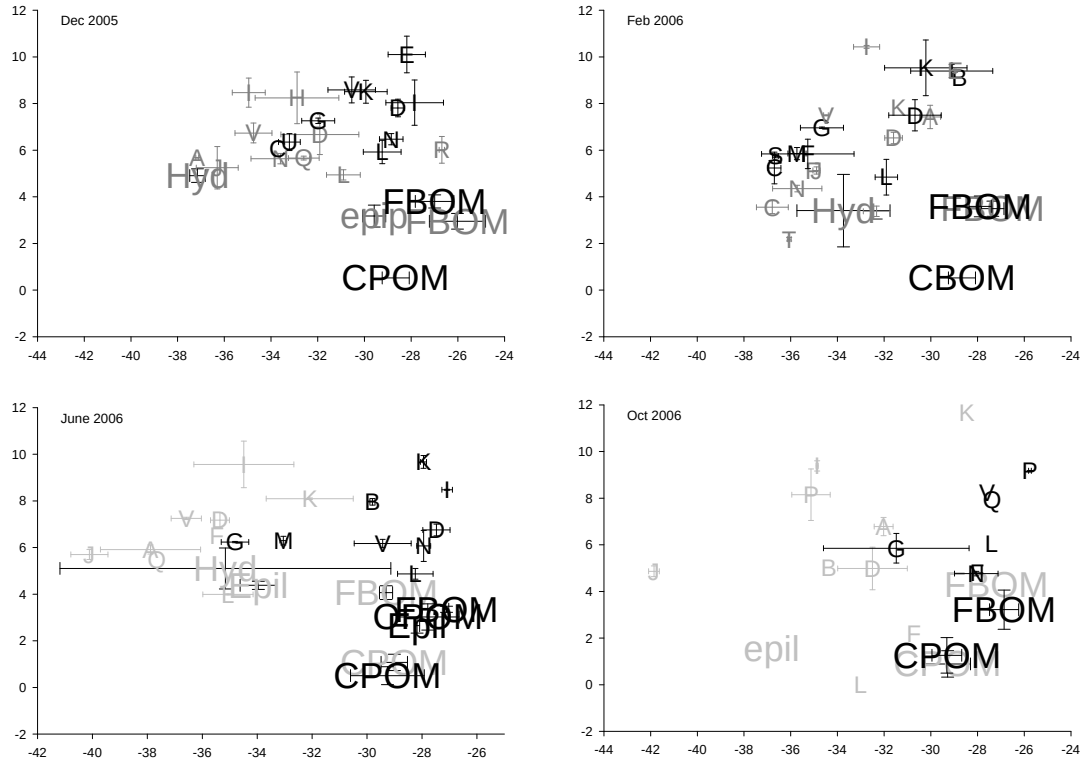

Figure 9b. Average $\delta^{13}C$ and $\delta^{15}N$ values for putative food sources and consumers for stream 11 in December 2005, February 2006, June 2006, and October 2006. Error bars are ±1 SE. Taxon names associated with each letter are found in the appendix..

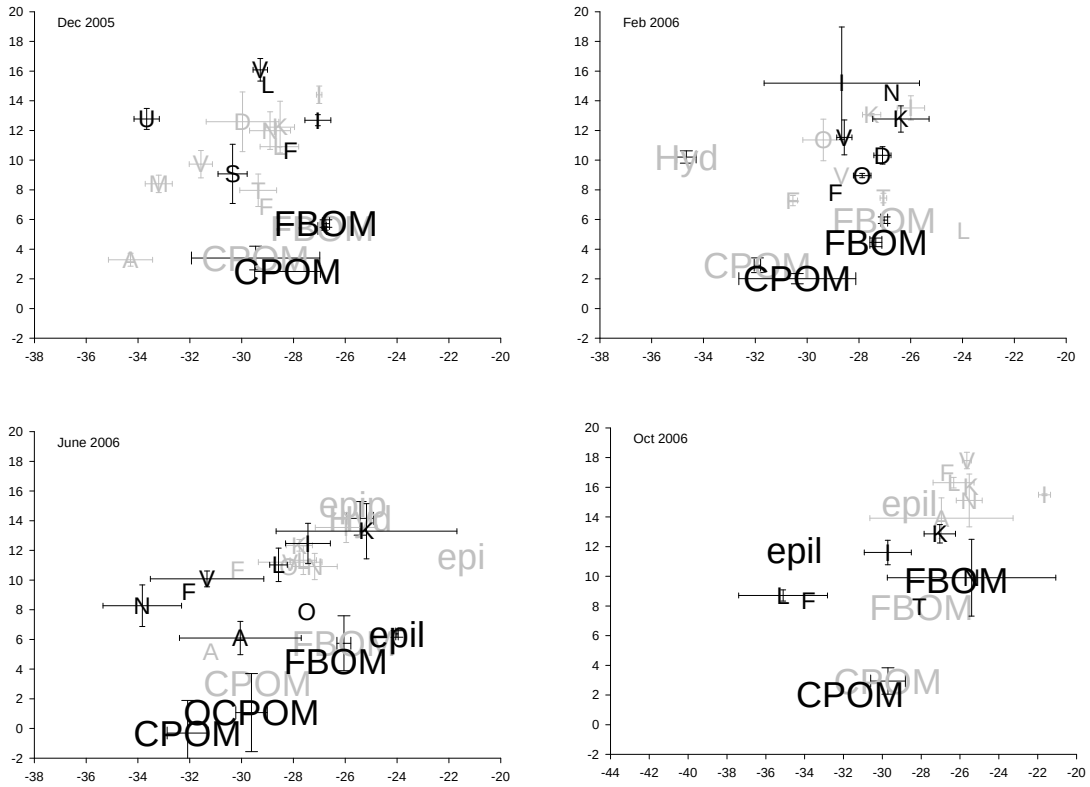

Figure 9c. Average $\delta^{13}C$ and δ^{15} N values for putative food sources and consumers for stream 13 in December 2005, February 2006, June 2006, and October 2006. Error bars are ±1 SE. Taxon names associated with each letter are found in the appendix.

2.4 Conclusions

The establishment of *H. verticillata*, driven by the removal of riparian trees, leads to dramatic changes in the chemical conditions of these streams. In fact, where *H. verticillata* biomass was the greatest anoxic conditions developed for extended periods. The macrophyte also greatly increases gross primary production, but the streams continue to have net heterotrophic conditions. This suggests potential carbon limitation can arise in reaches where *H. verticillata* is present, especially given the removal of other allochthonous carbon sources. Further, the establishment of *H. verticillata* in stream reaches leads to increased levels of community respiration and clearly macrophyte detritus fuels this activity. Natural abundance stable isotopes showed that *H. verticillata* derived carbon was present in the food webs of open canopy reaches. Unlike natural abundance carbon found in consumers, *H. verticillata* did not appear to alter nitrogen dynamics and this is likely related to the fact that nitrogen signatures are influenced by anthropogenic sources that change based on the type and degree of urban development.

Unlike our past work (Chadwick et al. 2006) where urbanization at the catchment –scale influenced ecosystem function (litter decomposition), this work shows that ecosystem function (metabolism) is affected by urban development at reach-scales. Potentially, degradation to streams where *H. verticillata* is not present could be avoided and restoration of channels where it is present could be achieved via riparian management that preserves vegetation that shades stream channels.

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2.6 Appendix 1

Average $\delta^{13}C$ and δ^{15} N values for putative food sources and consumers. Standard errors are reported parenthetically.

reach	stream	date	item	graph ID	$\delta^{13}C$	δ^{15} N
open canopy	5	Dec-05	FBOM	FBOM	-26.87 (0.08)	5.03 (0.14)
open canopy	5	Dec-05	*Hydrilla* rinse	epip	-29.49 (0.29)	7.80 (0.26)
open canopy	5	Dec-05	*Hydrilla* stems	Hyd	-29.49 (0.29)	7.80 (0.26)
open canopy	5	Dec-05	*Caenis*	C	-30.30 (NA)	6.18 (NA)
open canopy	5	Dec-05	Cambaridae	D	-26.44 (2.00)	8.26 (0.80)
open canopy	5	Dec-05	Chironomidae	F	-29.20 (NA)	7.12 (NA)
open canopy	5	Dec-05	*Corbicula*	G	-29.00 (0.17)	6.80 (0.27)
open canopy	5	Dec-05	*Fundulus*	H	-30.96 (0.04)	8.05 (0.25)
open canopy	5	Dec-05	*Gambusia*	I	-24.04 (1.31)	10.56 (0.01)
open canopy	5	Dec-05	*Hyallela*	L	-27.97 (0.36)	6.79 (0.11)
open canopy	5	Dec-05	*Melanoides*	N	-29.19 (1.86)	5.67 (0.39)
open canopy	5	Dec-05	Zygoptera	V	-29.20 (0.67)	7.93 (0.27)
shaded canopy	5	Dec-05	CPOM	CPOM	-29.34 (0.68)	1.93 (0.45)
shaded canopy	5	Dec-05	FBOM	FBOM	-27.65 (0.13)	3.60 (0.16)
shaded canopy	5	Dec-05	Filamentous algae	FA	-33.76 (2.31)	3.93 (0.29)
shaded canopy	5	Dec-05	*Hydrilla* rinse	epip	-31.34 (0.51)	6.36 (0.23)
shaded canopy	5	Dec-05	*Hydrilla* stems	Hyd	-31.34 (0.51)	6.36 (0.23)
shaded canopy	5	Dec-05	Cambaridae	D	-29.84 (0.66)	7.11 (0.66)
shaded canopy	5	Dec-05	Chironomidae	F	-26.18 (NA)	6.78 (NA)
shaded canopy	5	Dec-05	*Corbicula*	G	-29.83 (0.78)	6.03 (0.39)
shaded canopy	5	Dec-05	*Gambusia*	I	-30.07 (NA)	7.96 (NA)
shaded canopy	5	Dec-05	Hirudinea	K	-31.57 (1.30)	7.90 (0.58)
shaded canopy	5	Dec-05	*Hyallela*	L	-31.36 (0.62)	5.13 (0.39)
shaded canopy	5	Dec-05	Hydropsychidae	M	-35.53 (0.46)	5.63 (0.36)
shaded canopy	5	Dec-05	Trichoptera	U	-35.77 (1.36)	5.71 (0.50)

reach	stream	date	item	graph ID	$\delta^{13}C$	$\delta^{15}N$
shaded canopy	5	Dec-05	Zygoptera	V	-32.79 (1.13)	6.59 (0.40)
open canopy	5	Feb-06	CPOM	CPOM	-28.13 (0.78)	-1.40 (1.10)
open canopy	5	Feb-06	FBOM	FBOM	-26.20 (0.09)	5.68 (0.08)
open canopy	5	Feb-06	*Hydrilla* rinse	epip	-28.83 (0.17)	6.56 (0.05)
open canopy	5	Feb-06	*Hydrilla* rinse	epip	-29.19 (0.57)	8.38 (0.53)
open canopy	5	Feb-06	*Hydrilla* stems	Hyd	-29.19 (0.57)	8.38 (0.53)
open canopy	5	Feb-06	*Caenis*	C	-30.28 (NA)	7.25 (NA)
open canopy	5	Feb-06	Cambaridae	D	-27.59 (0.32)	8.87 (0.46)
open canopy	5	Feb-06	*Corbicula*	G	-29.27 (0.27)	6.99 (0.26)
open canopy	5	Feb-06	Hirudinea	K	-27.27 (NA)	10.77 (NA)
open canopy	5	Feb-06	*Hyallela*	L	-28.62 (0.12)	6.73 (0.30)
open canopy	5	Feb-06	Hydropsychidae	M	-32.00 (1.04)	7.84 (0.08)
open canopy	5	Feb-06	*Melanoides*	N	-29.92 (0.22)	8.00 (0.26)
open canopy	5	Feb-06	Sphaeridae	S	-29.03 (NA)	6.89 (NA)
open canopy	5	Feb-06	Zygoptera	V	-28.90 (1.13)	9.13 (0.20)
shaded canopy	5	Feb-06	CPOM	CPOM	-30.79 (0.66)	- 0.09 (0.60)
shaded canopy	5	Feb-06	FBOM	FBOM	-27.62 (0.61)	4.32 (0.31)
shaded canopy	5	Feb-06	*Caenis*	C	-29.87 (0.72)	6.58 (0.27)
shaded canopy	5	Feb-06	Cambaridae	D	-27.58 (0.25)	7.20 (0.14)
shaded canopy	5	Feb-06	Chironomidae	F	-29.56 (NA)	6.60 (NA)
shaded canopy	5	Feb-06	*Corbicula*	G	-30.26 (0.04)	6.28 (0.26)
shaded canopy	5	Feb-06	*Gambusia*	I	-27.74 (0.80)	9.38 (0.35)
shaded canopy	5	Feb-06	Hirudinea	K	-27.99 (NA)	9.30 (NA)
shaded canopy	5	Feb-06	*Hyallela*	L	-28.38 (0.21)	5.55 (0.21)
shaded canopy	5	Feb-06	Hydropsychidae	M	-32.23 (0.42)	6.91 (0.23)
shaded canopy	5	Feb-06	Sphaeridae	S	-28.57 (NA)	6.65 (NA)
shaded canopy	5	Feb-06	Zygoptera	V	-29.32 (0.42)	7.70 (0.54)
open canopy	5	Jun-06	FBOM	FBOM	-26.24 (0.35)	4.58 (0.17)
open canopy	5	Jun-06	*Hydrilla* rinse	epip	-25.16 (1.92)	6.29 (1.73)
open canopy	5	Jun-06	*Hydrilla* stems	Hyd	-25.16 (1.92)	6.29 (1.73)

reach	stream	date	item	graph ID	$\delta^{13}C$	$\delta^{15}N$
open canopy	5	Jun-06	Oxidized CPOM	OCPOM	-30.06 (0.79)	-0.48 (1.89)
open canopy	5	Jun-06	Belostomatidae	B	-24.47 (0.83)	5.91 (1.85)
open canopy	5	Jun-06	Cambaridae	D	-26.24 (0.14)	9.02 (0.01)
open canopy	5	Jun-06	Chironomidae	F	-27.89 (NA)	6.00 (NA)
open canopy	5	Jun-06	*Corbicula*	G	-27.78 (0.16)	7.27 (0.41)
open canopy	5	Jun-06	*Gambusia*	I	-25.98 (1.29)	10.76 (0.36)
open canopy	5	Jun-06	Hirudinea	K	-27.05 (NA)	10.64 (NA)
open canopy	5	Jun-06	*Hyallela*	L	-26.86 (1.18)	6.44 (0.93)
open canopy	5	Jun-06	Hydropsychidae	M	-27.97 (NA)	6.48 (NA)
open canopy	5	Jun-06	*Poecilia*	P	-24.58 (0.01)	12.13 (0.00)
open canopy	5	Jun-06	Zygoptera	V	-28.47 (1.21)	8.05 (0.48)
shaded cano py	5	Jun-06	epilithon	epil	-17.37 (0.38)	5.52 (0.91)
shaded canopy	5	Jun-06	FBOM	FBOM	-26.92 (0.07)	3.69 (0.46)
shaded canopy	5	Jun-06	*Caenis*	C	-28.58 (NA)	4.96 (NA)
shaded canopy	5	Jun-06	Cambaridae	D	-27.67 (0.40)	7.34 (0.81)
shaded canopy	5	Jun-06	*Corbicula*	G	-29.50 (0.07)	5.14 (0.15)
shaded canopy	5	Jun-06	*Gambusia*	I	-26.23 (0.65)	9.15 (0.27)
shaded canopy	5	Jun-06	Hirundinea	K	-28.04 (0.23)	8.23 (0.20)
shaded canopy	5	Jun-06	*Hyallela*	L	-27.74 (NA)	6.44 (NA)
shaded canopy	5	Jun-06	Hydropsychidae	M	-27.91 (0.30)	6.13 (0.07)
shaded canopy	5	Jun-06	*Melanoides*	N	-22.15 (4.43)	6.82 (0.61)
shaded canopy	5	Jun-06	Zygoptera	V	-27.73 (0.82)	6.25 (0.55)
open canopy	5	Oct-06	epilithon	epil	-27.09 (NA)	3.07 (NA)
open canopy	5	Oct-06	FBOM	FBOM	-26.94 (NA)	5.69 (NA)
open canopy	5	Oct-06	Belostomatidae	B	-27.91 (NA)	4.79 (NA)
open canopy	5	Oct-06	*Caenis*	C	-33.88 (NA)	4.89 (NA)
open canopy	5	Oct-06	Cambaridae	D	-26.37 (1.73)	6.51 (1.48)
open canopy	5	Oct-06	*Corbicula*	G	-27.57 (0.34)	7.37 (0.19)
open canopy	5	Oct-06	*Gambusia*	I	-27.54 (0.18)	6.45 (2.33)
open canopy	5	Oct-06	Hyallela	L	-30.41 (NA)	3.75 (NA)

reach	stream	date	item	graph ID	$\delta^{13}C$	$\delta^{15}N$
open canopy	5	Oct-06	*Hyallela*	L	-29.37 (0.82)	6.10 (1.03)
open canopy	5	Oct-06	*Poecilia*	P	-28.43 (2.22)	8.79 (1.33)
open canopy	5	Oct-06	*Pomacea*	Q	-29.83 (NA)	7.88 (NA)
open canopy	5	Oct-06	Zygoptera	V	-31.38 (0.31)	6.07 (0.05)
shaded canopy	5	Oct-06	CPOM	CPOM	-29.82 (0.74)	0.26 (0.13)
shaded canopy	5	Oct-06	epilithon	epil	-29.56 (NA)	5.72 (NA)
shaded canopy	5	Oct-06	FBOM	FBOM	-25.80 (NA)	5.09 (NA)
shaded canopy	5	Oct-06	Belostomatidae	B	-26.11 (NA)	7.73 (NA)
shaded canopy	5	Oct-06	*Caenis*	C	-32.84 (NA)	5.86 (NA)
shaded canopy	5	Oct-06	Cambaridae	D	-29.13 (0.34)	6.81 (0.37)
shaded canopy	5	Oct-06	Centrarchidae	E	-26.43 (NA)	9.68 (NA)
shaded canopy	5	Oct-06	*Corbicula*	G	-28.34 (0.12)	5.72 (0.12)
shaded canopy	5	Oct-06	*Gambusia*	I	-25.51 (1.02)	9.10 (0.34)
shaded canopy	5	Oct-06	*Hyallela*	L	-27.92 (0.11)	6.62 (0.24)
shaded canopy	5	Oct-06	Hydropsychidae	M	-29.12 (NA)	6.89 (NA)
shaded canopy	5	Oct-06	*Melanoides*	N	-24.14 (NA)	5.63 (NA)
shaded canopy	5	Oct-06	Zygoptera	V	-30.52 (0.60)	7.26 (0.10)
open canopy	11	Dec-05	FBOM	FBOM	-26.02 (1.20)	2.95 (0.34)
open canopy	11	Dec-05	*Hydrilla* rinse	epip	-29.58 (0.49)	3.18 (0.47)
open canopy	11	Dec-05	*Hydrilla* stems	Hyd	-37.15 (0.33)	4.91 (0.29)
open canopy	11	Dec-05	Anuran larvae	A	-37.16 (0.06)	5.68 (0.01)
open canopy	11	Dec-05	Cambaridae	D	-31.91 (1.67)	6.67 (0.85)
open canopy	11	Dec-05	*Fundulus*	H	-32.89 (1.79)	8.24 (1.11)
open canopy	11	Dec-05	*Gambusia*	I	-34.95 (0.71)	8.47 (0.62)
open canopy	11	Dec-05	Haliplidae	J	-36.30 (0.90)	5.25 (0.91)
open canopy	11	Dec-05	*Hyallela*	L	-30.90 (0.72)	4.94 (0.22)
open canopy	11	Dec-05	*Melanoides*	N	-33.60 (1.26)	5.64 (0.22)
open canopy	11	Dec-05	*Pomacea*	Q	-32.60 (0.66)	5.66 (0.08)
open canopy	11	Dec-05	Pomacea eggs	R	-26.69 (0.11)	6.01 (0.57)

reach	stream	date	item	graph ID	$\delta^{13}C$	$\delta^{15}N$
open canopy	11	Dec-05	Zygoptera	V	-34.75 (0.79)	6.74 (0.42)
shaded canopy	11	Dec-05	CPOM	CPOM	-28.66 (0.58)	0.52 (0.00)
shaded canopy	11	Dec-05	FBOM	FBOM	-27.00 (0.83)	3.80 (0.28)
shaded canopy	11	Dec-05	*Caenis*	B	-33.72 (NA)	6.08 (NA)
shaded canopy	11	Dec-05	Cambaridae	D	-28.57 (0.29)	7.81 (0.38)
shaded canopy	11	Dec-05	Centrarchidae	E	-28.19 (0.80)	10.10 (0.79)
shaded canopy	11	Dec-05	*Corbicula*	G	-31.98 (0.71)	7.26 (0.12)
shaded canopy	11	Dec-05	*Gambusia*	I	-27.85 (1.23)	8.04 (0.97)
shaded canopy	11	Dec-05	Hirudinea	K	-29.94 (0.91)	8.51 (0.49)
shaded canopy	11	Dec-05	*Hyallela*	L	-29.95 (1.86)	6.77 (0.08)
shaded canopy	11	Dec-05	*Melanoides*	N	-28.85 (0.50)	6.47 (0.24)
shaded canopy	11	Dec-05	Trichoptera	U	-33.21 (0.47)	6.35 (0.36)
shaded canopy	11	Dec-05	Zygoptera	V	-30.54 (1.02)	8.58 (0.56)
open canopy	11	Feb-06	FBOM	FBOM	-27.35 (0.48)	3.49 (0.33)
open canopy	11	Feb-06	*Hydrilla* rinse	epip	-33.74 (2.00)	3.41 (1.56)
open canopy	11	Feb-06	*Hydrilla* stems	Hyd	-33.74 (2.00)	3.41 (1.56)
open canopy	11	Feb-06	Anuran larvae	A	-30.03 (0.45)	7.43 (0.50)
open canopy	11	Feb-06	*Caenis*	C	-36.79 (0.68)	3.55 (0.27)
open canopy	11	Feb-06	Cambaridae	D	-31.59 (0.38)	6.52 (0.24)
open canopy	11	Feb-06	Chironomidae	F	-35.06 (NA)	5.13 (NA)
open canopy	11	Feb-06	*Gambusia*	I	-32.75 (0.56)	10.43 (0.06)
open canopy	11	Feb-06	Haliplidae	J	-34.89 (0.15)	5.13 (0.15)
open canopy	11	Feb-06	Hirudinea	K	-31.39 (NA)	7.84 (NA)
open canopy	11	Feb-06	*Hyallela*	L	-32.32 (0.57)	3.38 (0.22)
open canopy	11	Feb-06	*Melanoides*	N	-35.72 (1.05)	4.36 (0.14)
open canopy	11	Feb-06	Tipulidae	T	-36.06 (0.08)	2.18 (0.08)
shaded canopy	11	Feb-06	FBOM	FBOM	-27.89 (0.47)	3.59 (0.45)
shaded canopy	11	Feb-06	Belostomatidae	B	-28.77 (NA)	9.12 (NA)
shaded canopy	11	Feb-06	*Caenis*	C	-36.69 (0.28)	5.24 (0.68)
shaded canopy	11	Feb-06	Cambaridae	D	-30.68 (1.12)	7.50 (0.67)

reach	stream	date	item	graph ID	$\delta^{13}C$	$\delta^{15}N$
shaded canopy	11	Feb-06	Centrarchidae	E	-28.96 (0.03)	9.39 (0.06)
shaded canopy	11	Feb-06	Chironomidae	F	-35.27 (1.98)	5.84 (0.63)
shaded canopy	11	Feb-06	*Corbicula*	G	-34.66 (0.92)	6.96 (0.03)
shaded canopy	11	Feb-06	*Gambusia*	I	-29.10 (1.76)	9.40 (0.28)
shaded canopy	11	Feb-06	Hirudinea	K	-30.21 (1.76)	9.53 (1.19)
shaded canopy	11	Feb-06	*Hyallela*	L	-31.90 (0.48)	4.84 (0.77)
shaded canopy	11	Feb-06	Hydropsychidae	M	-35.73 (0.39)	5.85 (0.26)
shaded canopy	11	Feb-06	Sphaeridae	S	-36.65 (0.13)	5.75 (0.08)
shaded canopy	11	Feb-06	Zygoptera	V	-34.49 (0.10)	7.49 (0.02)
open canopy	11	Jun-06	CPOM	CPOM	-29.01 (0.48)	1.08 (0.35)
open canopy	11	Jun-06	epilithon	epil	-33.96 (0.66)	4.38 (0.17)
open canopy	11	Jun-06	FBOM	FBOM	-29.31 (0.24)	4.07 (0.29)
open canopy	11	Jun-06	*Hydrilla* rinse	epip	-35.16 (6.03)	5.10 (0.88)
open canopy	11	Jun-06	*Hydrilla* stems	Hyd	-35.16 (6.03)	5.10 (0.88)
open canopy	11	Jun-06	Anuran larvae	A	-37.89 (1.82)	5.91 (0.20)
open canopy	11	Jun-06	Cambaridae	D	-35.36 (0.34)	7.17 (0.33)
open canopy	11	Jun-06	Chironomidae	F	-35.47 (NA)	6.49 (NA)
open canopy	11	Jun-06	*Gambusia*	I	-34.49 (1.82)	9.57 (1.00)
open canopy	11	Jun-06	Haliplidae	J	-40.11 (0.67)	5.70 (0.22)
open canopy	11	Jun-06	Hirudinea	K	-32.09 (1.59)	8.10 (0.03)
open canopy	11	Jun-06	*Hyallela*	L	-35.06 (0.92)	3.99 (0.03)
open canopy	11	Jun-06	*Pomacea*	Q	-37.66 (NA)	5.50 (NA)
open canopy	11	Jun-06	Zygoptera	V	-36.58 (0.55)	7.25 (0.05)
shaded canopy	11	Jun-06	CPOM	CPOM	-29.26 (1.34)	0.51 (0.39)
shaded canopy	11	Jun-06	epilithon	epil	-28.18 (0.10)	2.65 (0.32)
shaded canopy	11	Jun-06	FBOM	FBOM	-27.11 (0.09)	3.35 (0.13)
shaded canopy	11	Jun-06	Oxidized CPOM	OCPOM	-27.79 (1.15)	3.02 (0.56)
shaded canopy	11	Jun-06	Belostomatidae	B	-29.80 (0.09)	7.96 (0.14)
shaded canopy	11	Jun-06	Cambaridae	D	-27.47 (0.50)	6.75 (0.25)
shaded canopy	11	Jun-06	Corbicula	G	-34.81 (0.50)	6.24 (0.03)

reach	stream	date	item	graph ID	$\delta^{13}C$	$\delta^{15}N$
shaded canopy	11	Jun-06	*Gambusia*	I	-27.09 (0.19)	8.48 (0.02)
shaded canopy	11	Jun-06	Hirudinea	K	-27.95 (0.11)	9.67 (0.28)
shaded canopy	11	Jun-06	*Hyallela*	L	-28.24 (0.65)	4.87 (0.23)
shaded canopy	11	Jun-06	Hydropsychidae	M	-33.05 (0.12)	6.30 (0.18)
shaded canopy	11	Jun-06	*Melanoides*	N	-27.94 (0.25)	6.07 (0.67)
shaded canopy	11	Jun-06	Zygoptera	V	-29.43 (1.04)	6.18 (0.18)
open canopy	11	Oct-06	CPOM	CPOM	-29.28 (0.98)	0.89 (0.57)
open canopy	11	Oct-06	epilithon	epil	-36.81 (NA)	1.54 (NA
open canopy	11	Oct-06	FBOM	FBOM	-27.19 (NA)	4.29 (NA)
open canopy	11	Oct-06	Anuran larvae	A	-32.02 (0.40)	6.78 (0.39)
open canopy	11	Oct-06	Belostomatidae	B	-34.36 (NA)	5.02 (NA)
open canopy	11	Oct-06	Cambaridae	D	-32.50 (1.49)	4.99 (0.92)
open canopy	11	Oct-06	Chironomidae	F	-30.74 (NA)	2.19 (NA)
open canopy	11	Oct-06	*Gambusia*	I	-34.87 (0.04)	9.39 (0.22)
open canopy	11	Oct-06	Haliplidae	J	-41.86 (0.23)	4.87 (0.23)
open canopy	11	Oct-06	Hirudinea	K	-28.46 (NA)	11.66 (NA)
open canopy	11	Oct-06	*Hyallela*	L	-33.02 (NA)	0.00 (NA)
open canopy	11	Oct-06	*Poecilia*	P	-35.13 (0.83)	8.15 (1.11)
open canopy	11	Oct-06	*Pomacea* eggs	R	-23.62 (NA)	3.45 (NA)
shaded canopy	11	Oct-06	CPOM	CPOM	-29.31 (0.64)	1.26 (0.76)
shaded canopy	11	Oct-06	FBOM	FBOM	-26.86 (0.62)	3.22 (0.84)
shaded canopy	11	Oct-06	Chironomidae	F	-28.02 (NA)	4.79 (NA)
shaded canopy	11	Oct-06	*Corbicula*	G	-31.48 (3.12)	5.85 (0.63)
shaded canopy	11	Oct-06	*Hyallela*	L	-27.41 (NA)	6.03 (NA)
shaded canopy	11	Oct-06	*Melanoides*	N	-28.05 (0.93)	4.76 (0.10)
shaded canopy	11	Oct-06	*Poecilia*	P	-25.76 (0.06)	9.18 (0.00)
shaded canopy	11	Oct-06	*Pomacea*	Q	-27.38 (NA)	7.96 (NA
shaded canopy	11	Oct-06	Zygoptera	V	-27.58 (NA)	8.25 (NA)
open canopy	13	Dec-05	CPOM	CPOM	-29.46 (2.48)	3.40 (0.80)
open canopy	13	Dec-05	FBOM	FBOM	-26.89 (0.16)	5.39 (0.11)

reach	stream	date	item	graph ID	$\delta^{13}C$	$\delta^{15}N$
open canopy	13	Dec-05	Anuran larvae	A	-34.29 (0.85)	3.28 (0.44)
open canopy	13	Dec-05	Cambaridae	D	-29.97 (1.40)	12.59 (2.01)
open canopy	13	Dec-05	Chironomidae	F	-29.06 (NA)	6.83 (NA)
open canopy	13	Dec-05	*Gambusia*	I	-27.01 (0.10)	14.41 (0.58)
open canopy	13	Dec-05	Hirudinea	K	-28.52 (0.55)	12.23 (1.74)
open canopy	13	Dec-05	*Hyallela*	L	-28.54 (0.75)	10.91 (0.01)
open canopy	13	Dec-05	Hydropsychidae	M	-33.20 (0.52)	8.40 (0.59)
open canopy	13	Dec-05	*Melanoides*	N	-28.90 (0.79)	11.99 (1.27)
open canopy	13	Dec-05	Tipulidae	T	-29.36 (0.71)	7.97 (1.09)
open canopy	13	Dec-05	Zygoptera	V	-31.57 (0.45)	9.73 (0.92)
shaded canopy	13	Dec-05	CPOM	CPOM	-28.23 (1.27)	2.50 (0.00)
shaded canopy	13	Dec-05	FBOM	FBOM	-26.75 (0.14)	5.72 (0.25)
shaded canopy	13	Dec-05	Chironomidae	F	-28.12 (NA)	10.66 (NA)
shaded canopy	13	Dec-05	*Gambusia*	I	-27.06 (0.50)	12.69 (0.38)
shaded canopy	13	Dec-05	*Hyallela*	L	-29.00 (NA)	15.07 (NA)
shaded canopy	13	Dec-05	Sphaeridae	S	-30.35 (0.56)	9.07 (1.99)
shaded canopy	13	Dec-05	Trichoptera	U	-33.67 (0.49)	12.78 (0.71)
shaded canopy	13	Dec-05	Zygoptera	V	-29.28 (0.28)	16.09 (0.76)
open canopy	13	Feb-06	CPOM	CPOM	-31.92 (0.12)	2.92 (0.49)
open canopy	13	Feb-06	FBOM	FBOM	-27.03 (0.13)	5.96 (0.22)
open canopy	13	Feb-06	*Hydrilla* rinse	epip	-34.66 (0.38)	10.21 (0.41)
open canopy	13	Feb-06	*Hydrilla* stems	Hyd	-34.66 (0.38)	10.21 (0.41)
open canopy	13	Feb-06	Chironomidae	F	-30.55 (0.18)	7.28 (0.34)
open canopy	13	Feb-06	*Gambusia*	I	-25.99 (0.53)	13.52 (0.82)
open canopy	13	Feb-06	Hirudinea	K	-27.51 (0.35)	13.06 (0.08)
open canopy	13	Feb-06	*Hyallela*	L	-23.97 (NA)	5.27 (NA)
open canopy	13	Feb-06	Oligochaeta	O	-29.37 (0.79)	11.36 (1.40)
open canopy	13	Feb-06	Tipulidae	T	-27.06 (0.13)	7.45 (0.32)
open canopy	13	Feb-06	Zygoptera	V	-28.67 (NA)	8.96 (NA)
shaded canopy	13	Feb-06	CPOM	CPOM	-30.38 (2.26)	2.01 (0.35)

reach	stream	date	item	graph ID	$\delta^{13}C$	$\delta^{15}N$
shaded canopy	13	Feb-06	FBOM	FBOM	-27.35 (0.23)	4.46 (0.29)
shaded canopy	13	Feb-06	Cambaridae	D	-27.09 (0.33)	10.32 (0.59)
shaded canopy	13	Feb-06	Chironomidae	F	-28.90 (NA)	7.82 (NA)
shaded canopy	13	Feb-06	*Gambusia*	I	-28.66 (3.00)	15.19 (3.79)
shaded canopy	13	Feb-06	Hirudinea	K	-26.38 (1.09)	12.78 (0.88)
shaded canopy	13	Feb-06	Melanoides	N	-26.73 (NA)	14.52 (NA)
shaded canopy	13	Feb-06	Oligochaeta	O	-27.88 (0.34)	8.96 (0.14)
shaded canopy	13	Feb-06	Zygoptera	V	-28.56 (0.29)	11.53 (1.18)
open canopy	13	Jun-06	CPOM	CPOM	-29.38 (NA)	3.01 (NA)
open canopy	13	Jun-06	epilithon	epil	-21.52 (NA)	11.60 (NA)
open canopy	13	Jun-06	FBOM	FBOM	-26.05 (0.27)	5.74 (1.85)
open canopy	13	Jun-06	*Hydrilla* rinse	epip	-25.43 (0.52)	14.16 (1.13)
open canopy	13	Jun-06	*Hydrilla* stems	Hyd	-25.43 (0.52)	14.16 (1.13)
open canopy	13	Jun-06	Anuran larvae	A	-31.19 (NA)	5.20 (NA)
open canopy	13	Jun-06	Chironomidae	F	-30.16 (NA)	10.73 (NA)
open canopy	13	Jun-06	*Gambusia*	I	-25.96 (1.19)	13.54 (1.01)
open canopy	13	Jun-06	Hirudinea	K	-27.77 (0.51)	12.34 (0.39)
open canopy	13	Jun-06	*Hyallela*	L	-27.62 (0.51)	11.34 (0.96)
open canopy	13	Jun-06	*Melanoides*	N	-27.18 (0.87)	10.91 (0.88)
open canopy	13	Jun-06	Oligochaeta	O	-28.17 (NA)	10.94 (NA)
open canopy	13	Jun-06	Zygoptera	V	-28.13 (1.23)	11.20 (0.16)
shaded canopy	13	Jun-06	CPOM	CPOM	-32.08 (0.79)	-0.30 (2.20)
shaded canopy	13	Jun-06	epilithon	epil	-24.00 (0.05)	6.37(0.22)
shaded canopy	13	Jun-06	FBOM	FBOM	-26.36 (NA)	4.50 (NA)
shaded canopy	13	Jun-06	Oxidized CPOM	OCPOM	-29.62 (0.61)	1.07 (2.63)
shaded canopy	13	Jun-06	Anuran larvae	A	-30.05 (2.35)	6.10 (1.12)
shaded canopy	13	Jun-06	Chironomidae	F	-32.04 (NA)	9.20 (NA)
shaded canopy	13	Jun-06	*Gambusia*	I	-27.44 (0.86)	12.47 (1.36)
shaded canopy	13	Jun-06	Hirudinea	K	-25.18 (3.49)	13.29 (1.86)

reach	stream	date	item	graph ID	$\delta^{13}C$	$\delta^{15}N$
shaded canopy	13	Jun-06	*Hyallela*	L	-28.57 (0.34)	11.02 (1.12)
shaded canopy	13	Jun-06	*Melanoides*	N	-33.83 (1.51)	8.27 (1.41)
shaded canopy	13	Jun-06	Oligochaeta	O	-27.48 (NA)	7.89 (NA)
shaded canopy	13	Jun-06	Zygoptera	V	-31.33 (2.19)	10.08 (0.53)
open canopy	13	Oct-06	CPOM	CPOM	-29.71 (0.89)	2.94 (0.89)
open canopy	13	Oct-06	epilithon	epil	-28.60 (NA)	14.89 (NA)
open canopy	13	Oct-06	FBOM	FBOM	-27.98 (NA)	7.88 (NA)
open canopy	13	Oct-06	Anuran larvae	A	-26.96 (3.69)	13.92 (1.36)
open canopy	13	Oct-06	Chironomidae	F	-26.66 (NA)	16.96 (NA)
open canopy	13	Oct-06	*Gambusia*	I	-21.65 (0.31)	15.49 (0.06)
open canopy	13	Oct-06	Hirudinea	K	-25.43 (NA)	16.02 (NA)
open canopy	13	Oct-06	*Hyallela*	L	-26.33 (1.06)	16.31 (0.36)
open canopy	13	Oct-06	*Melanoides*	N	-25.53 (0.66)	15.12 (1.78)
open canopy	13	Oct-06	Zygoptera	V	-25.65 (0.23)	17.80 (0.55)
shaded canopy	13	Oct-06	CPOM	CPOM	-31.65 (NA)	2.02 (NA)
shaded canopy	13	Oct-06	epilithon	epil	-34.52 (NA)	11.73 (NA)
shaded canopy	13	Oct-06	FBOM	FBOM	-26.19 (NA)	9.70 (NA)
shaded canopy	13	Oct-06	Chironomidae	F	-33.80 (NA)	8.34 (NA)
shaded canopy	13	Oct-06	*Gambusia*	I	-29.72 (1.21)	11.61 (0.82)
shaded canopy	13	Oct-06	Hirudinea	K	-27.04 (0.80)	12.86 (0.62)
shaded canopy	13	Oct-06	*Hyallela*	L	-35.11 (2.28)	8.71 (0.38)
shaded canopy	13	Oct-06	*Melanoides*	N	-25.41 (4.33)	9.91 (2.59)
shaded canopy	13	Oct-06	Tipulidae	T	-28.08 (NA)	7.93 (NA**)**

3. Assessment of ammonium uptake in an urbanized headwater tributary of the St. Johns River using a ^{15}N tracer addition.

3.1 Introduction

First-order streams have been shown to play an important role in nitrogen cycling in ecosystems (Peterson et al. 2001). When undisturbed, greater than 50% of inorganic nitrogen received by low-order streams can be retained or transformed. These processes can occur quickly (hours to minutes) and over small distances (10 -100 meters of stream; Peterson et al. 2001). Elevated concentrations of dissolved nitrogen can lead to reduced storage and increased transport distances, potentially leading to eutrophication downstream (Peterson et al. 2001, Marti et al. 2004, Haggard et al. 2005, Bernot et al. 2006). In fact nitrogen transport, as shown by ammonium uptake, in urban streams (~0.1 mm s^{-1}) has been shown to be reduced relative to undisturbed, forested streams (~0.2 mm s^{-1}, Webster et al. 2003, Meyer et al. 2005, Bernhardt and Palmer 2007). However, nutrient cycling measurements in disturbed systems have been found to be more variable than forested systems. This is likely due to the differences in nutrient loads, hydrologic regimes, and channel geomorphology that reflect catchment – specific urbanization (Meyer et al. 2005, Walsh et al 2005). Given this, quantifying nitrogen dynamics and investigation the mechanism that regulate this vital ecosystem function are important factors to consider when restoring urbanized streams and rivers (Grimm et al. 2005, Bernhardt and Palmer 2007).

Nutrient spiraling describes the interactions between nutrient cycles and downstream transport (Stream Solutes Workgroup 1990) and is a key function that

regulates ecosystem structure and function. Nutrient uptake and its inverse, spiraling length, can be measured with tracer additions (e.g., stable isotope ^{15}N) or short-term nutrient additions (Stream Solute Workshop 1990, Mulholland et al. 2002, Webster et al. 2003). Both methods have advantages and disadvantages (e.g.., expense vs. accuracy). Measurements using nutrient additions will tend to overestimate uptake length and this overestimation is related to both nutrient limitation and concentration of the addition. Measurements using tracers avoid this problem, but can be much more expensive. In urbanized streams where nutrients levels can be very high, measuring nutrient uptake with short-term additions may not feasible due to potential saturation of biological uptake which necessitates using the tracer methods.

Studies using stable isotopes as tracers have revealed much about nitrogen dynamics in streams (Mulholland et al. 2000, Tank et al. 2000, Dodds et al. 2002, Webster et al. 2003, Grimm et al. 2005). However, the majority of these studies have focused on systems with limited anthropogenic disturbance (however see Grimm et al. 2005). In summer 2006, we conducted a 21-day tracer addition of $^{15}NH_4Cl$ in Mimm's Creek, a first-order urban stream in Jacksonville, Florida. Our goal was to investigate how catchment urbanization affects ammonium uptake.

3.2 Methods

3.2.1 Study site

Mimm's Creek is a first-order urban stream in Jacksonville, Florida (Fig. 1). Catchment boundaries and estimates of land cover were provided by the St. John's River Water Management District (Fig. 2, Table 1). The study reach (250 m) was

directly upstream of the St, Johns River. Weekly water samples were analyzed for ammonium (NH_4), nitrate (NO_3) and soluble reactive phosphate (SRP).

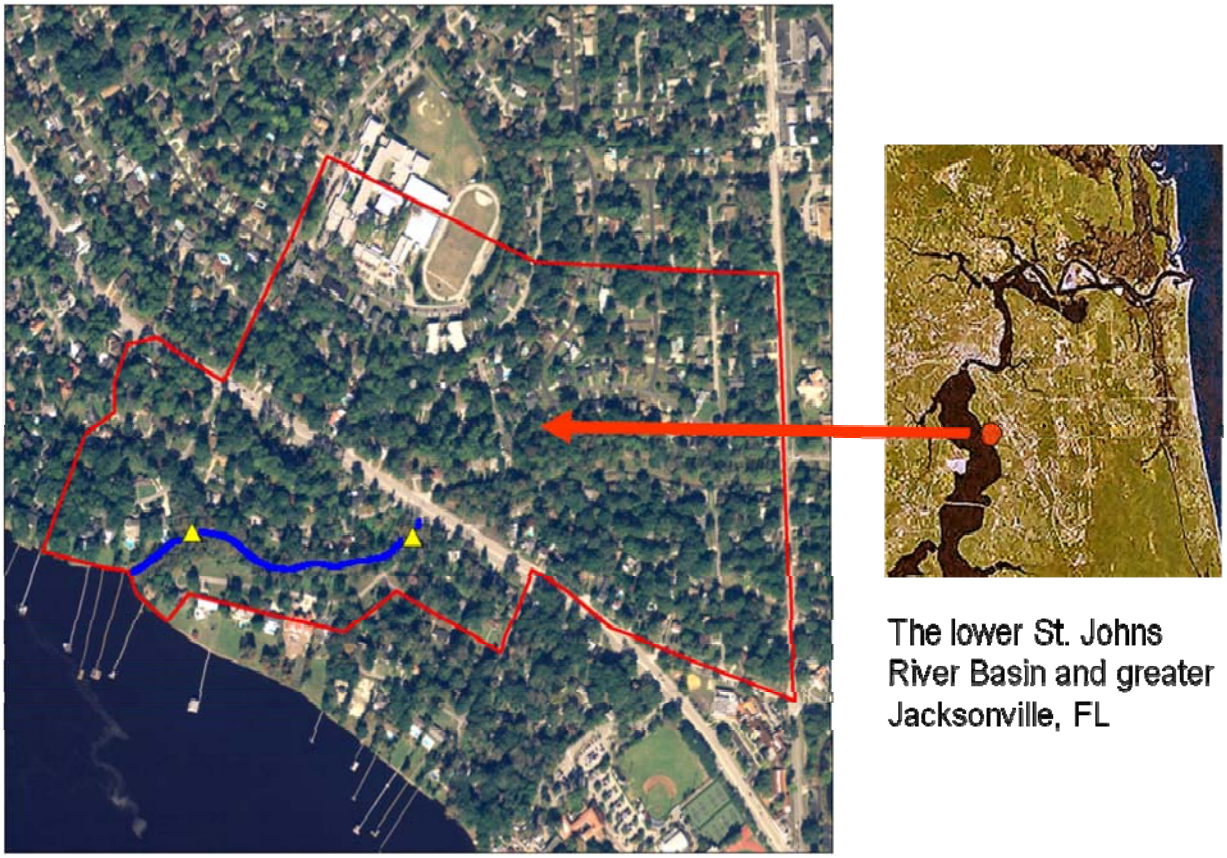

Figure 1. Mimm's Creek catchment, delineated with thin red lines, is located in the lower St. Johns River Basin. The study reach (250 m) is identifies with a blue line. The yellow triangles indicate the position of the $^{15}NH_4Cl$ release (upstream) and the end of the of the study reach (downstream).

Water was filtered on-site and all samples were analyzed within 24 hours of collection. Water temperatures were measured at the time of collection with a YSI meter. Both the St. Johns River Water Management District laboratory and contracted laboratories were used for analysis of the array of water quality constituents. All analyses were performed using U.S. EPA and Florida Department of Environmental Protection approved methods (40 CFR 100-149, APHA 1998). Current velocities, water depth, and cross-sectional area were measured in each stream and used to calculate discharge.

3.2.1 $^{15}NH_4$ uptake experiment

Ammonium uptake was measured in Mimm's Creek in summer 2006 using stable isotopes as tracers (see Mulholland et al 2000 for detailed methods). Briefly, we added $^{15}NH_4Cl$ for 21 days (starting on 13 July 2006) using a battery powered fluid metering pump with the goal to enrich stream ^{15}N by 500‰ without increasing ambient inorganic-nitrogen concentrations. The solution was added at a constricted portion of the stream channel to increase mixing. Water samples for $^{15}NH_4$ were collected one day after the addition was started (day 1), just before the addition was stopped (day 21), and one day after the addition was stopped (day 22). Samples were collected from 9 locations (Fig. 2) using a Geopump^{TM} with an inline filter. Isolation of ^{15}N from the water samples was accomplished using ammonia diffusion methods (Holmes et al. 1998) and ^{15}N:^{14}N was quantified by mass spectrometer at the Ecosystem Center laboratory, Marine Biological Laboratory, Woods Hole, Ma. Uptake length (S_w), uptake velocity (V_f), and whole stream uptake (U) were then calculated following procedures found in Mulholland et al. (2000) and Stream Solute Workshop (1990).

Figure 2. Locations where water samples were collected along Mimm's Creek during the $^{15}NH_4Cl$ tracer experiment.

3.3 Results and Discussion

3.3.1 Study site

The catchment of Mimm's Creek is dominated by urban/residential land use and is an important conveyance for storm water (Table 1). The 250-meter reach used for the ammonium addition was deeply incised with sandy substrata. Discharge was uniform and low (~3 L s^{-1}) and stream NH_4 concentrations averaged ~250 µg L^{-1} during the release (Table 2).

Table 1. Summary of the distribution of percent land use, percent total impervious area (PTIA) and catchment area (CA in hectares) for Mimm's Creek. Residential (LD) is low density housing with < 2 dwellings per acre, residential (MD) is medium density housing with 2-5 dwelling per acre, undeveloped land use includes a mixture of wetlands, forests, ponds, and streams. Impervious area (hectares) was calculated using methods from Arnold and Gibbons (1996).

Land use	Area (ha)	% cover	Impervious area (ha)
Residential (LD)	16.6	17	3.3
Residential (MD)	77.4	79	23.2
Commercial	3.9	4	2.9
Undeveloped	0.1	<1	0
total	98	100	29.4
PTIA	**30**		

Table 2. Summary of selected physical and chemical conditions in Mimm's Creek during the ammonium uptake experiment started on 13 July 2006.

Parameter	Value
Discharge	3 L s^{-1}
Mean width	1.5 m
Mean depth	20 cm
Mean velocity	2.2 cm s^{-1}
Temperature	26 ^{o} C
NH_4	60 – 350 µg L^{-1}
NO_3	80 – 850 µg L^{-1}
SRP	90 – 300 µg L^{-1}

3.3.2. Ammonium uptake

As expected, δ^{15}N-NH_4 declined exponentially with distance from the release location (Fig. 3A). δ^{15}N-NH_4 flux ranged from <0.1 to 0.9 ug ^{15}N s^{-1} (Fig. 3B). Uptake lengths (S_w) were 83.6 m and 104.3 m, uptake velocities (V_f) were 0.0315 and 0.0292 mm s^{-1}, and whole stream uptake rates (U) were 0.2295 and 0.3739 g m^{-2} d^{-1} on days 1 and 21, respectively.

Ammonium uptake measures for Mimm's Creek were much different than forest streams of similar size (e.g., LINX – Webster et al. 2003, Table 3). Uptake length (S_w) was 3 to 7 times longer, uptake velocity (V_f) were 4 to 9 times slower, and whole stream uptake (U) was 5 to 10 times greater. Ammonium concentrations in Mimm's Creek were also 1 to 2 orders of magnitude greater than the LINX streams. Given this, the difference we found in uptake are not surprising (sensu Dodds et al. 2002).

When compared to other urbanized streams in the southeastern United States (Meyer et al. 2005), values from Mimm's Creek were similar (Fig. 4). However, these systems are much larger than Mimm's Creek which suggest that ambient ammonium concentration alone (i.e., not stream channel size or flow dynamics) are regulating uptake rates.

A further comparison of uptake velocities vs. ammonium concentrations among 18 streams of differing size (1^{st} to 3^{rd} order) and land use (forested, urbanized, agriculture, wastewater effluent) revealed that uptake velocities decreased exponentially (Fig. 5). From these data it appears that regardless of stream type, ammonium uptake velocities stabilize at concentrations > 40 µg L^{-1}. When ammonium concentrations are below this threshold, it is likely that variation in uptake is driven by factors that affect the balance of autotrophic and heterotrophic metabolism (Dodds et al. 2002, Webster et al. 2003). When concentrations are above this threshold, uptake velocity are plausibly slowed by both increased NH_4 concentrations and decreased biotic uptake driven by impairment caused by anthropogenic stressors. (Meyer et al. 2005).

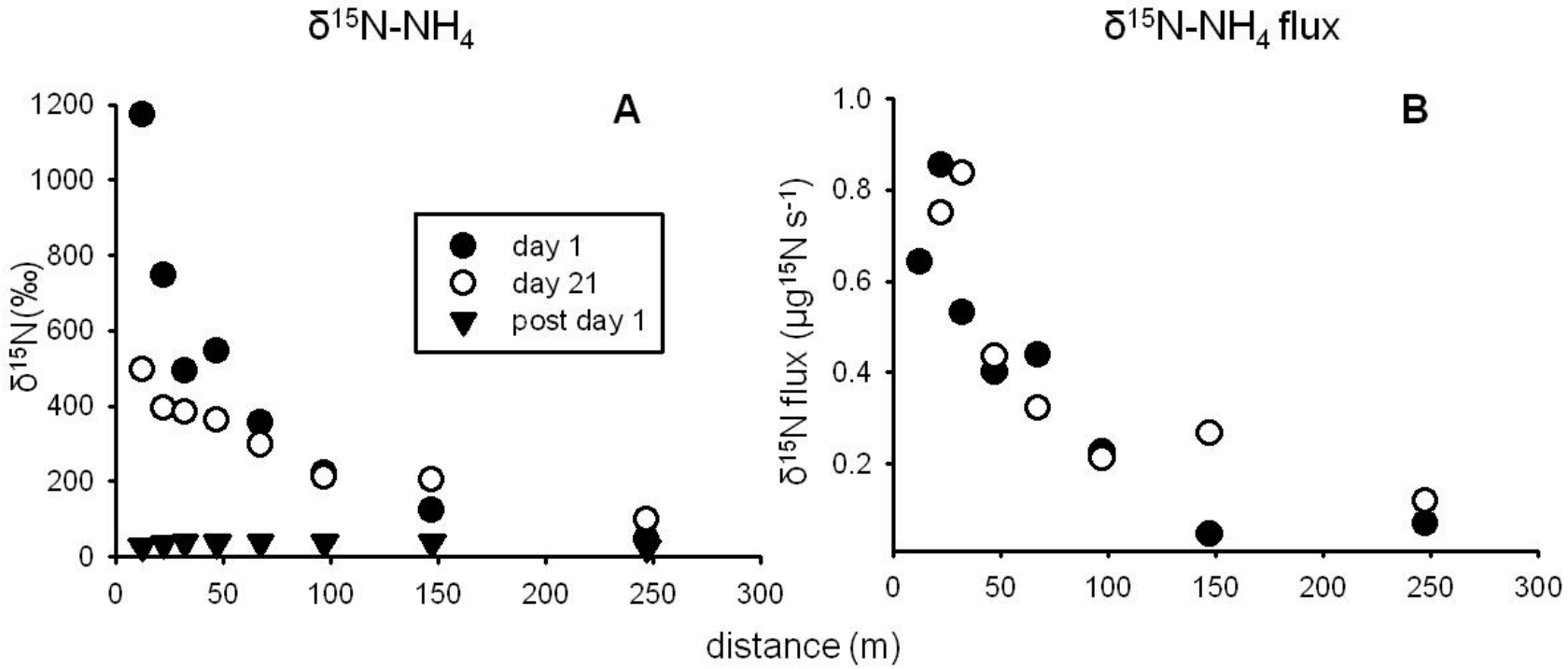

Figure 3. A) δ^{15}N-NH_4 values in water collected on day 1, day 21, and day 22 (post day 1). B) Tracer δ^{15}N-NH_4 flux from days 1 and 21.

Table 3. Comparison of average ammonium dynamics of Mimm's Creek with selected LINX streams (Webster et al. 2003). Uptake length (S_w) is in m, uptake velocity (V_f) is mm s^{-1}, Total stream uptake (U) is g N m^{-2} d^{-1}, discharge (Q) is L s^{-1}, ammonium concentration is µg L^{-1}.

Stream	Sw	Vf	U	Q	NH^4
Mimm's Creek	**94**	**0.0304**	**0.3016**	**3**	**60-350**
Walker Branch	23	0.1360	0.0317	9	3
Bear Brook	14	0.1190	0.0411	4	4
Gallina Creek	21	0.1540	0.0691	6	5
Quebrada Bisley	26	0.1440	0.0523	13	4
Kings Creek	58	0.3020	0.0626	11	2

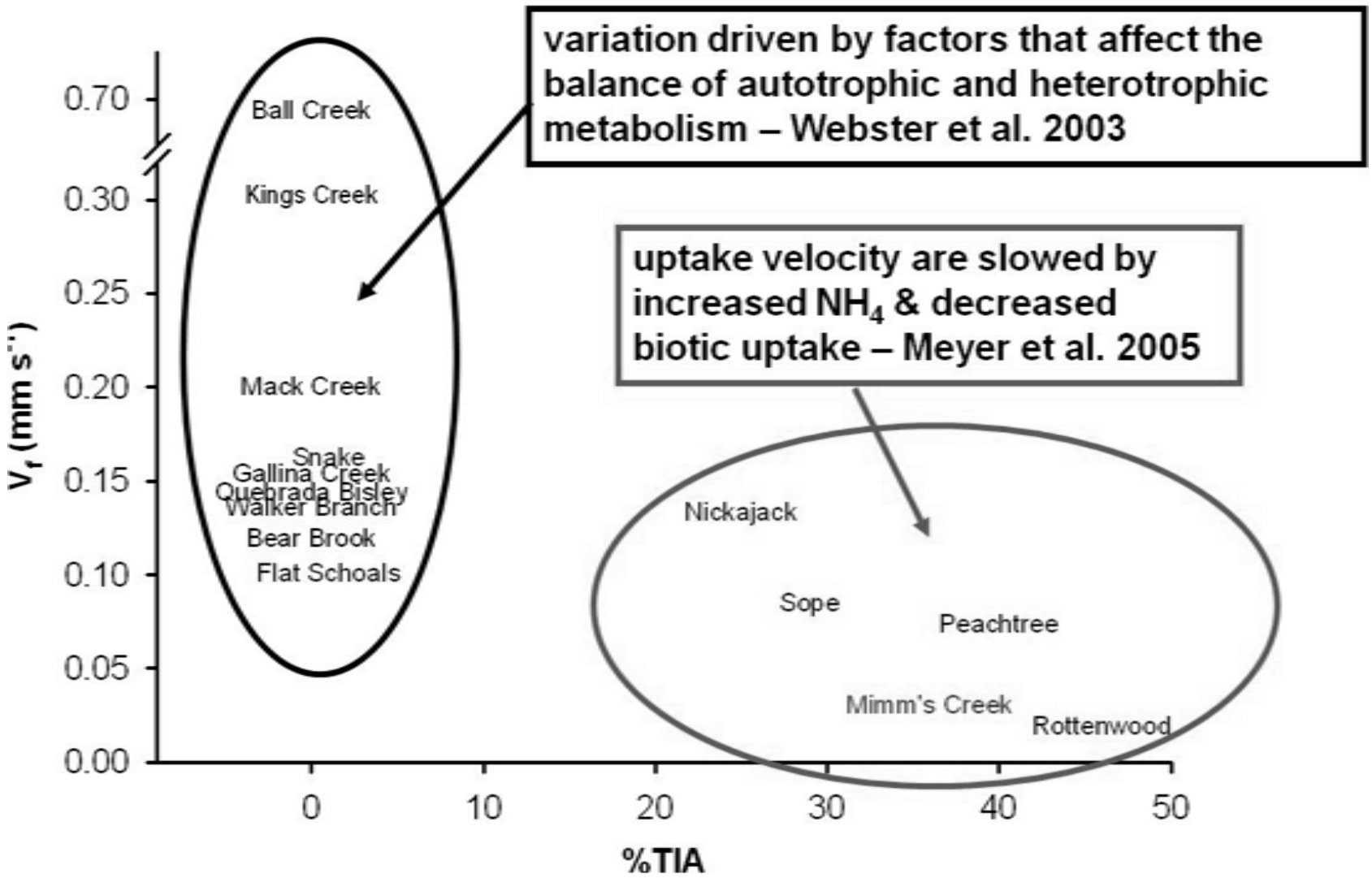

Figure 4. Comparison of uptake velocity (V_f) between forested streams (circled in black) and urban streams (circled in grey). Values for all streams (excluding Mimm's Creek) are from either Webster et al. (2003) or Meyer et al. (2005).

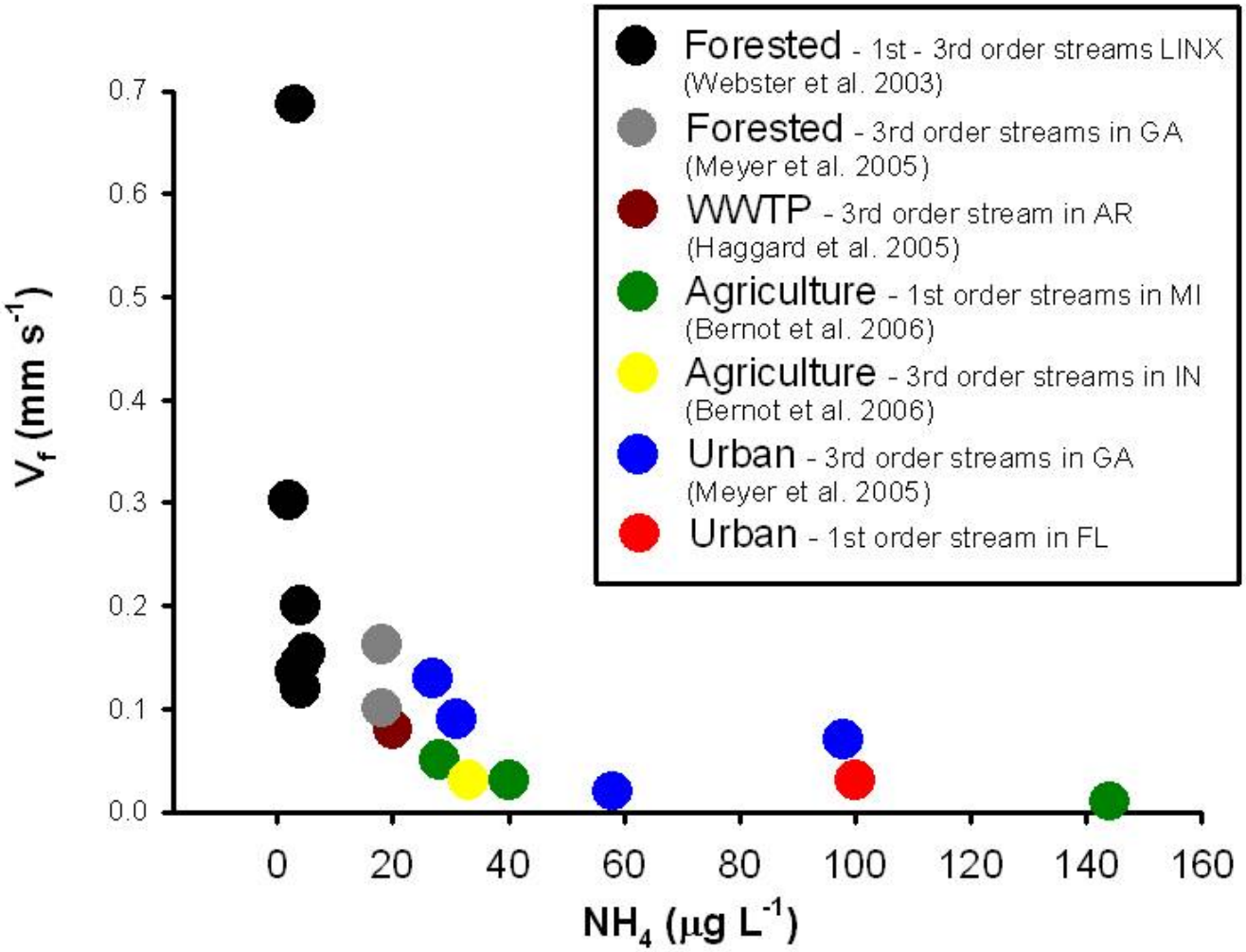

Figure 5. Comparison of uptake velocities (V_f) vs. ammonium concentrations among 18 streams of differing size and land use. From these data it appears that regardless of stream type ammonium uptake velocities stabilize at concentrations > 40 µg L^{-1}. WWTP=wastewater treatment plant effluent

3.4 Conclusion

Understanding how nitrogen dynamics are altered in urbanized headwater streams is an important step in protecting downstream reaches. This work shows that increased dissolved nitrogen concentrations due to urbanization result in longer uptake lengths, slower uptake velocities, but higher whole stream uptake. Further, by comparing our results with other published values it appears that regardless of land use or stream size, uptake velocity slows to ~0.03 mm s^{-1} when ammonium concentrations are greater that ~40 µg L-1. Given this and the degree of development that continues to occur in greater Jacksonville, eutrophication of the St. Johns River will continue if steps are not taken to reduce nitrogen loading that originates from lower-order streams.

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3. Assessment of ammonium uptake in an urbanized headwater tributary of the St. Johns River using a ^{15}N tracer addition.

3.1 Introduction

First-order streams have been shown to play an important role in nitrogen cycling in ecosystems (Peterson et al. 2001). When undisturbed, greater than 50% of inorganic nitrogen received by low-order streams can be retained or transformed. These processes can occur quickly (hours to minutes) and over small distances (10 -100 meters of stream; Peterson et al. 2001). Elevated concentrations of dissolved nitrogen can lead to reduced storage and increased transport distances, potentially leading to eutrophication downstream (Peterson et al. 2001, Marti et al. 2004, Haggard et al. 2005, Bernot et al. 2006). In fact nitrogen transport, as shown by ammonium uptake, in urban streams (~0.1 mm s^{-1}) has been shown to be reduced relative to undisturbed, forested streams (~0.2 mm s^{-1}, Webster et al. 2003, Meyer et al. 2005, Bernhardt and Palmer 2007). However, nutrient cycling measurements in disturbed systems have been found to be more variable than forested systems. This is likely due to the differences in nutrient loads, hydrologic regimes, and channel geomorphology that reflect catchment – specific urbanization (Meyer et al. 2005, Walsh et al 2005). Given this, quantifying nitrogen dynamics and investigation the mechanism that regulate this vital ecosystem function are important factors to consider when restoring urbanized streams and rivers (Grimm et al. 2005, Bernhardt and Palmer 2007).

Nutrient spiraling describes the interactions between nutrient cycles and downstream transport (Stream Solutes Workgroup 1990) and is a key function that

regulates ecosystem structure and function. Nutrient uptake and its inverse, spiraling length, can be measured with tracer additions (e.g., stable isotope ^{15}N) or short-term nutrient additions (Stream Solute Workshop 1990, Mulholland et al. 2002, Webster et al. 2003). Both methods have advantages and disadvantages (e.g.., expense vs. accuracy). Measurements using nutrient additions will tend to overestimate uptake length and this overestimation is related to both nutrient limitation and concentration of the addition. Measurements using tracers avoid this problem, but can be much more expensive. In urbanized streams where nutrients levels can be very high, measuring nutrient uptake with short-term additions may not feasible due to potential saturation of biological uptake which necessitates using the tracer methods.

Studies using stable isotopes as tracers have revealed much about nitrogen dynamics in streams (Mulholland et al. 2000, Tank et al. 2000, Dodds et al. 2002, Webster et al. 2003, Grimm et al. 2005). However, the majority of these studies have focused on systems with limited anthropogenic disturbance (however see Grimm et al. 2005). In summer 2006, we conducted a 21-day tracer addition of $^{15}NH_4Cl$ in Mimm's Creek, a first-order urban stream in Jacksonville, Florida. Our goal was to investigate how catchment urbanization affects ammonium uptake.

3.2 Methods

3.2.1 Study site

Mimm's Creek is a first-order urban stream in Jacksonville, Florida (Fig. 1). Catchment boundaries and estimates of land cover were provided by the St. John's River Water Management District (Fig. 2, Table 1). The study reach (250 m) was

directly upstream of the St, Johns River. Weekly water samples were analyzed for ammonium (NH_4), nitrate (NO_3) and soluble reactive phosphate (SRP).

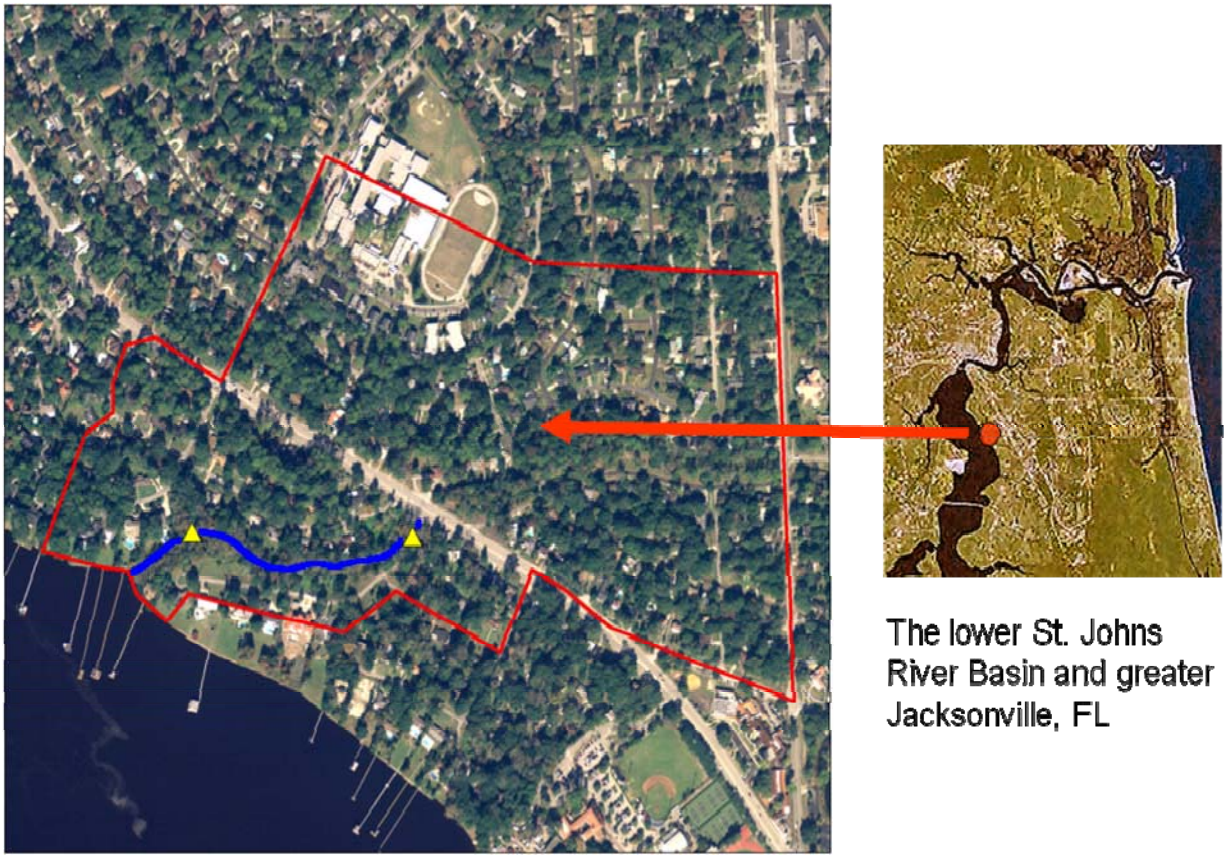


Figure 1. Mimm's Creek catchment, delineated with thin red lines, is located in the lower St. Johns River Basin. The study reach (250 m) is identifies with a blue line. The yellow triangles indicate the position of the $^{15}NH_4Cl$ release (upstream) and the end of the of the study reach (downstream).

Water was filtered on-site and all samples were analyzed within 24 hours of collection. Water temperatures were measured at the time of collection with a YSI meter. Both the St. Johns River Water Management District laboratory and contracted laboratories were used for analysis of the array of water quality constituents. All analyses were performed using U.S. EPA and Florida Department of Environmental Protection approved methods (40 CFR 100-149, APHA 1998). Current velocities, water depth, and cross-sectional area were measured in each stream and used to calculate discharge.

3.2.1 $^{15}NH_4$ uptake experiment

Ammonium uptake was measured in Mimm's Creek in summer 2006 using stable isotopes as tracers (see Mulholland et al 2000 for detailed methods). Briefly, we added $^{15}NH_4Cl$ for 21 days (starting on 13 July 2006) using a battery powered fluid metering pump with the goal to enrich stream ^{15}N by 500‰ without increasing ambient inorganic-nitrogen concentrations. The solution was added at a constricted portion of the stream channel to increase mixing. Water samples for $^{15}NH_4$ were collected one day after the addition was started (day 1), just before the addition was stopped (day 21), and one day after the addition was stopped (day 22). Samples were collected from 9 locations (Fig. 2) using a Geopump^{TM} with an inline filter. Isolation of ^{15}N from the water samples was accomplished using ammonia diffusion methods (Holmes et al. 1998) and ^{15}N:^{14}N was quantified by mass spectrometer at the Ecosystem Center laboratory, Marine Biological Laboratory, Woods Hole, Ma. Uptake length (S_w), uptake velocity (V_f), and whole stream uptake (U) were then calculated following procedures found in Mulholland et al. (2000) and Stream Solute Workshop (1990).

Figure 2. Locations where water samples were collected along Mimm's Creek during the $^{15}NH_4Cl$ tracer experiment.

3.3 Results and Discussion

3.3.1 Study site

The catchment of Mimm's Creek is dominated by urban/residential land use and is an important conveyance for storm water (Table 1). The 250-meter reach used for the ammonium addition was deeply incised with sandy substrata. Discharge was uniform and low (~3 L s^{-1}) and stream NH_4 concentrations averaged ~250 µg L^{-1} during the release (Table 2).

Table 1. Summary of the distribution of percent land use, percent total impervious area (PTIA) and catchment area (CA in hectares) for Mimm's Creek. Residential (LD) is low density housing with < 2 dwellings per acre, residential (MD) is medium density housing with 2-5 dwelling per acre, undeveloped land use includes a mixture of wetlands, forests, ponds, and streams. Impervious area (hectares) was calculated using methods from Arnold and Gibbons (1996).

Land use	Area (ha)	% cover	Impervious area (ha)
Residential (LD)	16.6	17	3.3
Residential (MD)	77.4	79	23.2
Commercial	3.9	4	2.9
Undeveloped	0.1	<1	0
total	98	100	29.4
PTIA	**30**		

Table 2. Summary of selected physical and chemical conditions in Mimm's Creek during the ammonium uptake experiment started on 13 July 2006.

Parameter	Value
Discharge	3 L s^{-1}
Mean width	1.5 m
Mean depth	20 cm
Mean velocity	2.2 cm s^{-1}
Temperature	26 ^{o} C
NH_4	60 – 350 µg L^{-1}
NO_3	80 – 850 µg L^{-1}
SRP	90 – 300 µg L^{-1}

3.3.2. Ammonium uptake

As expected, δ^{15}N-NH_4 declined exponentially with distance from the release location (Fig. 3A). δ^{15}N-NH_4 flux ranged from <0.1 to 0.9 ug ^{15}N s^{-1} (Fig. 3B). Uptake lengths (S_w) were 83.6 m and 104.3 m, uptake velocities (V_f) were 0.0315 and 0.0292 mm s^{-1}, and whole stream uptake rates (U) were 0.2295 and 0.3739 g m^{-2} d^{-1} on days 1 and 21, respectively.

Ammonium uptake measures for Mimm's Creek were much different than forest streams of similar size (e.g., LINX – Webster et al. 2003, Table 3). Uptake length (S_w) was 3 to 7 times longer, uptake velocity (V_f) were 4 to 9 times slower, and whole stream uptake (U) was 5 to 10 times greater. Ammonium concentrations in Mimm's Creek were also 1 to 2 orders of magnitude greater than the LINX streams. Given this, the difference we found in uptake are not surprising (sensu Dodds et al. 2002).

When compared to other urbanized streams in the southeastern United States (Meyer et al. 2005), values from Mimm's Creek were similar (Fig. 4). However, these systems are much larger than Mimm's Creek which suggest that ambient ammonium concentration alone (i.e., not stream channel size or flow dynamics) are regulating uptake rates.

A further comparison of uptake velocities vs. ammonium concentrations among 18 streams of differing size (1^{st} to 3^{rd} order) and land use (forested, urbanized, agriculture, wastewater effluent) revealed that uptake velocities decreased exponentially (Fig. 5). From these data it appears that regardless of stream type, ammonium uptake velocities stabilize at concentrations > 40 µg L^{-1}. When ammonium concentrations are below this threshold, it is likely that variation in uptake is driven by factors that affect the balance of autotrophic and heterotrophic metabolism (Dodds et al. 2002, Webster et al. 2003). When concentrations are above this threshold, uptake velocity are plausibly slowed by both increased NH_4 concentrations and decreased biotic uptake driven by impairment caused by anthropogenic stressors. (Meyer et al. 2005).

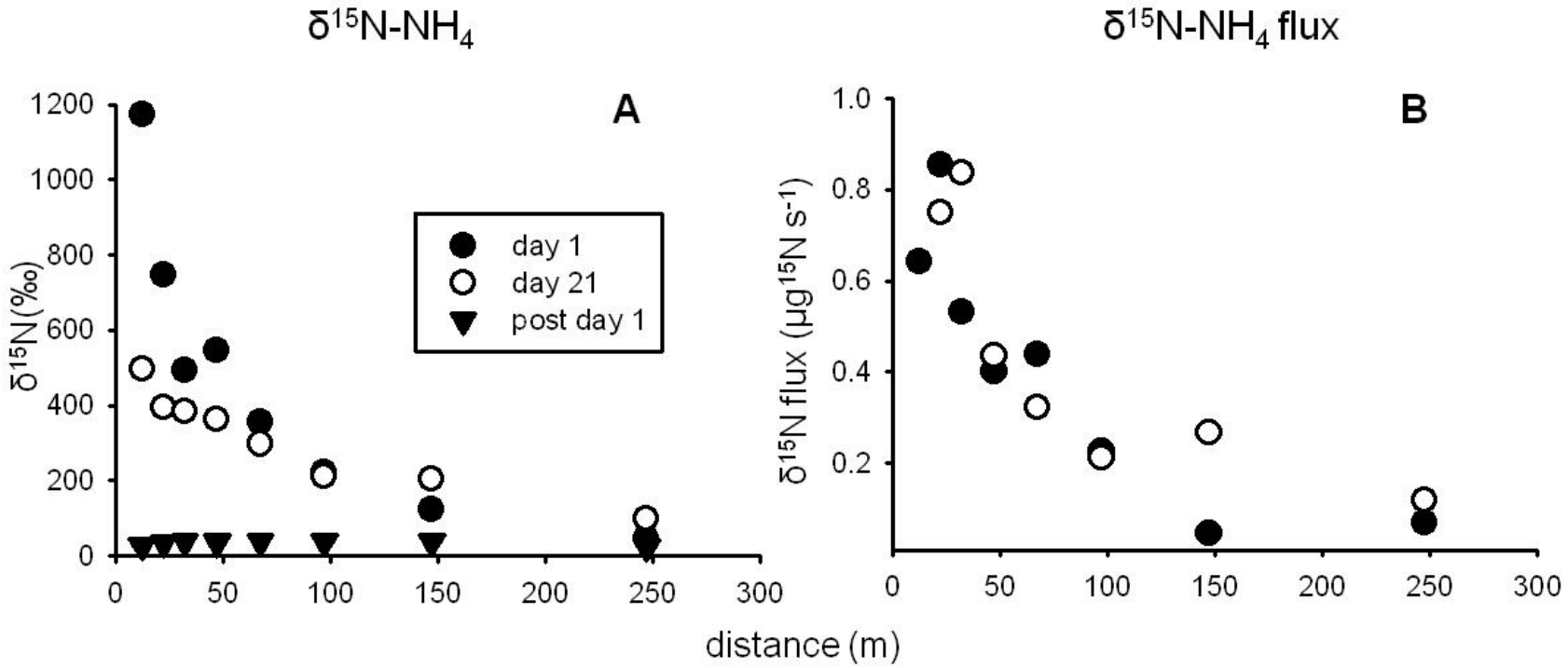
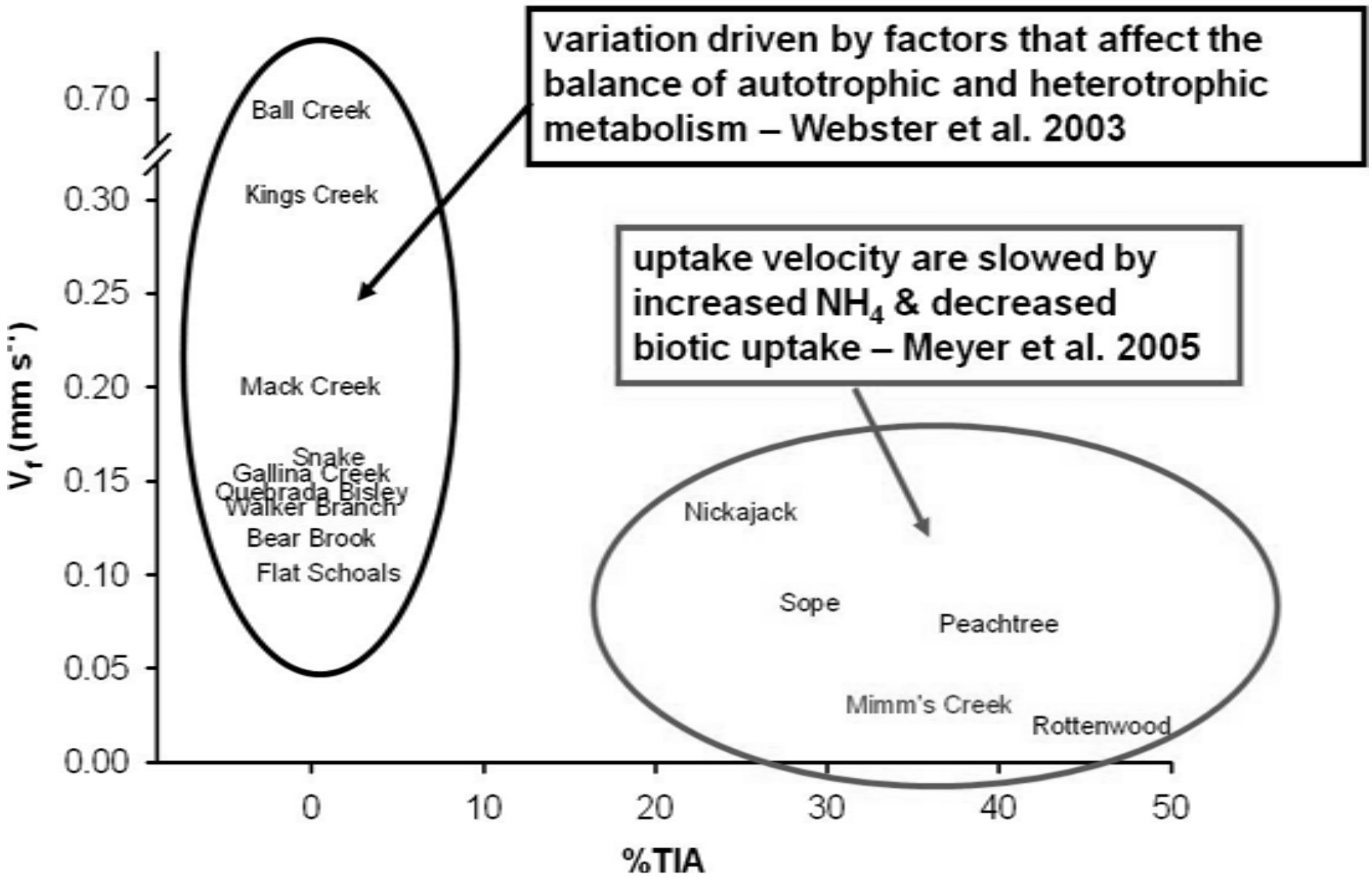


Figure 3. A) δ^{15}N-NH_4 values in water collected on day 1, day 21, and day 22 (post day 1). B) Tracer δ^{15}N-NH_4 flux from days 1 and 21.

Table 3. Comparison of average ammonium dynamics of Mimm's Creek with selected LINX streams (Webster et al. 2003). Uptake length (S_w) is in m, uptake velocity (V_f) is mm s^{-1}, Total stream uptake (U) is g N m^{-2} d^{-1}, discharge (Q) is L s^{-1}, ammonium concentration is µg L^{-1}.

Stream	Sw	Vf	U	Q	NH^4
Mimm's Creek	**94**	**0.0304**	**0.3016**	**3**	**60-350**
Walker Branch	23	0.1360	0.0317	9	3
Bear Brook	14	0.1190	0.0411	4	4
Gallina Creek	21	0.1540	0.0691	6	5
Quebrada Bisley	26	0.1440	0.0523	13	4
Kings Creek	58	0.3020	0.0626	11	2



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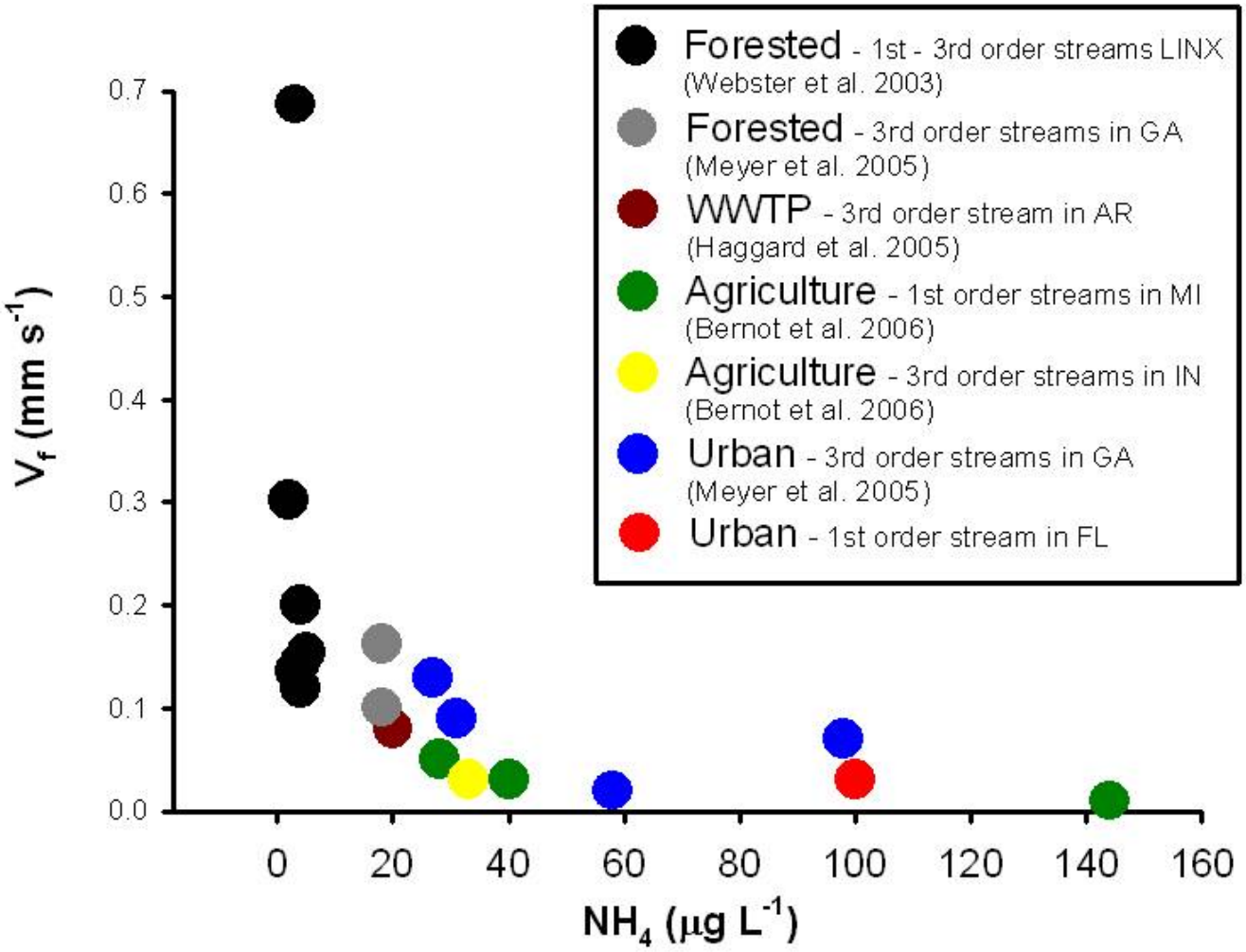

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