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# SYNOPTIC BIOLOGICAL SURVEY OF 14 SPRING-RUN STREAMS IN NORTH AND CENTRAL FLORIDA

## I. SUBMERGED AQUATIC VEGETATION COMMUNITIES - MACROPHYTES

by

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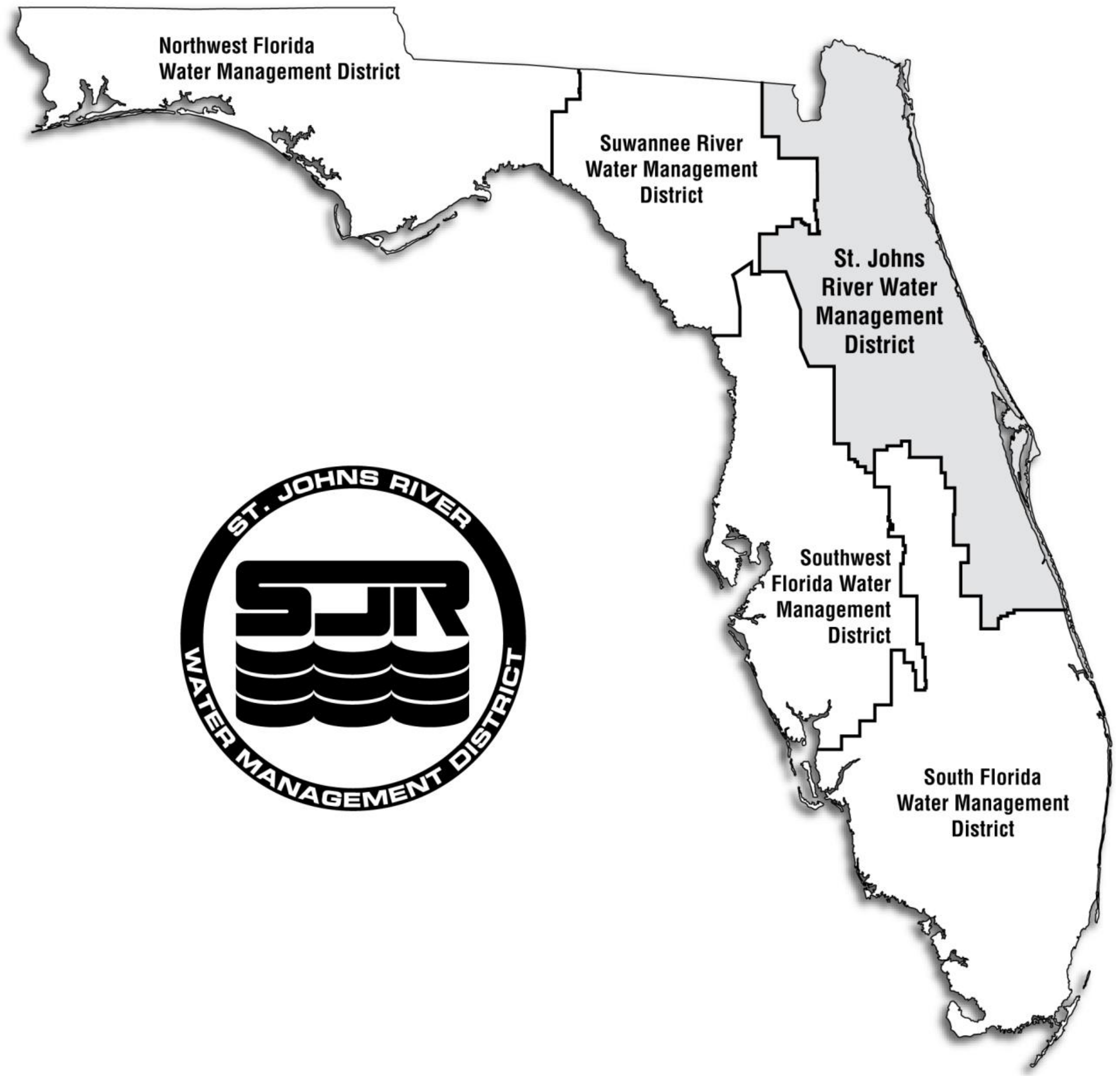


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# EXECUTIVE SUMMARY


As part of a broader initiative to better understand, manage, and restore the springs of the St. Johns River, it was determined that some type of field study was needed to complement other research work. To address this, a short-term, synoptic biological study of 14 springs and their spring-run streams was undertaken by the St. Johns River Water Management District in 2015 to generate field data to evaluate springs ecology. This study quantitatively sampled some basic physical-chemical characteristics and several biological measures in these spring-run streams (submerged macrophyte cover and dry weight; macro- and epiphytic algal cover, dry weight and ash-free dry weight; and vegetation-associated macroinvertebrate community richness, density, diversity, and biological characteristics). One focus of the study was the submerged aquatic vegetation community (SAV – both macrophytes and algae) and its characteristics. This was due to the prevalence of this community in spring-run streams and because of the changes observed in this community over the past 50 years, including a shift in many of these systems from a macrophyte-dominated to an algae-dominated community. This report presents the submerged macrophyte cover and standing crop data and analyses from the springs synoptic sampling effort. Algae, macroinvertebrate, and vegetation morphometric data and analyses will be presented in subsequent reports.

Six sampling events were conducted in 2015 to measure physical-chemical (physico-chemical) conditions (stream physical characteristics and in situ water quality). The springs exhibited a wide range of physicochemical characteristics, including channel width and depth, canopy cover, discharge, base water chemistry, and nutrient concentrations. Spring discharges ranged from small second-magnitude springs (Juniper) to some of the largest first-magnitude spring groups in Florida (Silver, Rainbow). Base water chemistry (concentration of dissolved solids such as calcium, chloride, etc.) ranged from near softwater, low ion springs (Juniper) to salt springs (Silver Glen). Nutrient concentrations (based on existing data, not collected in this study) also varied, from systems with low concentrations of nitrogen (as Nitrate-Nitrite Nitrogen, NOx) and phosphorus (as Total Phosphorus, TP), indicating natural background water quality conditions (Juniper, Alexander), to systems with elevated concentrations of one or both nutrients (Silver, Wekiva).

Quantitative biological sampling was conducted at two sampling events, in spring and fall 2015. Twelve of the 14 spring-run streams supported submerged macrophytes in the SAV community. Nine species/taxa of macrophytes were collected at 24 transects in the 12 spring-run streams that supported submerged macrophytes. The dominant three species, by frequency of occurrence, cover, and dry weight standing crop, were eelgrass (*Vallisneria americana*), spring tape (*Sagittaria kurziana*), and hydrilla (*Hydrilla verticillata*). The sampling design used in this study precluded the use of standard parametric and/or non-parametric statistical tests. Graphical and tabular summaries and multi-variate analyses of cover and standing crop data were done to explore for general patterns. Generally, two groups of springs were delineated based on patterns in the physicochemical and macrophyte data: springs on the mainstem of the St. Johns River (SJR springs) versus those not on the St. Johns River (Other – O). Physicochemical factors responsible for this separation included

conductivity (SJR springs generally being higher conductivity systems), turbidity, stream channel width, and current velocity. The main biological difference between the two groups was a dominance of *Vallisneria americana* (eelgrass) in the SJR spring-run streams versus a dominance of *Sagittaria kurziana* (spring tape) at the O spring-run streams. Examination of cover and standing crop data at each individual transect and multi-variate analysis indicated no consistent differences between the spring and fall sampling episodes at any transect.

Review of the literature indicated some of the principal physicochemical factors influencing the submerged macrophyte communities of spring-run streams included light regime (influenced by tree canopy cover over the stream channel and water clarity conditions), substrate type, current velocity, and other water quality measures. Analysis of the data collected in this study indicated very weak or no relationships between macrophyte cover and standing crop and canopy cover, stream velocity, and other physicochemical variables (pH, conductivity, turbidity, water temperature, nitrate and phosphorus).

Comparison of the data collected in this study (macrophyte cover and standing crop) with similar data collected in prior studies of submerged macrophytes in Florida spring-run streams indicated generally similar levels of macrophyte cover and standing crop in many spring-run streams, suggesting that submerged macrophyte communities in some of these streams have been relatively stable over the last 10–60 years. Some of the spring-run streams sampled in this study exhibited lower macrophyte standing crop than measured historically (e.g., Silver Glen Run, Weeki Wachee River), indicating that there may have been changes over the past few decades in these streams. Anecdotal and some quantitative data indicate significant increases in abundance of algae (benthic and epiphytic) over the past 10–60 years, in some streams accompanied by a decline in abundance of macrophytes (Homosassa River, Manatee Spring Run). Spring-run stream SAV communities appear to represent good "sentinel" communities to monitor for overall ecological integrity, as used in other aquatic ecosystems (lakes, estuaries) and it is recommended that this sampling effort be repeated in future years.

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# INTRODUCTION

The karst geology of Florida is the basis for the existence of perhaps the densest concentration of springs in the world (Florida Springs Task Force 2000). These aquatic 7resources have long captivated explorers, visitors, artists and scientists, ranging from Ponce de Leon's mythological search for the "fountain of youth" to the writer Marjory Stoneman Douglas' description of Florida springs as "bowls of liquid light." In Florida, there are two main types of springs (Copeland 2003); those which originate from shallow aquifers (seep springs) and those which originate from deeper aquifers that are partially confined, resulting in groundwater that is under artesian pressure (vent springs). Of the 1,089 individual springs currently mapped in Florida, most are fed by artesian flow from the Floridan Aquifer System, a large regional aquifer system that underlies all of Florida and parts of South Carolina, Georgia, and Alabama. A number of Florida springs, particularly those in the Suwannee River Basin, are estavelles (Copeland 2003). When the rivers partially fed by these springs flood, the pressure from the overlying surface water overcomes the groundwater pressure head, and the springs reverse flow, taking in surface (river) water.

Florida springs have long been classified by Mienzer's system of spring discharge (Scott et al. 2004), which is typically expressed in cubic feet per second (cfs). First-magnitude springs are the largest, with a mean annual discharge of greater than 100 cfs (64.6 million gallons/day). Second-magnitude springs discharge between 10 and 100 cfs, and third-magnitude springs discharge between 1 and 10 cfs. The system goes down to eighth-magnitude springs with a discharge of <1 pint/minute (200 gal/day). Florida has 33 first-magnitude springs and spring groups (groups of spring vents that collectively discharge water and are in close proximity).

Springs are also classified by the composition of the ions and minerals dissolved in the spring water (Woodruff 1993, Slack and Rosenau 1979). Seep springs fed by shallow surficial aquifers are mostly softwater springs with very low concentrations of dissolved solids. Most vent springs discharge water containing dissolved calcium bicarbonate and other ions. This water is considered "hard" water (containing dissolved calcium carbonate) and originates from the carbonate rocks that comprise the Floridan Aquifer System. Some springs are a mixed or salt water quality type, with higher concentrations of chloride and other dissolved solids. These are found in the St. Johns River valley and along the Gulf coast from Taylor County south to Hernando County. The existence of highly mineralized saline groundwater in the aquifer contributing to these springs is related to the depth of the water source in the aquifer and proximity to the coast. In the St. Johns River Valley, the saline groundwater is relict seawater left behind in the aquifer during periods of higher sea level in the Pleistocene Epoch. Along the Gulf Coast, however, this is due to recharge of saline water from the adjacent Gulf of Mexico.

The water discharged from Florida's springs historically had extremely low concentrations of nitrogen compounds, particularly nitrate-nitrite as nitrogen (generally 0.05-0.1 mg/L NOx-N), due to a lack of natural sources other than atmospheric deposition (Scott et al. 2004). Background phosphorus concentrations have been moderate in some springs (0.04-0.06 mg/L as total phosphorus, (TP) due to the existence of natural phosphate deposits in some geologic formations in portions of Florida. In general, spring ecosystems are adapted to naturally low nutrient concentrations and may suffer when these are increased (Brown et al. 2008).

Many Florida springs give rise to lotic (flowing water) ecosystems known as spring-run streams. The exceptionally clear water in these streams allows for the proliferation of dense beds of submerged aquatic vegetation (SAV). The SAV habitat (which includes submerged macrophytes and associated algal communities) found in spring-run streams are a major source of primary production, provide habitat for diverse macroinvertebrate and fish communities and provide food sources for freshwater turtles and the endangered Florida Manatee (Odum 1957a, Walsh et al. 2009, Walsh and Williams 2003). The springs also provide a warm water winter refuge habitat for manatee populations. Many springs are also inhabited by endemic species, including certain species in the snail family Hydrobiidae ("silt snails") which are found nowhere else in the world (Thompson 1968). Similarly, the submerged cave systems associated with many springs support one or more species of cave crayfish which may only be associated with that particular spring cave system (Franz et al. 1994). These crayfish have adaptations, including blindness (no eyes), albinism, and a highly adapted sensory system of feel and vibration which permits them to survive underground in complete darkness.

Florida's springs have been subjected to many of the same pressures which have affected other aquatic ecosystems in the state: degradation of water quality and alterations in hydrology (Copeland et al. 2009). Groundwater quantity and quality are both affected by human activities that occur in the highly vulnerable karst areas of Florida. Many springs are discharging water with increased concentrations of nitrate. Nitrogen loading to the landscape in these springsheds comes from agricultural and urban development (MACTEC 2010, Katz et al. 1999). The increased nitrate concentration is one factor that may be contributing to ecological changes in these springs. In addition, many springs in Florida are exhibiting reduced discharge, leading to decreases in current velocity (Kaplan et al. 2017; King 2014). These changes in hydrology are the cumulative result of multiple factors, including changes in rainfall, drainage alteration, and groundwater withdrawals (Copeland et al. 2009). Florida's burgeoning human population, which now exceeds 20 million residents, is placing increasing demands on the state's groundwater resources, and spring ecosystems are exhibiting responses to these demands.

## PURPOSE AND OBJECTIVES

This study was conducted as part of a broader management initiative begun by the St. Johns River Water Management District (SJRWMD or the District) in 2013. Called the Springs Protection Initiative (SPI), the effort involved a combination of scientific studies and identification of projects to implement which, 1) reduce nutrient loading (particularly nitrogen) to the landscape of springsheds, and/or, 2) reduce groundwater withdrawal/ pumping. These projects were selected based on a combination of existing data and best professional judgement. As part of the science component of the SPI, District scientists determined that a broad field study of the biology of multiple springs and their spring-run streams was needed. The data from this study would be analyzed to investigate patterns in vegetation communities and selected elements of the faunal communities and their relationships with physicochemical conditions. This study resulted from that determination.

A major focus of the SPI science component (SPIS) was to better understand the drivers which exert the greatest influence on the primary producer community structure (the submerged macrophyte and algal communities) in spring-run streams (Reddy et al. 2017). This was driven by the observation in many of these streams of proliferation of large mats of "nuisance" benthic algae, which either replaced the macrophytes, and/or substantially increased epiphytic algal biomass on the macrophyte leaves. Hypotheses advanced to explain these biological shifts include increased nitrate concentrations and loads discharged from the springs (Scott et al. 2004, Mattson et al. 2006, Stevenson et al. 2007), decreased spring flows resulting in reduced current velocity (King 2014, Kaplan et al. 2017), and reductions in algal grazer populations, possibly due to lower dissolved oxygen (DO) concentrations in the spring discharge (Heffernan et al. 2010, Liebowitz et al. 2014). Of broader note, Hudon et al. (2014) report that proliferation of nuisance benthic algae (particularly the filamentous cyanobacterium *Lyngbya wollei*, now called *Microseira wollei*) appears to be a growing phenomenon in freshwater ecosystems worldwide.

The specific objectives of this study were:

- Select a range of springs and their spring-run streams in which to conduct quantitative biological sampling and some related physicochemical sampling.
- Quantitative sampling of SAV and algae to assess current ecological conditions; include quantitative sampling of one or more major groups of fauna.
- Analyze the data to evaluate similarities and differences within and among the spring-run streams.

These data will form a baseline set of data that can be used to compare with future sampling efforts, and these data will also be compared to similar biological data collected in prior studies of Florida spring-run streams.

## DESCRIPTIONS OF SPRING-RUN STREAMS

In 2015, SJRWMD employed Amec Foster Wheeler (now Wood Environment and Infrastructure) to conduct an intensive, synoptic (short-term) biological survey in 14 spring-run streams in north and central Florida (Figure 1). Seven of these were in the St. Johns River Basin (northeast and east central Florida): Alexander Springs Creek, Blue Spring Run, Juniper Creek, Rock Springs Run, Silver River, Silver Glen Spring Run, and Wekiva River. Three spring-run streams were in west central Florida: Rainbow River, Gum Slough, and Weeki Wachee River. Four streams were in north Florida: Manatee Spring Run, Ichetucknee River, Wacissa River, and Wakulla River. These 14 streams were selected because all had a long term ($\geq$10 years) record of discharge and water chemistry. They were also chosen based on the personal knowledge of the senior author in consultation with other SJRWMD scientists,


Figure 1. Map of the region showing the locations of the 14 study streams.

scientists with other water management districts and the Florida Department of Environmental Protection (FDEP). Following are brief descriptions of each spring-run stream and its headspring(s). A summary of some physicochemical characteristics of each (and data sources) is presented in Table 1.

*Alexander Spring Creek*. This stream originates at Alexander Spring, a first-magnitude spring located in the Ocala National Forest in Lake County. Mean annual flow of Alexander Spring is 102 cfs (Appendix A) and the flow originates from a single main vent. The groundwater contributing area, or springshed (Copeland 2003) is approximately 151.52 $km^2$ (Walsh et al. 2009). The spring-run stream flows 19.1 km from the headspring to the mainstem of the St. Johns River, the confluence with the river located near Lake Dexter. Alexander Spring base water quality has been characterized as a mixed spring (Woodruff 1993), with moderately high levels of dissolved ions and salts. Nutrient concentrations (nitrate-nitrite nitrogen, NOx-N, and total phosphorus, TP) in Alexander Spring are low and reflective of background conditions (0.05-0.1 mg/L NOx-N and <0.06 mg/L TP). Human use of the recreational area at the headspring is high, particularly in the summer, but attendance figures (number of persons/day) were not available. Much of Alexander Spring Creek below the County Road (CR) 445 bridge is open to motorized boat traffic, but it is not heavily used due to very shallow depths. Use of the creek by canoes and kayaks is moderate.

*Blue Spring Run*. Blue Spring Run originates at Blue Spring (also called Volusia Blue Spring because of the common use of this spring name throughout the state), located in Blue Spring State Park in Volusia County. Blue Spring is a first-magnitude spring, with a mean annual flow of 144 cfs (Appendix A), although mean annual flow is historically reported as 162 cfs (Scott et al. 2004). Spring flow and stage in the spring run are heavily influenced by backwater from the adjacent St. Johns River. The flow originates from a single main vent in the spring pool. The springshed area is approximately 270.09 $km^2$ (Shoemaker et al. 2004). The spring run flows 0.67 km to the mainstem of the St. Johns River. Blue Spring is characterized as a salt spring (Woodruff 1993), with high levels of dissolved sodium, chloride and other ions. The source of these is relict seawater in a groundwater zone beneath the St. Johns River corridor (Stringfield and Cooper 1951; J. Stewart, SJRWMD, pers. comm.). Nitrate concentrations in Blue Spring are elevated relative to background conditions (currently averaging 0.6-0.8 mg/L NOx-N). TP concentrations are slightly higher than background (averaging 0.07 mg/L P). Recreational use of the park is high, with an average annual attendance of 589,941 in 2016-17[1]. Blue Spring Run is closed to motorized boat traffic. Canoes and kayaks are permitted in the run during certain hours. The entire run and headspring is closed to all human use between November and March to permit manatee use as a warm water refuge.

*Juniper Creek*. Juniper Creek originates at Juniper Spring in the Ocala National Forest in Marion County. Juniper Spring is a second-magnitude spring, with a mean annual flow of 11 cfs (Appendix A). The flow originates from a single main vent and possibly one or more minor vents in the spring pool. The springshed area for Juniper Spring has not been determined to date. Two other springs contribute to Juniper Creek, Fern Hammock Spring, which flows into

[1] Attendance figures from this and subsequent descriptions are from: https://floridadep.gov/sites/default/files/Economic%20Impact%20Assessment%202016-2017.pdf

Table 1. Selected physicochemical characteristics of the headsprings of the 14 spring-run streams surveyed in this study. Data sources are indicated at bottom of the table. Period of record varies by spring and may not be current data. ND = not determined.

| | **Alexander** | **Blue** | **Juniper** | **Rock** | **Silver** | **Silver Glen** | **Wekiva** |
|---|---|---|---|---|---|---|---|
| Discharge[1] (cfs) | 102 | 144 | 11 | 54 | 722 | 101 | 62 |
| Total Length of Run (km) | 19.1 | 0.7 | 16.3 | 14.5 | 8.5 | 1.1 | 25.5 |
| Springshed area[1] ($km^2$) | 151.5 | 270.1 | ND | 43.5 | 2,238 | ND | 81.8 |
| Conductivity[2] (mean; µmhos/cm) | 1,109 | 1,676 | 115 | 261 | 464 | 1,815 | 338 |
| Total Dissolved Solids[2] (mean; mg/L) | 593 | 914 | 66 | 148 | 273 | 1002 | 193 |
| pH[2] (mean; units) | 7.88 | 7.37 | 8.46 | 7.64 | 7.20 | 7.74 | 7.39 |
| Alkalinity[2] (mean; mg/L as CaCO3) | 86 | 144 | 47 | 97 | 198 | 69 | 129 |
| Sodium[3] (total; mg/L) | 122 | 167 | 2.30 | 4.80 | 5.92 | 238 | 10.20 |
| Chloride[2] (mean; mg/L) | 252 | 379 | 5 | 9 | 11 | 437 | 16 |
| Dissolved Oxygen[2] (mean; mg/L) | 1.58 | 0.47 | 6.51 | 0.91 | 1.91 | 2.94 | 0.75 |
| Total Phosphorus[4] (mean; unfiltered mg/L) | 0.05 | 0.07 | 0.03 | 0.09 | 0.04 | 0.03 | 0.12 |
| Orthophosphate[2] (mean; mg/L) | 0.05 | 0.07 | 0.03 | 0.08 | 0.04 | 0.03 | 0.12 |
| Nitrate-Nitrite N[2] (mean; mg/L) | 0.04 | 0.51 | 0.10 | 1.29 | 1.14 | 0.06 | 1.00 |

1 – Appendix A or sources cited in text;
2 – Di and Mattson, unpublished report using data collected 2009-2013;
3 – from Scott et al. 2004 (single value sampled 2001 or 2002);
4 – calculated from data provided by SWFWMD (Rainbow, Gum, Weeki Wachee), SRWMD (Manatee, Ichetucknee, Wacissa), NWFWMD (Wakulla) and SJRWMD data (Alexander, Blue, Juniper, Rock, Silver, Silver Glen, Wekiwa)

Table 1. Continued.

| | Rainbow | Gum | Weeki Wachee | Manatee | Ichetucknee | Wacissa | Wakulla |
|---|---|---|---|---|---|---|---|
| Discharge[1] (cfs) | 687 | 81 | 171 | 181 | 326 | 439 | 417 |
| Total Length of Run (km) | 9.7 | 8.0 | 12.1 | 0.4 | 8.8 | 21.7 | 14.5 |
| Springshed area[1] ($km^2$) | 1,904 | ND | 622 | ND | 960 | ND | 5,180** |
| Conductivity[3] (µmhos/cm) | 161 | 318 | 320 | 430 | 319 | 326 | 328 |
| Total Dissolved Solids[3] (mg/L) | 89 | 175 | 176 | 268 | 183 | 184 | 183 |
| pH[3] (units) | 7.95 | 7.57 | 7.70 | 7.04 | 7.91 | 7.40 | 7.20 |
| Alkalinity[3] (mg/L as CaCO3) | 67 | 129 | 147 | 198 | 154 | 163 | 146 |
| Sodium[3] (total or unfiltered; mg/L) | 2.33 | 3.40 | 3.78 | 3.78 | 2.12 | 2.94 | 4.99 |
| Chloride[3] (total or unfiltered; mg/L) | 3.9 | 6.0 | 6.7 | 7.2 | 3.6 | 5.1 | 7.8 |
| Dissolved Oxygen[3] (mg/L) | 6.61 | 1.81 | 1.30 | 1.60 | 3.52 | 0.90 | 2.39 |
| Total Phosphorus[4] (unfiltered mg/L) | 0.03 | 0.03 | 0.01 | 0.03 | 0.03 | 0.04 | 0.03 |
| Orthophosphate[4] (mg/L) | 0.03 | 0.03 | 0.01 | 0.03 | 0.02 | 0.05 | 0.03 |
| Nitrate-Nitrite N[4] (mg/L) | 1.70 | 1.50 | 0.90 | 2.00 | 0.76 | 0.30 | 0.50 |

** - includes springshed area of Wakulla Spring, Spring Creek Spring group, and St. Marks River Rise

1 – Appendix A or sources cited in text;
2 – Di and Mattson, unpublished report using data collected 2009-2013;
3 – from Scott et al. 2004 (single value sampled 2001 or 2002);
4 – calculated from data provided by SWFWMD (Rainbow, Gum, Weeki Wachee), SRWMD (Manatee, Ichetucknee, Wacissa), NWFWMD (Wakulla) and SJRWMD data (Alexander, Blue, Juniper, Rock, Silver, Silver Glen, Wekiwa)

the creek downstream of Juniper Spring, and Sweetwater Spring, which flows into the creek near the State Road (SR) 19 crossing. Fern Hammock is a second-magnitude spring with a mean flow of 11 cfs (Appendix A). Sweetwater Spring is also a second-magnitude spring with a mean flow of 13 cfs (Appendix A). Juniper Creek flows 16.33 km from the headspring to a confluence with Lake George. Juniper and Fern Hammock are both calcium bicarbonate springs, while Sweetwater is a salt spring (Woodruff 1993). Nutrient concentrations (NOx-N and TP) in Juniper Spring are at or below background levels ($\leq$0.10 mg/L NOx-N; 0.04-0.06 mg/L TP). Visitor use of the recreational area at the headspring is moderate to high, but attendance figures were not available. The upper half of Juniper Creek (above the SR 19 crossing) is closed to motorized boat traffic but has moderate to heavy use by canoes and kayaks. The lower half of the creek is open to boat traffic, but shallow depths generally preclude most motorized craft from navigating all but the lower part of the creek, near the confluence with Lake George.

*Rock Springs Run*. Rock Springs Run originates at Rock Springs in Kelly Park, Orange County. Rock Springs is a second-magnitude spring, with a mean annual flow of 54 cfs (Appendix A). The flow emerges from two cave openings in a vertical rock face at the headspring. The springshed area of Rock Springs is approximately 43.51 $km^2$ (Walsh et al. 2009). A small spring known as Sulphur Spring contributes flow to the run downstream of Rock Springs. It is a fourth magnitude spring with a mean annual flow of 0.74 cfs (www.sjrwmd.com/waterways/springs/list/). Rock Springs Run flows 14.46 km to a confluence with the Wekiva River. Both Rock Springs and Sulphur Spring are calcium bicarbonate water chemistry types (Woodruff 1993), although the latter gets its name from the odor of hydrogen sulfide in the spring water. Rock Springs is characterized by elevated NOx-N ($\geq$2.0 mg/L) and somewhat elevated TP (0.082 mg/L). Recreational use of the spring is high, with an average monthly attendance of 54,373. Annual attendance over the period 1998-2005 ranged from 73,626-214,983 (201.7-589 persons/day; Wetland Solutions Inc. 2007). Rock Springs Run is closed to motorized boat traffic but has moderate to heavy use by canoes and kayaks.

*Silver River*. The Silver River is a tributary of the Ocklawaha River. The headspring area of the river is known as the Silver Springs group (Copeland 2003), because it consists of at least 30 mapped, named spring vents (Munch et al. 2006). Historically, Silver Springs was the largest inland spring in the state by discharge, with a mean annual flow of 820 cfs (Scott et al. 2004), and the second largest spring in Florida overall. Based on current data, the mean average flow of the Silver Springs group is 722 cfs (Sutherland et al. 2017). About half of this flow is discharged from the main headspring, known as Mammoth Spring or Silver Spring. Flow in the Silver River is influenced by backwater effects during high stage on the Ocklawaha River (Baird et al. Unpublished Report). The springshed area of the springs group is listed as 2,238 $km^2$, which constitutes the “1,000-year capture zone” as delineated by groundwater modeling (Munch et al. 2006). The Silver River runs 8.5 km to the Ocklawaha River confluence. The Silver Springs group is a calcium bicarbonate water chemistry type (Woodruff 1993). Nitrate concentrations discharged from the springs group are elevated, averaging 1.1-1.3 mg/L NOx-N. Phosphorus as TP is at background concentration (0.04 mg/L P). Since the 1920s, the headspring area of Silver Springs has been a tourist attraction, one of the main features being glass-bottom boat rides to view the underwater communities, accompanied by narration from the boat captain (which continues today). The Silver River is now part of Silver River State Park and the Ocklawaha River Aquatic Preserve. Total annual attendance at the park in 2016–2017 was 480,272. The Silver River is open to motorized boat traffic up to the headspring and also is used heavily by canoes and kayaks.

*Silver Glen Spring Run*. Silver Glen Spring Run originates at Silver Glen Springs in the Ocala National Forest in Marion County. Silver Glen is a first-magnitude spring with a mean annual flow of 101 cfs (Appendix A) and a historical mean flow of 110.5 cfs (Scott et al. 2004). Since 2010, the flow of the spring has rarely reached over 100 cfs (SJRWMD unpublished data). The flow emerges from two vents; the main vent (Silver Glen) and a secondary vent known as the "Natural Well". Flow and water level in the spring and spring run are influenced by backwater from the adjacent St. Johns River. The springshed area of Silver Glen Springs has not been determined to date. The run flows for 1.13 km to a confluence with Lake George. Silver Glen Spring is characterized as a salt spring due to high levels of dissolved solids (Woodruff 1993). Nutrient concentrations (NOx-N and TP) in Silver Glen Springs are at or below background levels. Recreational use of the headspring and run is very high. Boat traffic is permitted, and large numbers of boats use the spring run, with no restriction on size or draft. A rope barrier prevents boats from entering the headspring pool. Attendance figures were unavailable.

*Wekiva River*. The Wekiva River originates at Wekiwa Springs (the spring spelling is different from the river) in Wekiwa Springs State Park, Orange County. The Wekiva River mainstem and all or portions of the tributaries are part of the Wekiva River Aquatic Preserve. Wekiwa Springs is a second-magnitude spring with a mean annual flow of 62 cfs (Appendix A). The flow originates primarily from a single main vent but there is a secondary vent in the spring pool that occasionally exhibits flow. Flow and water level are occasionally affected by backwater effects during high stage on the St. Johns River (SJRWMD unpublished data). The springshed area of Wekiwa Springs is approximately 81.84 $km^2$ (Walsh et al. 2009). The Wekiva River runs 25.47 km to its confluence with the St. Johns River downstream of Lake Monroe. The river receives inflow from three major tributary streams; Rock Springs Run, the Little Wekiva River, and Blackwater Creek. All of these tributaries receive some of their flow from a number of springs, ranging from second to sixth magnitude. A total of 31 named springs contribute flow to the Wekiva River and its tributaries. Wekiwa Spring is a calcium bicarbonate water chemistry type. Nutrient concentration in the spring are elevated relative to background conditions; NOx-N has been as high as >2 mg/L and TP concentrations average 0.12 mg/L. Recreational use of Wekiwa Spring is high, with an annual state park attendance in 2016–2017 of 399,040. Annual visitor attendance over the period 1993–2006 ranged from 94,962–166,738 (260.2–456.8 persons/day; Wetland Solutions Inc. 2007). The Wekiva River below the Rock Springs Run confluence is open to boat traffic, but shallow depths and abundant woody snags restrict boat use to smaller craft

*Rainbow River*. The Rainbow River begins at the Rainbow Springs group (a complex of multiple spring vents, similar to the Silver Springs group). The river is located in western Marion County, near the city of Dunnellon, and is a tributary of the southern Withlacoochee River. Total length of the river is 9.7 km. The Rainbow Springs group is a first-magnitude springs group, with a median flow of 687 cfs (SWFWMD 2015). Flow in the lower Rainbow River is influenced by backwater effects during high stages on the Withlacoochee River (SWFWMD 2015). Historically, the springs group was the overall third largest spring in Florida by discharge. The springshed of the springs group encompasses about 1,904 $km^2$ (SWFWMD 2015). The base water chemistry of the Rainbow Springs group is a calcium bicarbonate type (Woodruff 1993). Nitrate concentrations (as NOx-N) are elevated, averaging over 2 mg/L. Phosphorus levels (as TP) are at background concentrations. The headspring area and part of the upper Rainbow River are within Rainbow Springs State Park, and the entire Rainbow River is a state-designated Aquatic Preserve. Annual attendance in the park in 2016-17 was 316,796 persons. Historically the springs were privately owned and operated as a tourist attraction, featuring “submarine boat” tours of the headspring area. The Rainbow River is open to boat traffic and there are many private residences on the river, but the headspring area is closed to motorized boat traffic and only canoes and kayaks are allowed.

*Gum Slough*. Gum Slough begins at the Gum Springs group, a complex of at least 6–7 spring vents (Scott et al. 2004). The land surrounding the springs and much of the slough is in private ownership. The headsprings and slough are in Sumter County and the slough discharges to the southern Withlacoochee River upstream of the Rainbow River confluence. Total length of the slough is about 8 km. The Gum Springs group is a second-magnitude springs group with a mean annual flow of 81 cfs (King 2014). The base water quality of the springs is a calcium bicarbonate water quality type. The headsprings exhibit elevated nitrate concentrations (1.5 mg/L NOx-N). Phosphorus concentrations (as TP) are slightly below average.

*Weeki Wachee River*. The Weeki Wachee River originates at Weeki Wachee Spring in Hernando County. The spring is a first-magnitude spring, with a mean annual flow of 171 cfs (SWFWMD 2017). The Weeki Wachee springshed encompasses 622 $km^2$ (SWFWMD 2017). The Weeki Wachee River is about 12 km in length and discharges to the Gulf of Mexico near Bayport. The lower part of the river is affected by tidal fluctuation from the adjacent Gulf of Mexico. The base water chemistry of Weeki Wachee Spring is a calcium bicarbonate water quality type (Woodruff 1993). Nitrate concentrations in Weeki Wachee Spring are elevated, averaging 0.9 mg/L as NOx-N. Phosphorus concentrations are very low (0.01 mg/L TP). The headspring and upper river are part of Weeki Wachee Springs State Park. Historically the headspring was privately owned and operated as a tourist attraction, the main draw being an underwater theatre where visitors would watch performances featuring women portraying mermaids and other characters. The state park continues to operate the underwater show today, along with pontoon boat tours on the river. Annual attendance at the park in 2016–2017 was 418,844. Downstream of the headspring/state park there are many private residences and subdivisions along the river and it receives heavy recreational use by boats, canoes and kayaks.

*Manatee Spring Run*. Manatee Spring is located in Manatee Springs State Park, near the city of Chiefland in Levy County. The spring is a first-magnitude spring with a historic mean annual flow of 181 cfs (Scott et al. 2004). The spring run is 0.37 km in length and discharges to the lower Suwannee River. During low river flows in the Suwannee, water levels in the spring are affected by tidal fluctuation. The springshed area of Manatee Spring has not been determined because it is difficult to delineate it from the adjacent Fanning Springs springshed. Manatee

Spring is a calcium bicarbonate water quality type (Woodruff 1993). Nitrate concentrations are elevated, averaging over 2.0 mg/L NOx-N. Phosphorus concentrations (as TP) are slightly below the typical concentration. The spring run is closed to motorized boat traffic, but canoes and kayaks are allowed on the spring run. The state park experiences heavy recreational use by swimmers, snorkelers, and divers. Annual attendance in 2016–2017 was 308,175.

*Ichetucknee River*. The Ichetucknee River originates at the Ichetucknee Springs group; a complex of seven named springs. The springs and river are at the border of Suwannee and Columbia Counties, near the town of Fort White. The springs group and the upper half of the Ichetucknee River are within Ichetucknee Springs State Park. The mean annual flow of the springs group is 326 cfs (Katz et al. 2009). About half of that flow comes from Ichetucknee Spring (second-magnitude; mean flow 45 cfs) and the Blue Hole or Jug Spring (first-magnitude; mean flow 144 cfs). The springshed area encompasses 960 $km^2$ (Katz et al. 2009). The Ichetucknee River flows for 8.8 km to the lower Santa Fe River, a tributary of the middle Suwannee River. The springs of the Ichetucknee group all exhibit a calcium bicarbonate water quality type (Woodruff 1993). Nitrate concentrations in most of the springs in the spring group are elevated (>0.50 mg/L NOx-N). Phosphorus concentrations (as TP) are within the background range (0.04-0.06 mg/L TP). The upper half of the river within the state park is closed to motorized boat traffic, but is heavily used for tubing, swimming, snorkeling, and canoeing/kayaking, particularly between Memorial Day and Labor Day. Total annual attendance in the park in 2016-17 was 416,892. The lower half of the river is bordered by private residences with docks and boats are permitted to access this part of the river.

*Wacissa River*. The Wacissa River originates at the Wacissa Springs group, a complex of at least 16 known springs (Hornsby and Ceryak 2000). The springs and river are in Jefferson County. Much of the land around the river is state-owned as part of the Aucilla Wildlife Management Area. The Wacissa River is a tributary of the Aucilla River and runs 21.7 km from the headsprings group to the Aucilla River confluence. The mean annual flow of the springs group is 439 cfs, making it the overall fourth largest spring in the state by discharge (Hornsby and Ceryak 2000). The springshed area has not been determined. The base water chemistry of the springs comprising the springs group is a calcium bicarbonate type. Nitrate concentrations in many of the springs are somewhat elevated over natural background, although not as much as seen in many of the other spring-run streams in this study. Phosphorus concentrations are at background levels. The river is mainly accessed from a county park at the headspring group and at the Goose Pasture public recreation area on the river, but attendance figures were not available.

*Wakulla River*. The Wakulla River begins at Wakulla Spring. The spring and the upper third of the Wakulla River are within Wakulla Springs State Park. The springs and river lie entirely within Wakulla County. The river runs 14.5 km to its confluence with the St. Marks River near where it empties into the Gulf of Mexico near the town of St. Marks. The mean annual flow of Wakulla Spring is 417 cfs (K. Coates, NWFWMD Pers. Comm.). The springshed area cannot be delineated from the overlapping springsheds of the Springs Creek Springs group on the coast and the St. Marks River Rise (K. Coates, NWFWMD Pers. Comm.). The overall area of these is 5,180 $km^2$. The base water chemistry of Wakulla Spring is a calcium bicarbonate type.

Nitrate concentrations are elevated over background (0.5-0.6 mg/L NOx-N), although nitrate concentrations have been decreasing over the past decade with the implementation of improved domestic wastewater effluent disposal practices in the upper springshed. Phosphorus concentrations (as orthophosphate) are below natural background. Annual attendance at the state park in 2016–2017 was 239,270.

# METHODS

## SAMPLING STATIONS

Figure 1 showed the locations of the 14 spring-run streams in this study. Two sampling locations were established at 10 of these streams, consisting of a transect across the stream channel from bank-to-bank and perpendicular to the channel thalweg. One transect was established upstream, close to the main headspring or headspring group. The other transect was established at a downstream location in the spring-run stream proper. Three transects were established on the Silver River (upstream, mid-reach, and downstream) to help support other scientific work being conducted on that stream. On the three shorter spring runs (Manatee Spring, Blue Spring, and Silver Glen Spring), a single transect was established downstream of the headspring in the run itself. The locations of the transects were not established randomly; they were selected based on the occurrence of beds of SAV and professional judgement. Table 2 presents descriptive and location data on the transects in the 14 study streams and Appendix B presents maps showing the transect locations and the locations of related long-term ambient water quality sampling stations.

## FIELD METHODS

A detailed summary of all methods used in this study was presented in Amec Foster Wheeler (2016). For purposes of this technical report, a general summary of the methodology is presented. Field methods and QA/QC followed Standard Operating Procedures (SOPs) of SJRWMD and U.S. Geological Survey (USGS) as referenced in Amec Foster Wheeler (2016). Two types of data were collected at each sample transect: physicochemical data (current velocity, in situ water chemistry, and stream channel characteristics such as depth and tree canopy cover) and biological data (macrophyte cover and dry weight standing crop). Physicochemical data were collected on six separate sampling trips to the 14 study streams in 2015. Biological sampling was conducted concurrently on two of these sampling trips in spring and fall (May–June and September–October 2015, respectively).

### Physicochemical Sampling

For the physicochemical sampling, upon arrival at a transect location, a measuring tape and a tag line (if necessary) were stretched across the stream channel. All sampling occurred along the tape/tag line. Current velocity was measured and recorded with a SonTek FlowTracker handheld Acoustic Doppler Velocimeter (ADV). Up to 10 individual measurements of current velocity were made at locations across the stream channel at depths above the top of the SAV canopy. In situ water quality was measured using a multi-parameter sonde and a hand-held turbidity meter at a point approximately mid-stream on the transect. The following physicochemical variables were measured at each transect:

- Total water depth
- Height of the SAV canopy (as total depth minus depth to the top of the canopy)

Table 2. Location data and description of the sampling transects in this study.

| Station ID | Latitude (decimal degrees) | Longitude (decimal degrees) | Description |
|---|---|---|---|
| ALE1 | 29.08259003 | -81.57825003 | Alexander Springs Creek near headspring |
| ALE2 | 29.07929 | -81.56691997 | Alexander Springs Creek downstream of County Road 445 |
| GUM1 | 28.95340999 | -82.23836998 | Gum Slough near headspring group |
| GUM2 | 28.95974999 | -82.23209001 | Gum Slough between Gum Springs 3 & 4 |
| ICH1 | 29.9799 | -82.7589 | Ichetucknee River downstream of Blue Hole Spring |
| ICH2 | 29.957241 | -82.780301 | Ichetucknee River above U.S. 27 |
| JUN1 | 29.18449004 | -81.70372999 | Juniper Creek near headspring |
| JUN2 | 29.21174997 | -81.65322003 | Juniper Creek downstream of State Road 19 |
| MAN1 | 29.48948003 | -82.97798002 | Manatee Spring Run downstream of headspring |
| RAI1 | 29.09076667 | -82.42656667 | Rainbow River near headsprings group |
| RAI2 | 29.06896667 | -82.42753333 | Rainbow River downstream of K.P. Hole park |
| ROC1 | 28.77171667 | -81.50291667 | Rock Springs Run downstream of King’s Landing |
| ROC2 | 28.7411 | -81.46794002 | Rock Springs Run near Indian Mound camp site |
| SIL1 | 29.21573333 | -82.04845 | Silver River in headspring group (near Christmas Tree Spring) |
| SIL2 | 29.21528333 | -82.0417 | Silver River at USGS gauge/1,200 meter station |
| SIL3 | 29.20348333 | -82.015 | Silver River near SJRWMD minimum flows and levels transect 5 |
| SLG1 | 29.24471 | -81.64127001 | Silver Glen Spring Run downstream of headspring |
| VOL1 | 28.94707 | -81.33972 | Blue Spring Run downstream of headspring |
| WAC1 | 30.327034 | -83.987714 | Wacissa River near headspring group |
| WAC2 | 30.203283 | -83.970364 | Wacissa River at Goose Pasture |
| WAK1 | 30.234019 | -84.294372 | Wakulla River near headspring |
| WAK2 | 30.211438 | -84.259876 | Wakulla River downstream of County Road 365 |
| WEE1 | 28.51895 | -82.573891 | Weeki Wachee River near headspring |
| WEE2 | 28.519443 | -82.583234 | Weeki Wachee River downstream |
| WEK1 | 28.71415 | -81.45805 | Wekiva River near headspring (downstream of lagoon) |
| WEK2 | 28.79926667 | -81.4144 | Wekiva River upstream of State Road 46 |

- Tree canopy cover (using a Model-C spherical densiometer)
- Current velocity (up to ten points across the stream channel with the SonTek ADV)
- Staff gauge reading of water surface elevation, if a gauge was present at the sampling transect
- Specific conductance (YSI-5 series multi-parameter probe)
- Dissolved oxygen (YSI-5 series multi-parameter probe)
- pH (YSI-5 series multi-parameter probe)
- Water temperature (YSI-5 series multi-parameter probe)
- Turbidity (hand-held turbidimeter)

### Aquatic Vegetation Sampling

Sampling of submerged aquatic vegetation (macrophytes and algae) was conducted in a belt transect along the same transects that the physicochemical data were collected at (Figure 2). The belt transect “straddled” the measuring tape and tag line along which the physicochemical measurements were taken. Macrophyte cover was measured in five (5) 1 $m^2$ quadrats as described below. Quantitative samples of macrophytes (with associated epiphytic algae) and macroalgae mats were sampled with a modified Hess-type sampler as described below; three

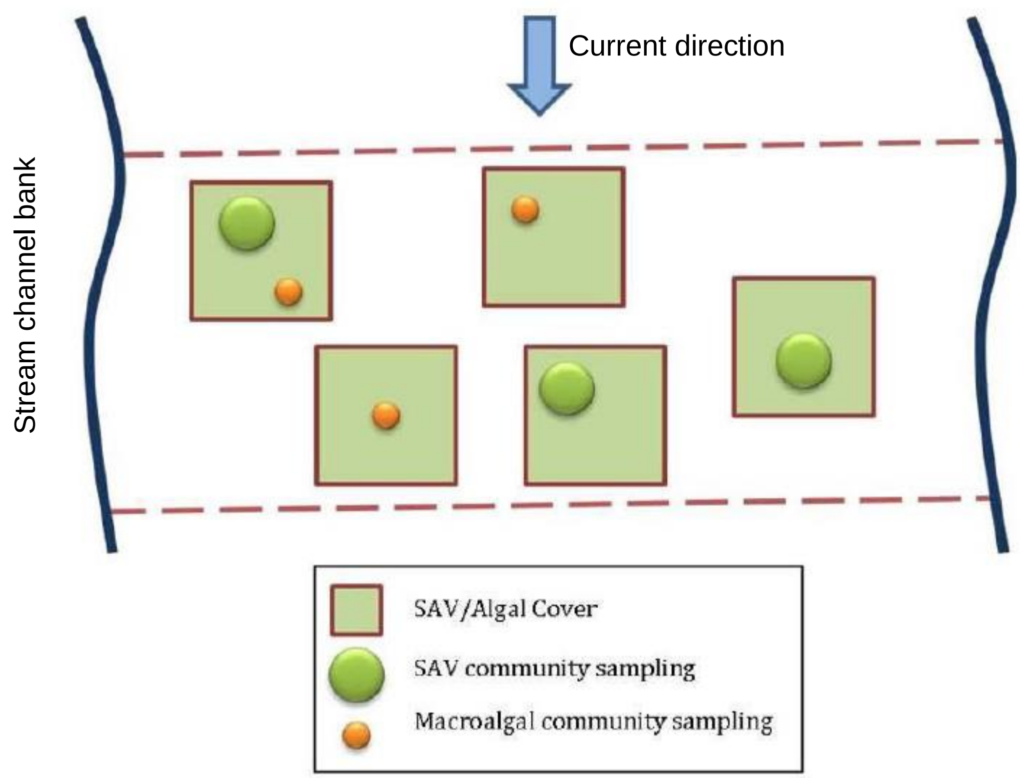



Figure 2. Schematic diagram showing the arrangement of replicate samples for SAV cover and standing crop (“community”) sampling. Source: Amec Foster Wheeler 2016.

(3) replicate macrophyte and three (3) replicate macroalgae samples were collected at each biological sampling event (spring and fall 2015). A schematic diagram showing the sampling design is presented in Figure 2.

As noted previously, transect and sample quadrat locations were determined in a non-random fashion by best professional judgement of three of us in the field (RAM, MLS, and MQG). Transects and sampling quadrats were located where beds of SAV (macrophytes and/or algae) were present in locations that appeared to us to be representative of the reach/area we located the transect in. Replicate samples for SAV cover and standing crop were also taken non-randomly (generally systematically across the stream channel from bank-to-bank); samples were collected where SAV was present.

SAV (macrophytes and algae) were sampled semi-quantitatively by estimating percent cover (as % cover) in a 1 $m^2$ quadrat divided into 100 10 X 10 cm sections to enable accurate estimation of vegetation coverage. Macrophyte cover was measured by plant species. Macrophyte samples (for measurement of above-ground dry weight standing crop) were collected using a modified Hess-type sampler with an area of 0.064 $m^2$ (Amec Foster Wheeler 2016). As noted above, three (3) replicate samples were collected within three of the 1-$m^2$ quadrats used for macrophyte cover measurement (Figure 2). The sampler was placed over an area of macrophytes and all plant material above the sediment surface was clipped or broken off and washed into a fine-mesh collection bag attached to the sampler. Collected plant material from each replicate was stored in plastic bags and preserved on ice for transport to the laboratory and then stored in cold storage until the sample was processed. The plant samples were generally analyzed within 24 hours of collection.

## LABORATORY METHODS

Macrophyte samples were preserved on ice and returned to the laboratory for processing. All macroinvertebrates were sorted from the vegetation and preserved for subsequent analysis of the SAV-associated invertebrate community (to be described in a separate report). Detritus, silt, sand, etc. were also washed from the vegetation samples. Macrophytes were sorted by species. For macrophyte dry weight standing crop, all epiphytic algae were washed and/or carefully scraped from the samples and the vegetation was dried to constant weight at 100 $^oC$ and weighed for dry weight, expressed as $g/m^2$.

## STATISTICAL ANALYSIS METHODS

All data summary and analysis were performed by District staff (RAM, DLH, and MQG). The physicochemical and vegetation data were summarized in tabular and graphical form, using Minitab™ version 17 software and program routines written by M.Q. Guyette in the R package. Due to the non-random placement of transects and sample sites within transects and the non-independence of transects within streams and sample sites within transects, statistical analysis for differences using conventional statistics (both parametric and/or nonparametric) were not possible. Consequently, results of the following analyses indicate general trends and relationships, rather than indicating true significant differences. Graphical and tabular summaries of the data were used to compare submerged macrophyte species composition and abundance among spring-run streams and to compare macrophyte abundance and physicochemical characteristics. The physical, chemical and biological data from spring and fall sampling events are presented and were analyzed separately.

Multivariate analyses of the physicochemical and vegetation data were conducted using the PRIMER™ software (Clarke and Gorley 2015), which was developed to specifically deal with species-by-sample data in the assessment of biological changes in response to changes in the abiotic environment (Clarke 1993). These analyses were conducted in an exploratory fashion to look for patterns in the data. Transects (e.g., upstream, downstream) within streams were analyzed separately. However, site-specific data was averaged within each transect (the means of cover and dry weight, rather than individual replicate samples). Data for spring and fall sampling events were analyzed separately to avoid seasonal differences that might overwhelm inter-transect differences. Physicochemical variables were log-transformed and normalized prior to analysis and Euclidian distance was used to calculate resemblance matrices to test for similarities among transects. SAV cover and dry weight were (log+1)-transformed prior to analysis and the Bray-Curtis similarity index (Bray and Curtis 1957) was used to calculate resemblance matrices to test for similarities among transects. SAV species were eliminated from the analyses if their biomass or abundance constituted <3% of the total biomass or abundance on each transect.

The following analyses were performed:

Principal Components Analysis (*PCA*) was used to orthogonally transform the set of physicochemical variables into a smaller set of linearly uncorrelated axes to look for similarities among transects. Orthogonal axes are created based on how much of the variability between transects in the physicochemical variables is captured by the combination of the original variables, with the most variability captured in the first axis, the second axis accounting for the greatest amount of the remaining variability, and so on until most of the variability between transects is accounted for. When the axes are plotted against one another, transects with similar values for the suite of physicochemical variables will occur close together.

Cluster Analysis (*CLUSTER*) was used to search for similarities among transects based on physicochemical or SAV compositional differences. Simultaneously, a Similarity Profile test (*SIMPROF*) was used to assess the significance of cluster groups. *SIMPROF* runs permutations of SAV community or physicochemical composition at each node in the cluster to determine whether there is any evidence of multivariate structure within the group. If multivariate structure is detected, then the transects within the group at that node are considered significantly different from the other transects.

Analysis of Similarity (*ANOSIM*) was used to determine whether there were any differences between spring-run streams that flow into the St. Johns River (SJR) and the other streams (O) or between upstream and downstream transects based on their physicochemical or SAV composition. When differences were found between groups (i.e., SJR vs O or upstream vs downstream), a Similarity Percentages (*SIMPER*) routine was used to pinpoint which variables or species accounted for those differences.

The Bio-Env Stepwise procedure (*BEST*) was used to determine if there was a correlation between the distribution of stream sites based on the composition of the SAV community and the distribution of sites based on the physicochemical variables collected at each site. The test compares resemblance matrices based on SAV and physicochemical similarities and determines what combination of physicochemical variables accounts for the pattern in SAV species composition among transects.

To further explore relationships between selected physicochemical variables and SAV measures, quantile regression was used to evaluate relationships between the physicochemical variables and macrophyte measures (cover and standing crop). Quantile regression evaluates the quantile components of a response variable (e.g., $10^{th}$ percentile, $50^{th}$ percentile, etc.) in a regression. This can provide a more complete view of possible cause/effect relationships between two variables (Cade and Noon 2003). Quantile regression analysis was performed using the Statistical Analysis System (SAS) software.

# RESULTS AND DISCUSSION

## PHYSICOCHEMICAL DATA

Table 3 shows the physicochemical data (mean values from the six sampling events) collected at the transects that supported submerged macrophytes in both spring and fall 2015. Channel width at each transect was generally similar in the spring and fall; variation is likely due to changes in water levels in the stream channel or sampling in a slightly different location. Tree canopy cover was variable, with generally higher tree cover associated with narrower stream channel width. Current velocity likewise exhibited considerable variation; in some systems the downstream transect had higher velocities (Wekiva River), but in others the upstream transects were higher (e.g., Gum Slough). Water temperatures were very consistent both among and within spring-run stream systems, varying from ~20–24 $^{0}$C across all transects, and generally being similar at both upstream and downstream transects in all streams and in both spring and fall sampling episodes. In many cases the fall water temperature was slightly cooler than the spring. The more northern springs (WAC and WAK) generally had lower mean water temperature than the springs further south. Highest conductivity was measured at the downstream Juniper Creek site (JUN2) and the Silver Glen Run transect (SLG1). Like water temperature, pH was very consistent among and within all stream systems; pH was generally circumneutral to slightly alkaline. Higher pH values (>8) appeared to generally be associated with high (supersaturated) dissolved oxygen (DO) concentrations, suggesting an effect of plant photosynthesis. DO was generally lower at upstream sites, nearer to the headspring discharge, but two upstream sites exhibited particularly high DO concentrations (JUN1 and RAI1). Turbidity was uniformly very low among and within the streams. Highest single turbidity was a value of 9.66 NTU at the Silver Glen Run transect in the fall. This may be due to recreational use of the spring on that day causing an increase in suspended sediments.

Principal Components Analysis showed that four variables accounted for most of the differences among the transects and spring-run streams across seasons: stream width, pH, and DO in the spring season, and stream width, pH, and conductivity in the fall. The cluster analysis (Figure 3) showed no significantly different clusters based on water quality in both seasons, but in general spring-run streams on the St. Johns River mainstem (SJR) clustered together and “Other” streams (not on the mainstem of the St. Johns) also tended to cluster. The ANOSIM showed significant differences between SJR spring-run streams vs. Other streams ($R=0.281$; $P=0.002$ in spring; $R=0.157$; $P=0.058$ in fall). The SIMPER analysis indicated that conductivity, turbidity, current velocity, and water depth were main factors separating SJR streams from other streams in both seasons. The SJR streams generally had higher conductivity and turbidity, while Other streams had greater water depth and/or current velocity (depending on season). In comparing upstream and downstream transects within a given spring-run stream with the SIMPER analysis, no significant differences were seen in the spring sampling, but there were significant upstream/downstream differences in the fall. Downstream sites had higher DO, water temperature, turbidity, current velocity, pH and conductivity.

Table 3. Mean values of physicochemical measurements made at the sampling transects in spring and fall 2015. ND = no data.

| TRANSECT | Channel Width (m) | Canopy Cover (%) | Current Velocity (m/sec) | Water Temp ($^0$C) | Conductivity (umhos/cm) | pH | Dissolved $O_2$ (mg/L) | Turbidity (NTU) |
|---|---|---|---|---|---|---|---|---|
| ALE1 sprg | 41.0 | 1.5 | 0.05 | 24.35 | 1,172 | 7.56 | 2.64 | 0.17 |
| ALE1 fall | 47.0 | 8.3 | 0.06 | 24.13 | 1,073 | 7.42 | 2.28 | 0.57 |
| ALE2 sprg | 64.0 | 0 | 0.09 | 26.28 | 1,164 | 8.28 | 5.95 | 0.07 |
| ALE2 fall | 64.0 | 0 | 0.15 | 24.30 | 1,080 | 7.92 | 5.59 | 1.40 |
| GUM1 sprg | 15.0 | 62.5 | 0.14 | 23.55 | 363 | 7.24 | 5.62 | 0.27 |
| GUM1 fall | 9.0 | 58.5 | 0.15 | 23.24 | 355 | 7.48 | 6.02 | 0.61 |
| GUM2 sprg | 20.0 | 66.8 | 0.13 | 23.42 | 356 | 6.60 | 4.99 | 0.73 |
| GUM2 fall | 18.0 | 64.8 | 0.07 | 23.23 | 364 | 7.65 | 4.96 | 0.92 |
| ICH1 sprg | 13.7 | 54.8 | 0.10 | 21.67 | 312 | 7.28 | 3.70 | 0.27 |
| ICH1 fall | 13.7 | 52.8 | 0.24 | 21.76 | 287 | 7.18 | 2.80 | 0.31 |
| ICH2 sprg | 21.9 | 43.5 | 0.16 | 23.71 | 320 | 7.21 | 9.56 | 0.87 |
| ICH2 fall | 21.3 | 38.3 | 0.28 | 22.04 | 304 | 7.26 | 4.54 | 1.14 |
| JUN1 sprg | 6.0 | 41.8 | 0.32 | 23.13 | 143 | 7.17 | 8.17 | 1.45 |
| JUN1 fall | ND | ND | ND | ND | ND | ND | ND | ND |
| JUN2 sprg | 20.0 | 2.3 | 0.34 | 23.20 | 2,050 | 7.42 | 6.72 | 1.41 |
| JUN2 fall | 17.0 | 6.25 | 0.08 | 23.76 | 1,940 | 8.00 | 7.75 | 0.97 |
| RAI1 sprg | 33.5 | 1.0 | 0.23 | 23.39 | 259 | 7.75 | 7.51 | 0.88 |
| RAI1 fall | 29.0 | 4.0 | 0.18 | 23.41 | 284 | 7.36 | 7.91 | 0.52 |
| RAI2 sprg | 51.8 | 5.0 | 0.17 | 23.63 | 265 | 8.01 | 8.85 | 0.75 |
| RAI2 fall | 42.7 | 2.5 | 0.20 | 24.27 | 283 | 7.89 | 10.70 | 0.35 |
| ROC1 sprg | 17.7 | 51.8 | 0.18 | 23.71 | 266 | 7.88 | 4.74 | 0.68 |
| ROC1 fall | 19.2 | 30.5 | 0.13 | 24.08 | 273 | 7.47 | 8.77 | 0.18 |
| ROC2 sprg | 11.6 | 16.0 | 0.13 | 24.44 | 271 | 7.93 | 7.15 | 1.51 |
| ROC2 fall | 9.1 | 31.0 | 0.44 | 23.00 | 350 | 6.97 | 6.55 | 1.04 |
| SIL1 sprg | 30.5 | 16.0 | 0.15 | 23.58 | 441 | 7.34 | 3.61 | 0.98 |
| SIL1 fall | 36.6 | 1.25 | 0.14 | 23.49 | 456 | 6.95 | 3.20 | 0.20 |
| SIL2 sprg | 54.9 | 1.5 | 0.24 | 24.12 | 430 | 7.87 | 5.94 | 0.61 |
| SIL2 fall | 54.9 | 0 | 0.20 | 23.60 | 434 | 7.09 | 3.85 | 0.44 |

Table 3. Continued.

| TRANSECT | Channel Width (m) | Canopy Cover (%) | Current Velocity (m/sec) | Water Temp ($^0$C) | Conductivity (umhos/cm) | pH | Dissolved $O_2$ (mg/L) | Turbidity (NTU) |
|---|---|---|---|---|---|---|---|---|
| SIL3 sprg | 31.4 | 36.0 | 0.19 | 24.73 | 446 | 7.47 | 7.86 | 1.29 |
| SIL3 fall | 27.4 | 26.3 | 0.14 | 23.89 | 393 | 6.65 | 4.32 | 2.28 |
| SLG1 sprg | 64.0 | 5.5 | 0.04 | 24.03 | 2,013 | 8.18 | 5.10 | 0.79 |
| SLG1 fall | 64.0 | 0 | 0.04 | 23.45 | 1,897 | 7.96 | 4.07 | 9.66 |
| WAC1 sprg | 54.9 | 1.0 | 0.10 | 20.72 | 223 | 7.47 | 5.64 | 0.88 |
| WAC1 fall | 54.9 | 1.3 | 0.14 | 20.71 | 279 | 7.34 | 4.02 | 0.38 |
| WAC2 sprg | 77.7 | 1.5 | 0.19 | 26.69 | 295 | 8.20 | 10.17 | 1.15 |
| WAC2 fall | 73.2 | 0 | 0.20 | 23.41 | 304 | 8.17 | 9.85 | 0.43 |
| WAK1 sprg | 57.9 | 1.5 | 0.06 | 21.16 | 286 | 7.69 | 4.26 | 1.09 |
| WAK1 fall | 62.2 | 0 | 0.22 | 20.67 | 308 | 7.30 | 2.48 | 0.38 |
| WAK2 sprg | 25.6 | 21.5 | 0.07 | 23.19 | 298 | 8.04 | 8.78 | 2.38 |
| WAK2 fall | 24.4 | 11.5 | 0.22 | 21.36 | 308 | 7.58 | 5.43 | 1.47 |
| WEE1sprg | 29.0 | 26.8 | 0.10 | 23.85 | 325 | 7.62 | 2.07 | 0.88 |
| WEE1 fall | 21.3 | 78.3 | 0.15 | 23.84 | 343 | 7.52 | 2.25 | 0.22 |
| WEE2 sprg | 13.7 | 32.3 | 0.39 | 24.38 | 325 | 7.78 | 4.52 | 0.62 |
| WEE2 fall | 15.2 | 49.3 | 0.42 | 24.32 | 341 | 7.74 | 5.06 | 0.17 |
| WEK1 sprg | 21.3 | 8.5 | 0.07 | 24.57 | 357 | 7.93 | 2.51 | 0.88 |
| WEK1 fall | 15.2 | 10.0 | 0.06 | 24.05 | 358 | 7.17 | 2.29 | 0.41 |
| WEK2 sprg | 35.1 | 0.8 | 0.18 | 25.39 | 356 | 7.66 | 5.84 | 3.03 |
| WEK2 fall | 36.6 | 1.0 | 0.12 | 22.69 | 353 | 7.06 | 4.80 | 2.13 |

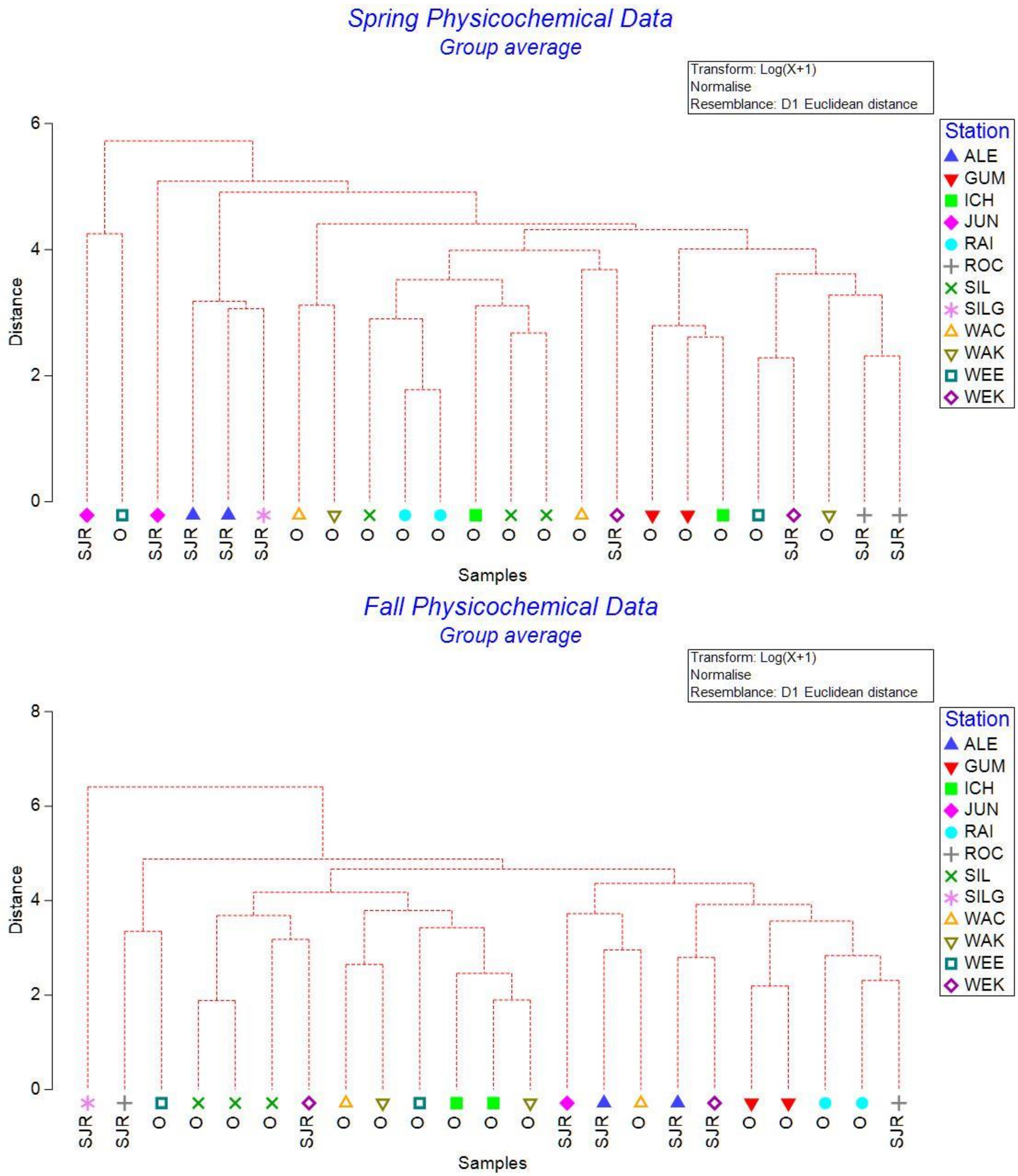



Figure 3. Cluster analysis of the physicochemical data at the transects supporting submerged macrophytes. No significant differences among transects were detected, but St. Johns River (SJR) transects tended to cluster together, as did Other (O) transects (those not on the St. Johns River).

## MACROPHYTE DATA

Nine taxa of macrophytes were collected from both biological sampling events:

*Ceratophyllum demersum* (coontail)
*Chara* (a macrophytic green alga)
An unidentified charophyte (also a green alga)
*Hydrilla verticillata* (hydrilla)
*Najas guadalupensis* (southern naiad)
*Potamogeton illinoensis* (Illinois pondweed)
*Potamogeton pectinatus* (sago pondweed, now called *Stuckenia pectinata*)
*Sagittaria kurziana* (spring tape or strap-leaf sag)
*Vallisneria americana* (eelgrass or wild celery)

No macrophytes were present in Blue Spring (VOL1) or Manatee Spring (MAN1), so these springs were not included in the analyses in this report.

The three most frequently occurring species during the spring were *Vallisneria*, *Sagittaria* and *Hydrilla*, occurring at 15, 11 and 6 transects, respectively. These were also the three most frequently occurring species during the fall, found at 16, 11, and 7 transects, respectively. *Vallisneria* was found at GUM2 in the fall but not during the spring. *Ceratophyllum* was only collected at ALE1 duirng spring and was not found at any transect during fall. *Chara* was only found at WAK2 during spring and was also not found at any transect during the fall. *Potamogeton illinoensis* was only found at WAC2, while *P. pectinatus* was only found at JUN2, and this pattern was seen in both spring and fall. *Najas* was measured at 5 transects during the fall (vs. 3 during the spring); it was measured in both seasons at ALE1 but was measured at WAK2 and WEK1 only during spring and at GUM2, RAI2, SIL3 and WAC1 only during fall.

### Macrophyte Cover

<u>Spring 2015</u>. Appendix C Tables 1–4 summarize the percent cover data in the spring for eight of the nine macrophyte taxa observed (the unidentified charophyte was very rare and only measured in small amounts at the downstream Silver River transect in the fall). Figure 4 shows macrophyte cover during spring for all three replicate samples at all transects. Based on inspection of Figure 4, generally highest percent cover of *Vallisneria* was seen at both transects on Alexander Springs Creek (ALE1 and ALE2) and the Wekiva River (WEK1 and WEK2), and at the downstream transect on the Ichtucknee River (ICH2). Highest *Sagittaria* cover was seen at the upstream Gum Slough transect (GUM1), the upstream Rainbow River transect (RAI1), the Silver River transects (especially the two upstream sites, SIL1 and SIL2) and both Wacissa River transects (WAC1, WAC2). Highest *Hydrilla* cover during spring was seen at SLG1 and WAK1. It was present at very low cover at the other transects where it occurred. The only other macrophyte taxon that occurred at multiple transects was *Najas*; percent cover of this plant was similar on the three transects it was found at during spring (ALE1, WAK2, and WEK1).

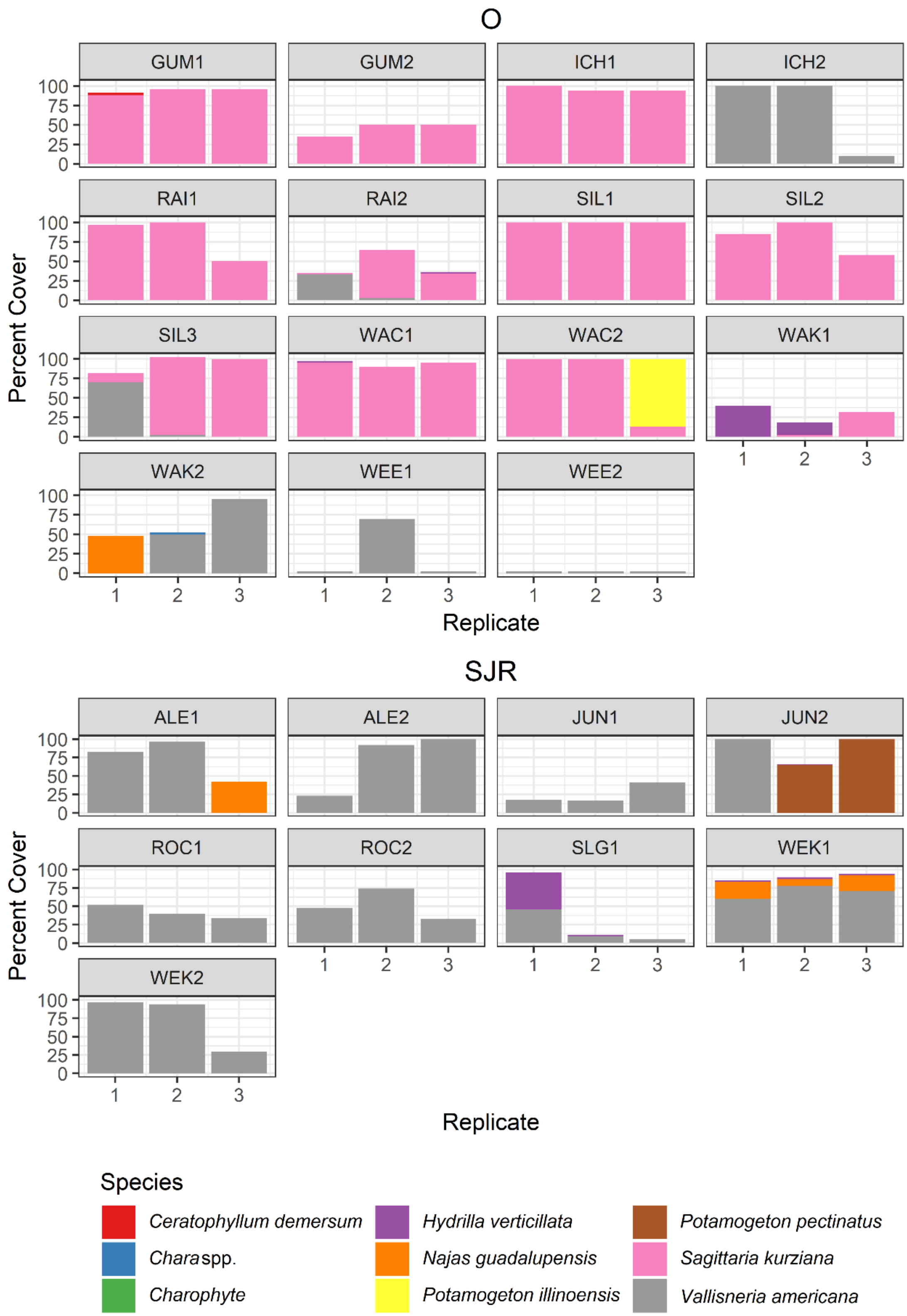



Figure 4. Percent cover at the sampling transects (individual replicate quadrats plotted) of macrophyte species during spring 2015. SJR=St. Johns River streams; O=Other streams.

*Vallisneria* and *Sagittaria* were the two dominant plant species by cover and generally exhibited opposite spatial trends in cover both among different spring-run streams and among transects within a stream during the spring sampling event. *Vallisneria* generally exhibited higher cover at streams on the St. Johns River (SJR), while *Sagittaria* exhibited highest cover at “Other” (O) streams (not on the St. Johns River – Figure 5). Within a particular stream where both *Vallisneria* and *Sagittaria* occurred, the former generally had higher cover at the downstream transects (Figures 4 and 5), while *Sagittaria* consistently exhibited higher cover at upstream transects (Figures 4 and 5). All the other macrophyte taxa were only present at a single transect on each spring-run stream. The lower reaches of many of these streams acquire a moderate to high level of water color and turbidity during periods of heavier rainfall due to surface water runoff. *Sagittaria* has higher light requirements than other macrophyte taxa in spring-run streams and *Vallisneria* is better able to tolerate the reduced light under these conditions (Szafraniec 2014). *Vallisneria* is also able to grow longer leaves to reach the water surface under reduced light conditions.

<u>Fall 2015</u>. Appendix C Tables 5–8 summarize the percent cover data in the fall sampling event. Figure 6 shows macrophyte cover (by species, individual replicate quadrats plotted) in the fall. Highest *Vallisneria* cover was seen at the downstream transects on the Ichtucknee River and Juniper Creek (ICH2 and JUN2), both Rock Springs Run transects (ROC1 and ROC2), the downstream Wakulla River transect (WAK2), and both Weeki Wachee River transects (WEE1 and WEE2). Highest *Sagittaria* cover was exhibited at the upstream transects on the Ichetucknee and Rainbow Rivers (ICH1, RAI1), the middle transect on Silver River (SIL2, which is more “upstream”) and the downstream Wacissa River transect (WAC2). In the fall, highest *Hydrilla* cover was at SLG1 and highest *Najas* cover was measured at ALE1 and GUM2.

The same general spatial patterns in macrophyte cover seen in the spring were also exhibited in the fall. *Vallisneria* dominated the cover at the SJR spring-run streams, while the O streams were largely dominated by *Sagittaria*, in terms of percent cover (Figure 7). When both species were found in the same stream, *Vallisneria* generally exhibited higher cover at the downstream transects (Figures 6 and 7) and *Sagittaria* higher cover upstream.

Cluster analysis showed two significant clusters in spring and three clusters in fall (Figure 8) based on sites dominated by *Vallisneria*, those dominated by *Sagittaria*, or sites with a mix of the two species. SJR transects generally clustered together. The ANOSIM analysis showed significant differences in macrophyte cover among the SJR and O transects in both the spring ($R=0.418$, $p=0.002$) and fall ($R=0.346$, $P=0.003$). The main differences were between spring-run streams on the St. Johns River (SJR) mainstem vs. “Other” spring-run streams (those spring-run streams not on the SJR mainstem, including Silver River). SIMPER analysis showed that the SJR vs. Other streams were differentiated by higher percent cover of *Vallisneria* on the former vs. generally higher *Sagittaria* cover on the latter. The Bio-Env (BEST) analysis showed weak correlation between physicochemical variables and SAV cover, with tree canopy cover, conductivity, turbidity, stream width and current velocity generally being most influential on SAV cover.

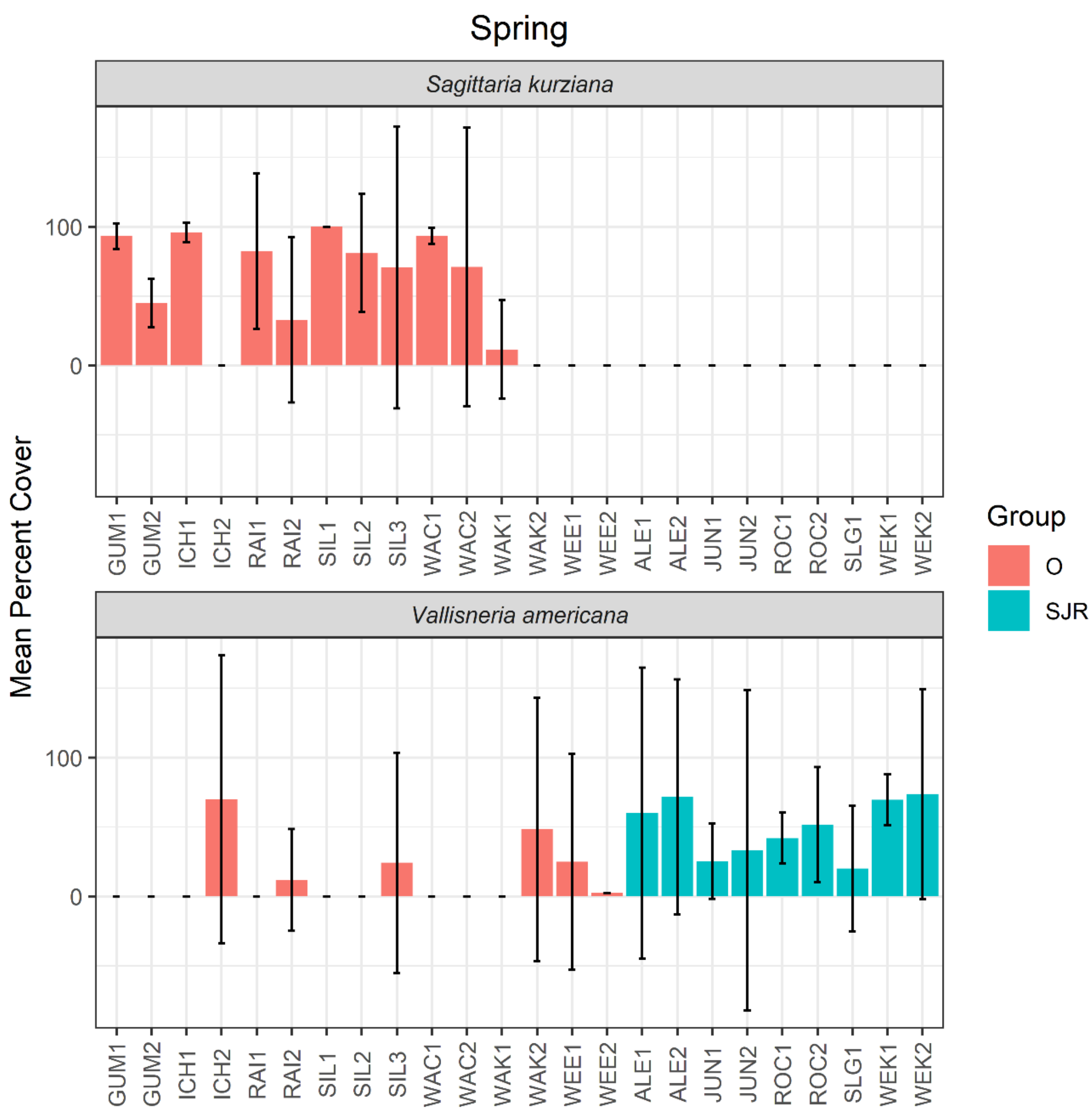



Figure 5. Mean percent cover (± 2 standard deviations) of *Sagittaria* and *Vallisneria* during spring 2015. SJR=St. Johns River streams; O=Other streams.

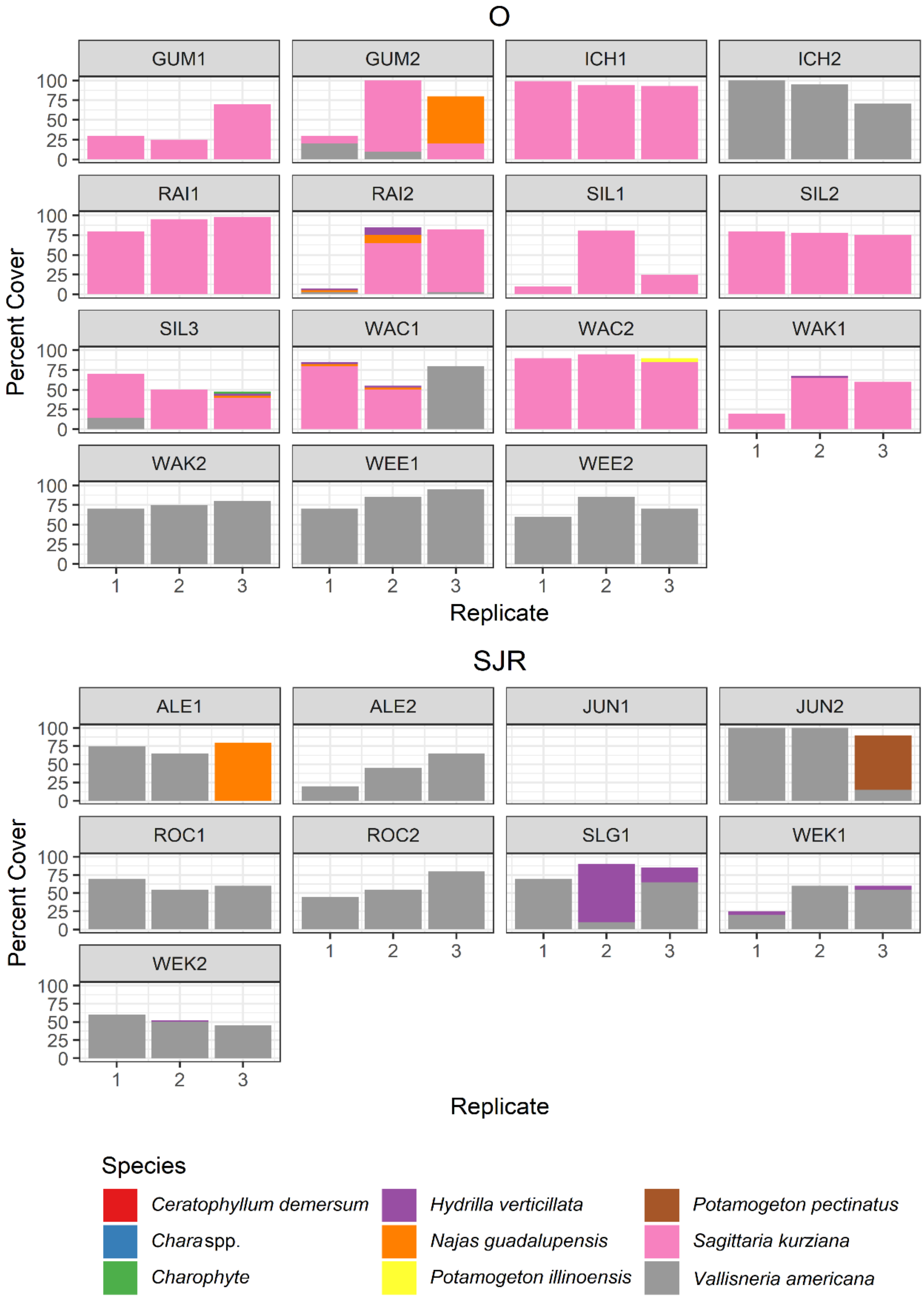



Figure 6. Percent cover at the sampling transects (individual replicate quadrats plotted) of macrophyte species during fall 2015. SJR=St. Johns River streams; O=Other streams.

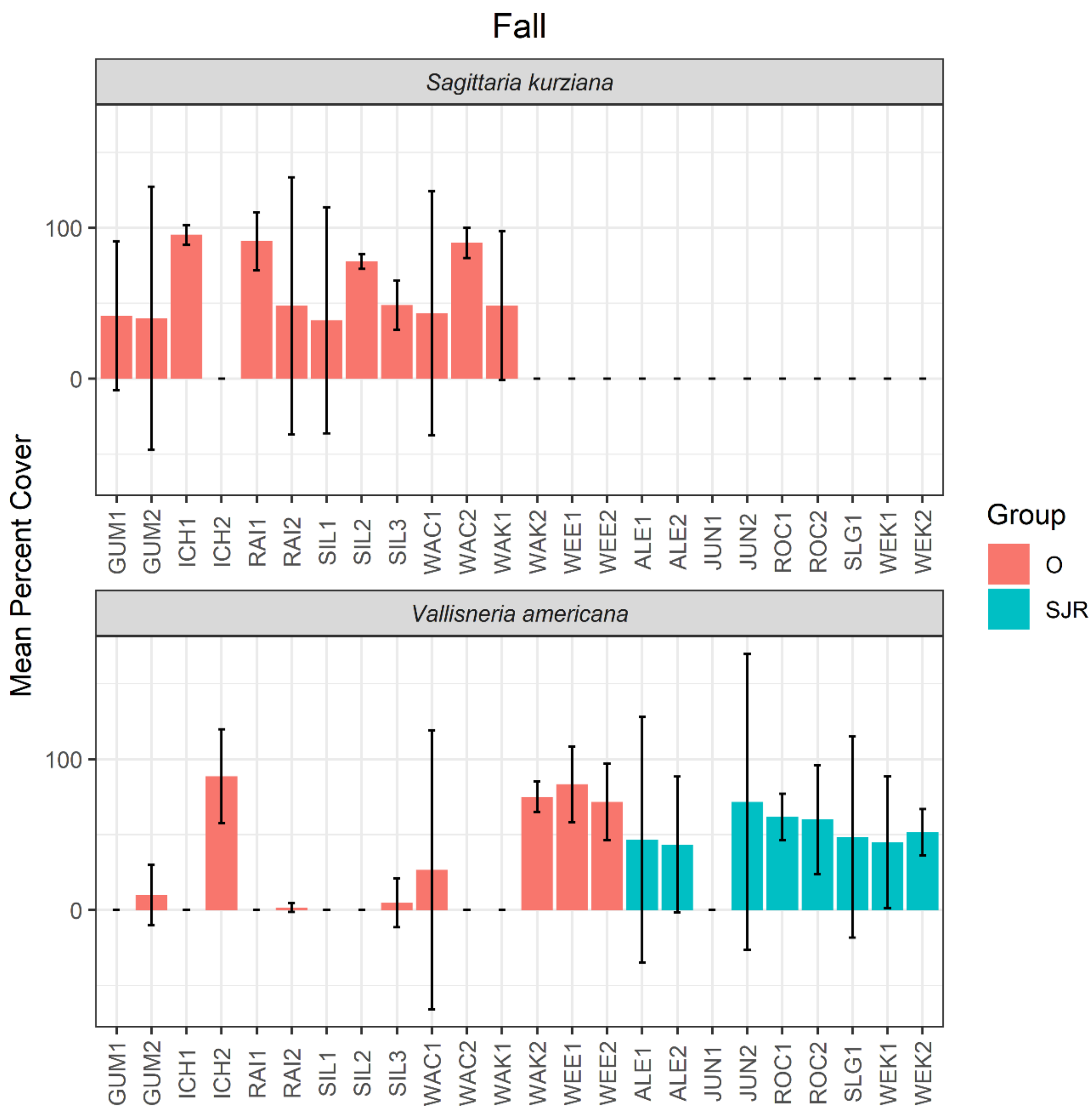
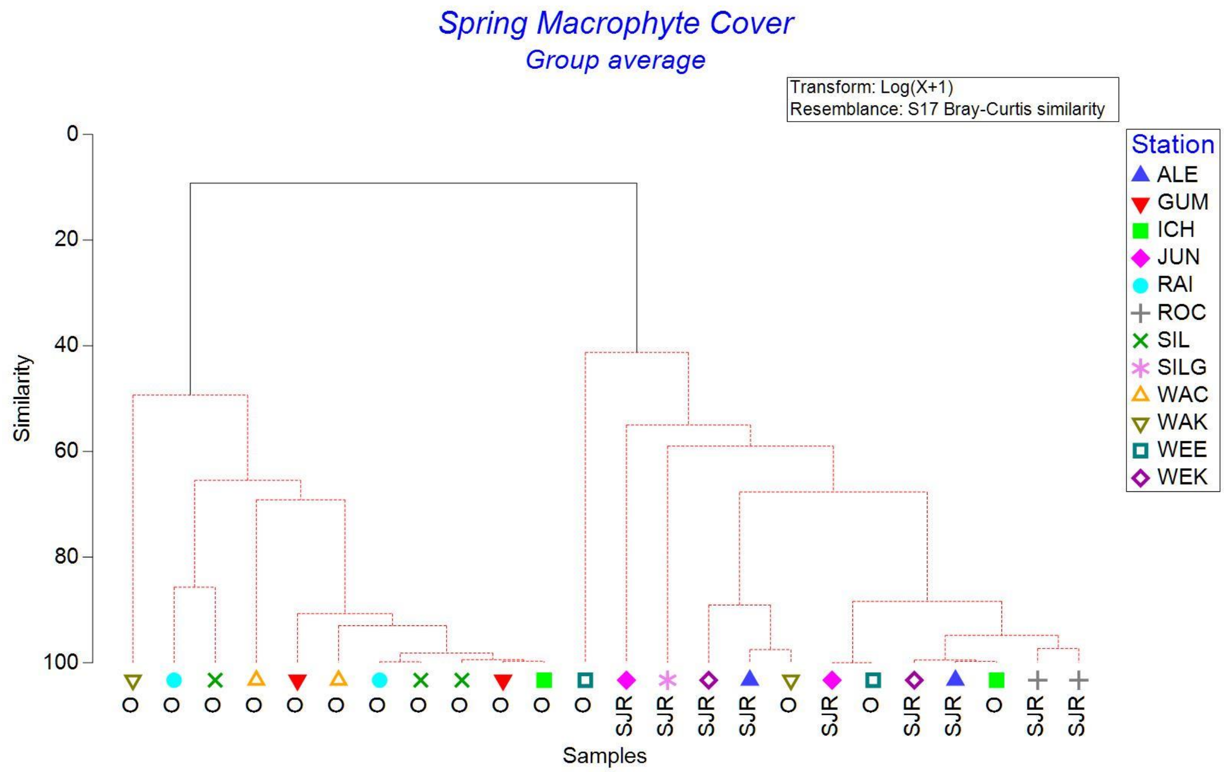



Figure 7. Mean percent cover (± 2 standard deviations) of *Sagittaria* and *Vallisneria* during fall 2015. SJR=St. Johns River streams; O=Other streams.



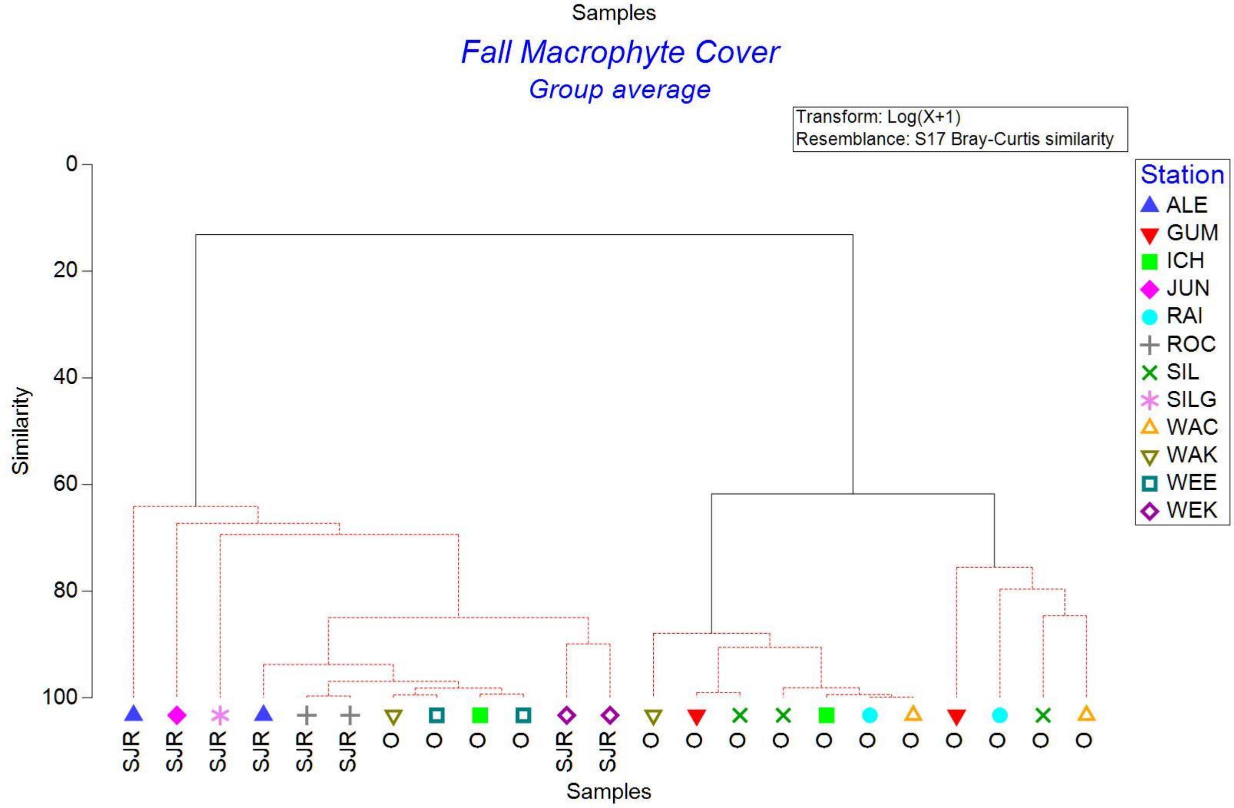




Figure 8. Cluster analysis diagrams of cover data during spring and fall 2015. Clusters connected with a solid line are significantly different.

### Macrophyte Dry Weight

Spring 2015. Appendix C Tables 9–12 summarize the macrophyte dry weight data from the spring sampling event. Figure 9 plots the dry weight data for all macrophyte species (all three replicate samples at a transect) during spring. Similar patterns were seen at some transects for both dry weight and cover, while at other transects the pattern was different. Highest *Vallisneria* standing crop was seen at the downstream Ichetucknee River transect (ICH2), both Rock Springs Run transects (ROC1 and ROC2), and the upstream Wekiva River transect (WEK1). Highest *Sagittaria* standing crop was seen at the upstream transects on the Rainbow River (RAI1), Silver River (SIL1, SIL2) and the Wacissa River (WAC1). *Hydrilla* exhibited highest dry weight standing crop at SLG1 and WAK1, while *Najas* exhibited highest standing crop at WAK2 (Figure 9).

Also, as seen in the percent cover data, *Vallisneria* and *Sagittaria* dominated the dry weight standing crop and *Vallisneria* generally exhibited higher mean standing crop at the St. Johns River streams (SJR) versus Other (O) streams (Figure 10), while *Sagittaria* was only found at the Other streams. Similarly, where both plant taxa occurred in the same spring-run stream, higher *Vallisneria* mean dry weight was generally exhibited at the downstream transects, while *Sagittaria* had higher mean dry weight at upstream transects (Figures 9 and 10).

Fall 2015. Appendix C Tables 13–16 summarize the macrophyte dry weight data from the fall sampling event. Figure 11 plots the dry weight data for all macrophyte species during the fall (individual replicate samples plotted). Highest *Vallisneria* standing crop was seen at some of the same transects with highest cover; ICH2, both ROC transects, WAC1, WAK2 and WEE1. Highest *Sagittaria* standing crop was measured at ICH1, SIL1, SIL2, and WAC2. *Hydrilla* standing crop was highest at SLG1 (Figure 11) and highest *Najas* standing crop was measured at ALE1. *Potamogeton pectinatus* persisted at JUN2 during the fall, as well as being present at this transect in the spring, but *P. illinoensis* was not found at WAC2 in the fall, while it did occur there in the spring.

As seen for dry weight during the spring, highest *Sagittaria* mean standing crop was exhibited at the transects on the Other spring-run streams (and it only occurred at these – Figure 12), while highest *Vallisneria* mean standing crop was exhibited at the SJR streams or at the downstream transects of O streams (Figures 11 and 12). This pattern was seen consistently in both spring and fall for both plant species.

Cluster analysis showed two clusters of transects that were significantly different in the spring and three clusters in the fall (Figure 13). These were largely based on dominance of *Vallisneria* or *Sagittaria* on a transect, similar to the results for cover. The ANOSIM analysis showed significant differences between SJR vs. Other springs (spring R=0.375, P=0.005; fall R=0.31, P=0.006), again largely based on dominance of *Valllisneria* in the former. SIMPER results likewise supported the difference between SJR and Other springs as due to dominance of one or the other plant (*Vallisneria* in SJR systems, *Sagittaria* in Other). The BEST analysis showed little correlation between physicochemical variables and macrophyte standing crop.

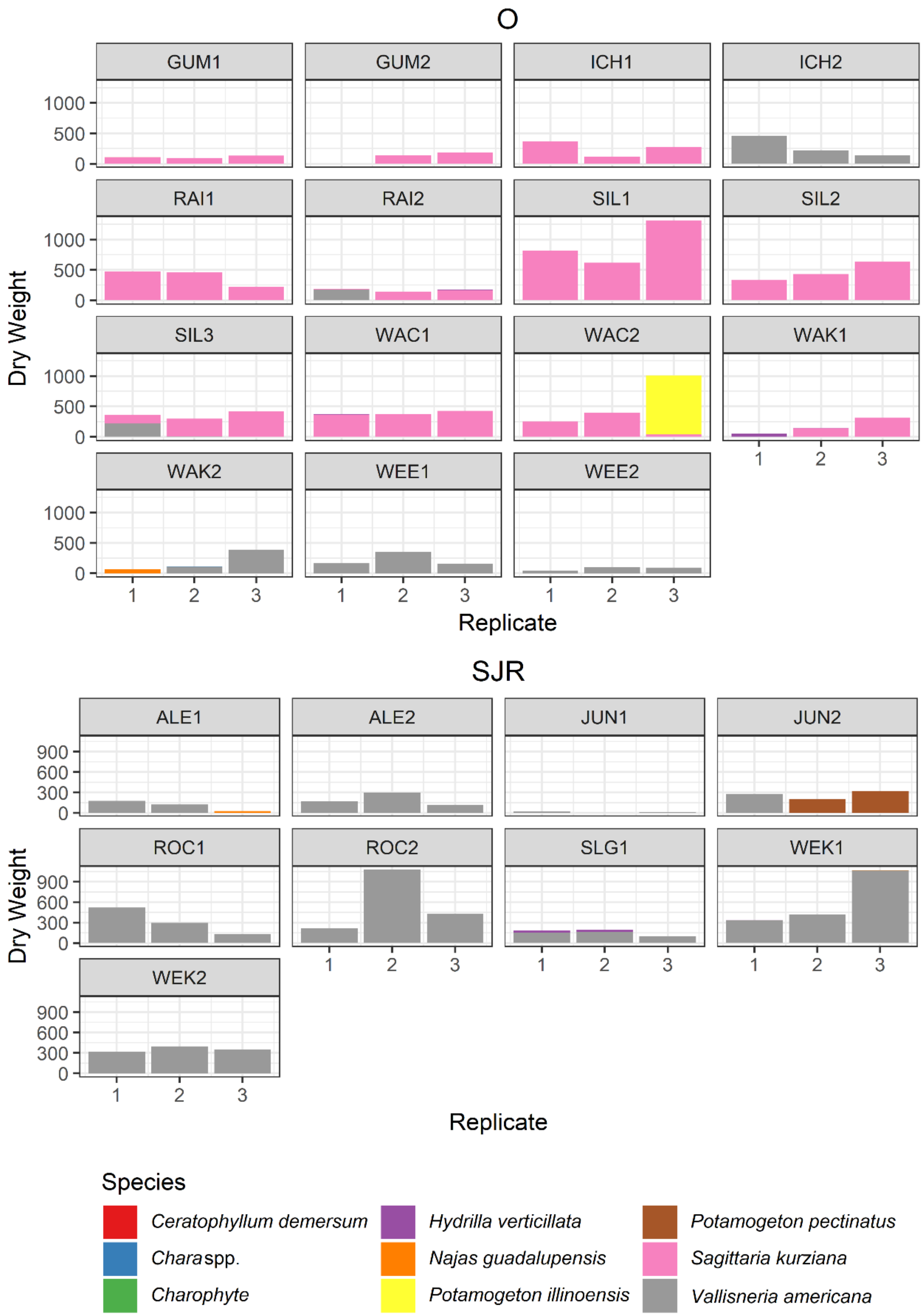



Figure 9. Dry weight at the sampling transects (g/m$^2$, individual replicates plotted) of all macrophyte species during spring 2015. SJR=St. Johns River streams; O=Other streams.

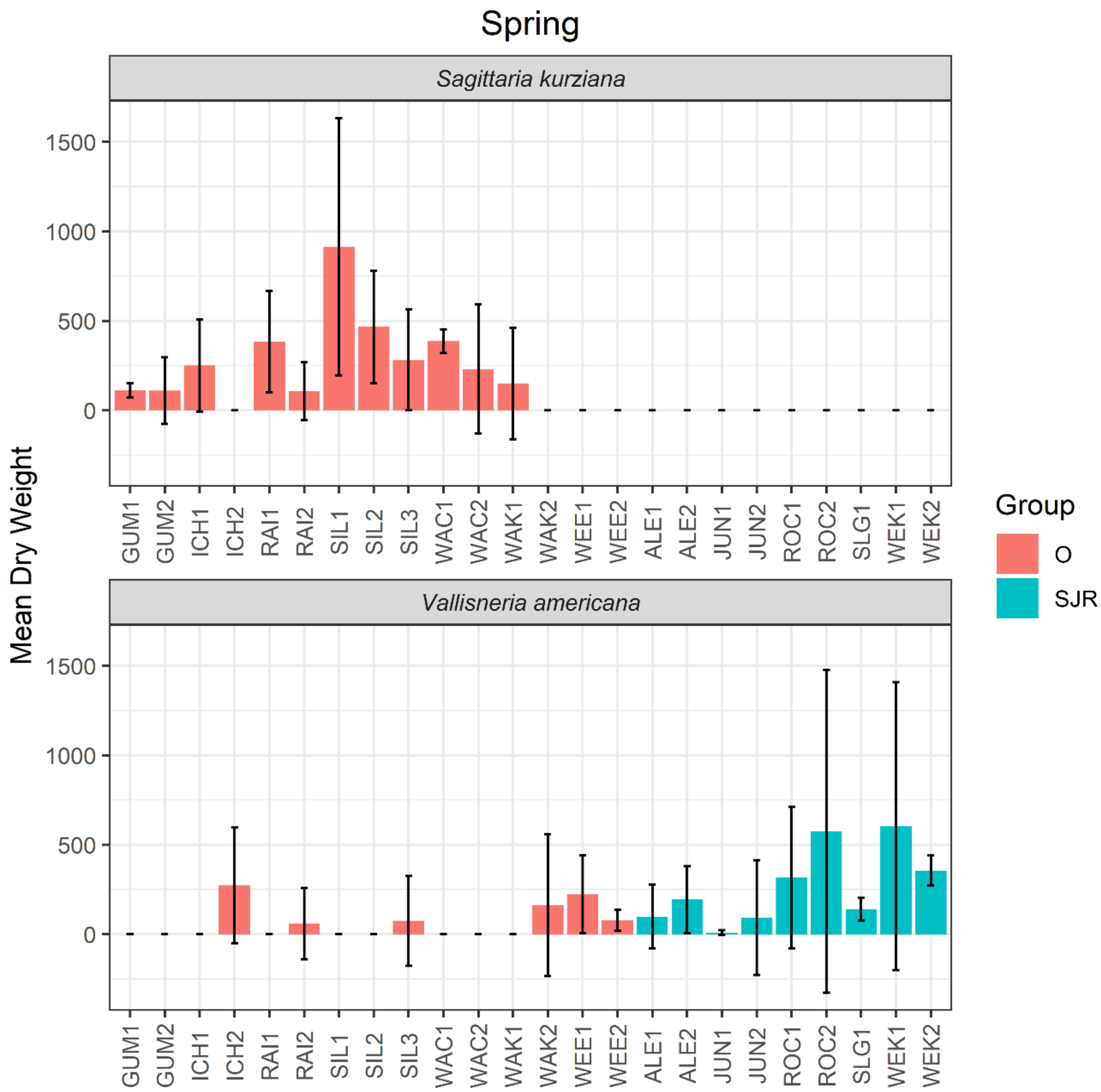



Figure 10. Mean dry weight (g/m$^2$, $\pm$ 2 standard deviations) of *Sagittaria* and *Vallisneria* during spring 2015. SJR=St. Johns River streams; O=Other streams.

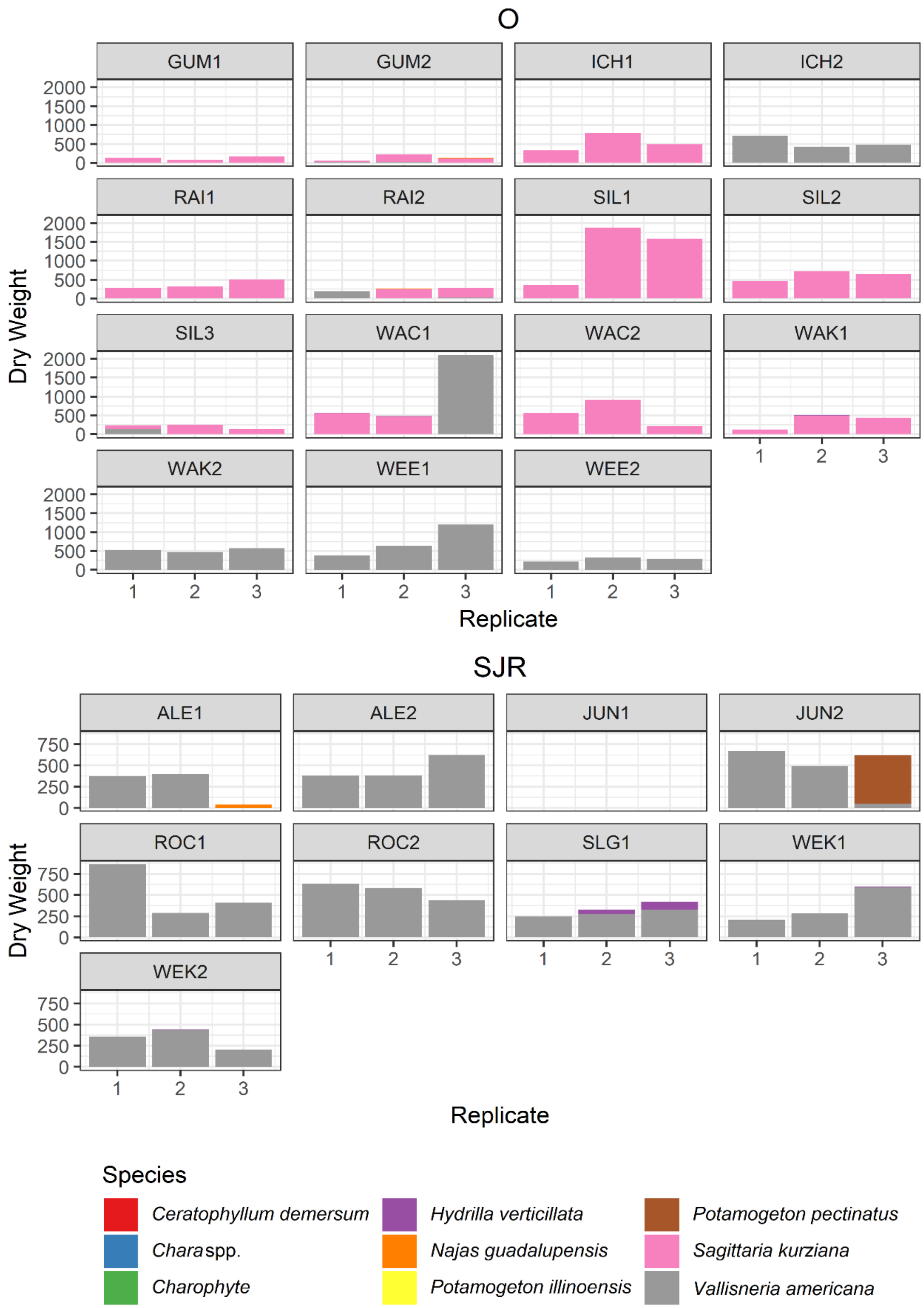



Figure 11. Dry weight at the sampling transects (g/m$^2$, individual replicates plotted) of all macrophyte species during fall 2015. SJR=St. Johns River streams; O=Other streams.

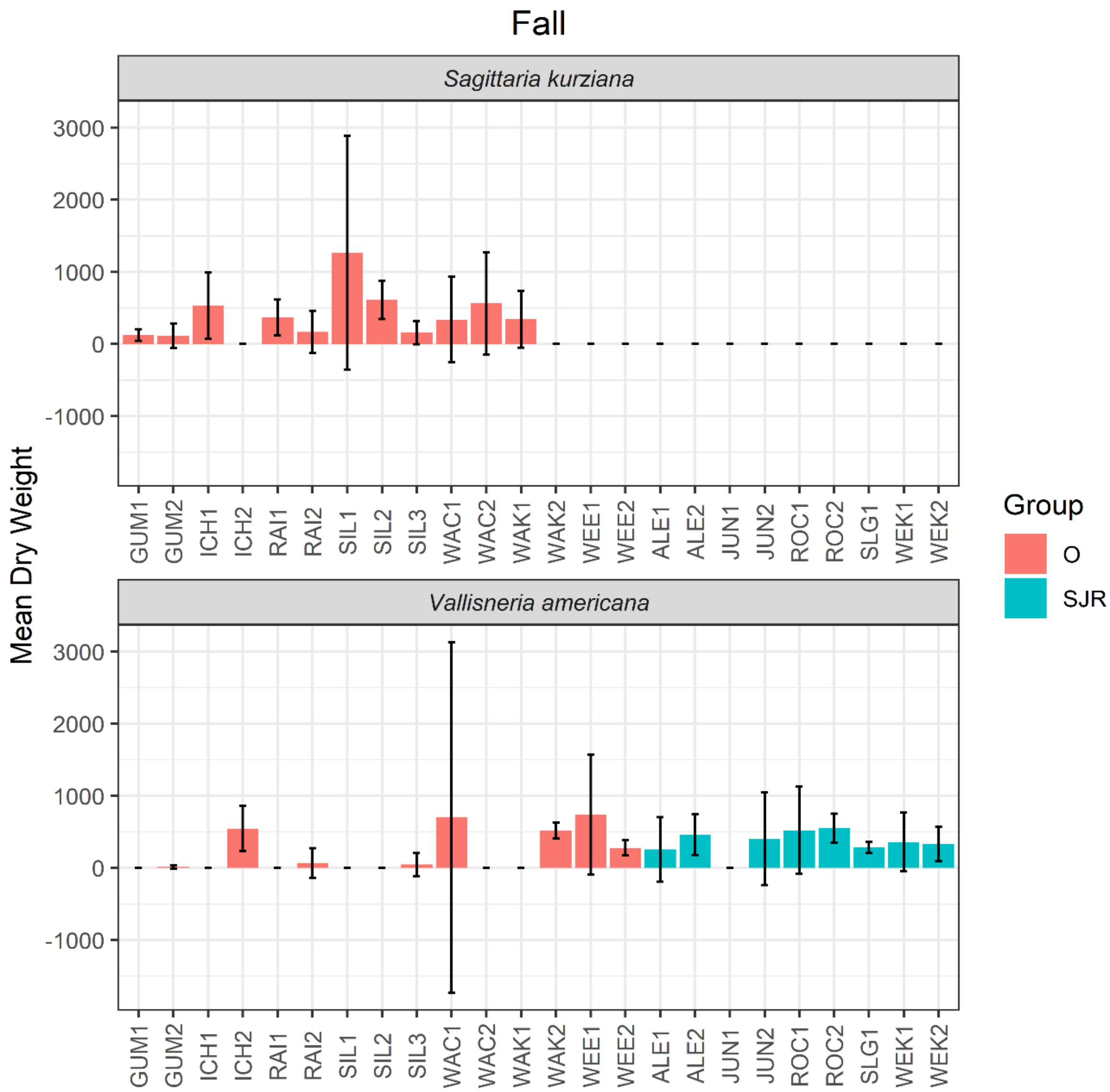



Figure 12. Mean dry weight (g/m$^2$, $\underline{+}$ 2 standard deviations) of *Sagittaria* and *Vallisneria* during fall 2015. SJR=St. Johns River streams; O=Other streams.

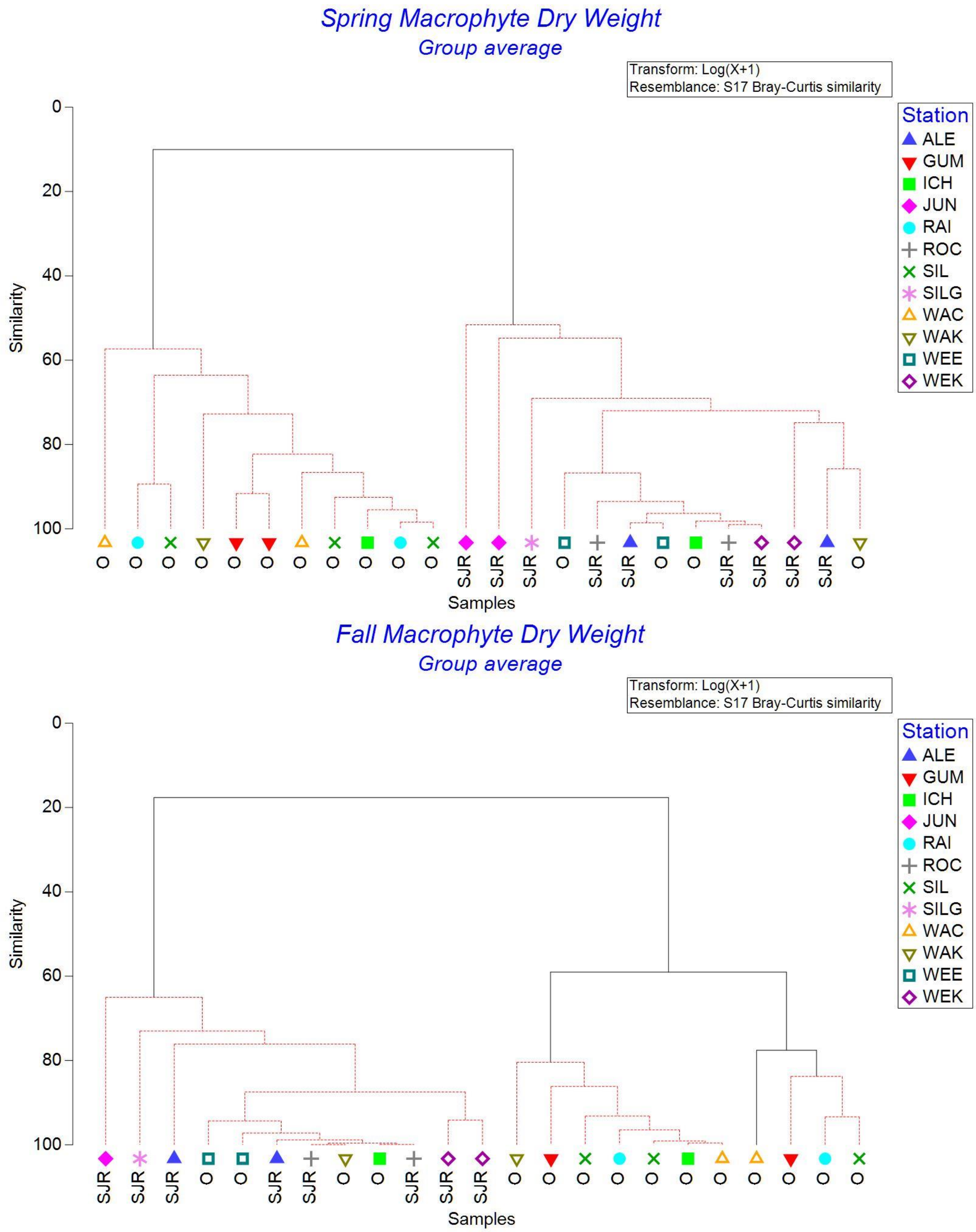



Figure 13. Cluster analysis diagrams of dry weight in spring and fall. Clusters connected with a solid line are significantly different.

### Seasonal Differences Within Transects

Table 4 and Figure 14 compare the mean total cover (all plant species combined) during the spring and fall 2015 at each transect. Table 5 and Figure 15 compare mean total dry weight standing crop similarly. Fall cover varied and was generally higher (compared to spring) at some transects (GUM2, WEE2), while fall cover was lower at other sites (ALE2, GUM1). Interestingly, standing crop exhibited opposite trend in some cases; while fall cover at ALE2 was lower (Table 4), fall standing crop was higher (Table 5). Most transects exhibited similar or higher standing crop in the fall compared to the spring, whereas cover tended to be somewhat more variable, with some transects having higher cover in the spring and others higher cover in fall.

## ECOLOGICAL RELATIONSHIPS

A variety of environmental factors influence the occurrence, species composition, and abundance of submerged macrophyte plant communities. Butcher (1933) stated that current is a primary factor influencing macrophyte growth in streams. Canfield and Hoyer (1988) and Duarte and Canfield (1990) stressed the importance of the light regime, mainly as influenced by the tree canopy cover over the stream channel. Hynes (1970) stated that current and water hardness (dissolved solids concentrations) were primary factors. Butcher (1933), Canfield and Hoyer (1988) and Hynes (1970) all note that channel substratum/bottom type (rock, sand, silt, etc.) is also a factor influencing occurrence and composition of the submerged macrophyte community, however substratum was not sampled in this study. These studies put varied emphasis on the importance of nutrients (nitrogen and phosphorus).

A survey of primary producers in Florida spring-run streams, found that light was a major influence on plant standing crop (Duarte and Canfield 1990). They found a statistically significant negative relationship between tree canopy cover over the stream channel and macrophyte standing crop (wet weight). Szafraniec (2014) found that *Sagittaria* was limited by the quality of light (spectral specificity requirements for blue light) available on the stream bottom. *Vallisneria* had a lower minimum light requirement than *Sagittaria* and could persist in more turbid, darker, and deeper water than *Sagittaria* (Szafraniec 2014). In this study, macrophyte cover was very weakly related to tree canopy cover (if at all). For the reasons stated in the Methods section (lack of sample independence and non-random transect and sample placement), standard statistical methods could not be used to test the relationship. However, plots are shown with a trend line plotted to give a general indication of the relationships between macrophyte community characteristics and physicochemical conditions. During spring, lower macrophyte cover was associated with higher tree canopy cover (Figure 16). However, the amount of variation in the former explained by the latter was very low. In the fall, there was actually a weak positive correlation between canopy cover and macrophyte cover (Figure 16).

Spring and fall macrophyte standing crop (as g/m$^2$ dry weight) were also compared with the respective seasonal canopy cover. During spring, a somewhat stronger negative relationship was seen between standing crop and canopy cover (Figure 17). In the fall, a generally similar

Table 4. Mean total percent cover during spring and fall.

| | Transect | Spring 2015 | Fall 2015 |
|---|---|---|---|
| Alexander Springs Creek | ALE1 | 74 | 73.4 |
| | ALE2 | 71.7 | 43.3 |
| Gum Slough | GUM1 | 94.3 | 41.7 |
| | GUM2 | 45 | 70 |
| Ichetucknee River | ICH1 | 96 | 95.3 |
| | ICH2 | 70 | 88.67 |
| Juniper Creek | JUN1 | 25.3 | 0 |
| | JUN2 | 88.6 | 96.7 |
| Rainbow River | RAI1 | 82.3 | 91 |
| | RAI2 | 45.4 | 58.31 |
| Rock Springs Run | ROC1 | 42 | 61.7 |
| | ROC2 | 51.7 | 60 |
| Silver River | SIL1 | 100 | 38.7 |
| | SIL2 | 81 | 77.7 |
| | SIL3 | 94.9 | 54.94 |
| Silver Glen Run | SLG1 | 37.3 | 81.6 |
| Wacissa River | WAC1 | 94.1 | 73.34 |
| | WAC2 | 100 | 91.7 |
| Wakulla River | WAK1 | 30.2 | 49.1 |
| | WAK2 | 64.3 | 75 |
| Weeki Wachee River | WEE1 | 25 | 83.3 |
| | WEE2 | 2.5 | 71.7 |
| Wekiva River | WEK1 | 89.9 | 48.3 |
| | WEK2 | 73.7 | 52.5 |

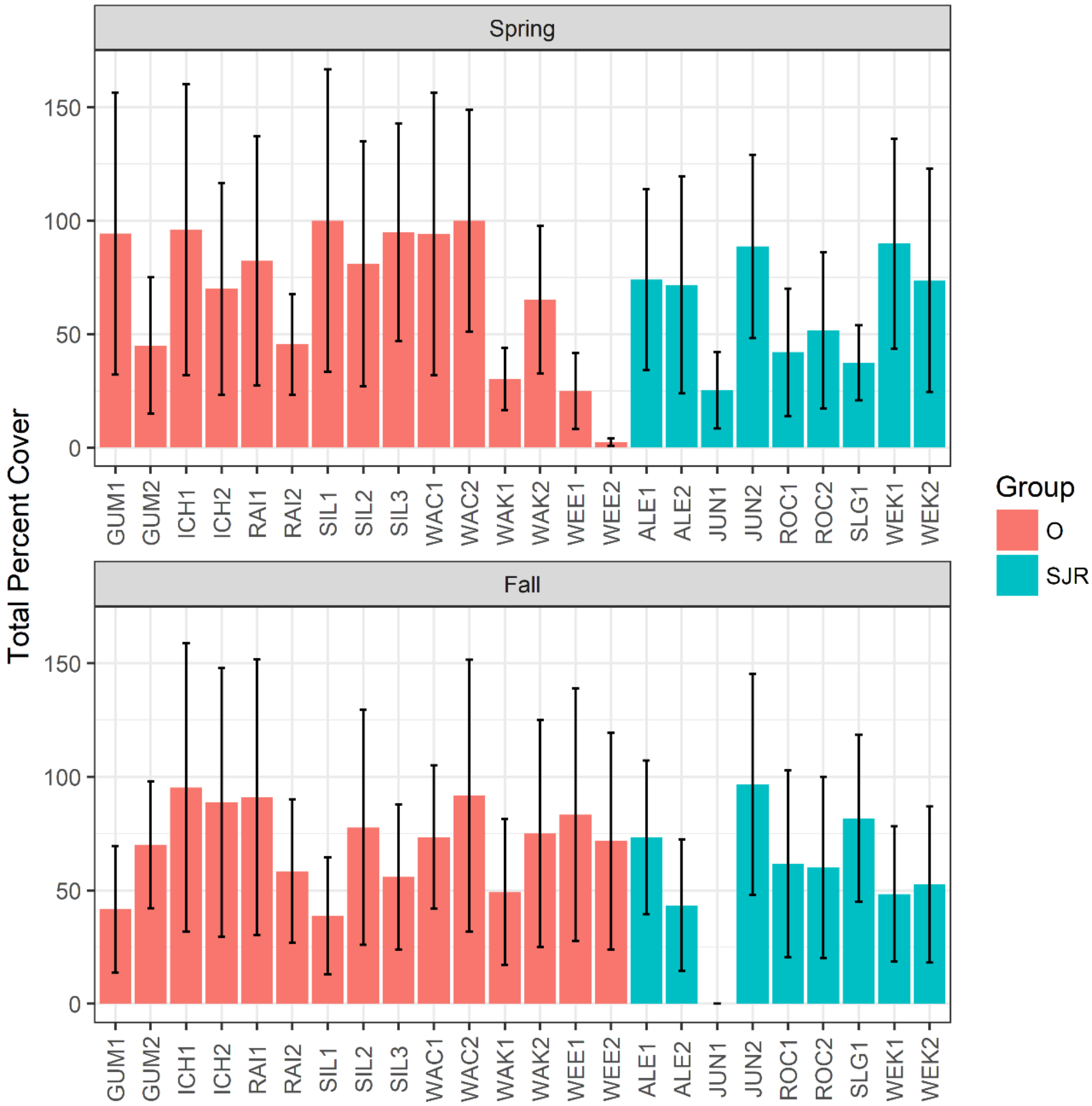



Figure 14. Mean total percent cover (+ 2 standard deviations) during spring and fall. Compare with Table 4. SJR=St. Johns River Streams; O=Other streams.

Table 5. Mean total dry weight (g/m$^2$) during spring and fall.

| | Transect | Spring 2015 | Fall 2015 |
|---|---|---|---|
| Alexander Springs Creek | ALE1 | 107.2 | 270.0 |
| | ALE2 | 193.2 | 462.0 |
| Gum Slough | GUM1 | 112.2 | 126.6 |
| | GUM2 | 109.7 | 132.4 |
| Ichetucknee River | ICH1 | 251.0 | 533.0 |
| | ICH2 | 272.4 | 544.3 |
| Juniper Creek | JUN1 | 8.8 | 0.0 |
| | JUN2 | 266.1 | 596.0 |
| Rainbow River | RAI1 | 384.9 | 368.2 |
| | RAI2 | 168.5 | 243.7 |
| Rock Springs Run | ROC1 | 316.0 | 520.0 |
| | ROC2 | 576.0 | 550.5 |
| Silver River | SIL1 | 914.0 | 1,267.0 |
| | SIL2 | 466.7 | 615.1 |
| | SIL3 | 357.3 | 207.1 |
| Silver Glen Run | SLG1 | 162.5 | 329.7 |
| Wacissa River | WAC1 | 389.7 | 1,049.9 |
| | WAC2 | 553.0 | 564.5 |
| Wakulla River | WAK1 | 169.8 | 353.3 |
| | WAK2 | 186.5 | 522.4 |
| Weeki Wachee River | WEE1 | 224.5 | 741.0 |
| | WEE2 | 78.1 | 279.7 |
| Wekiva River | WEK1 | 610.7 | 364.1 |
| | WEK2 | 355.2 | 333.7 |

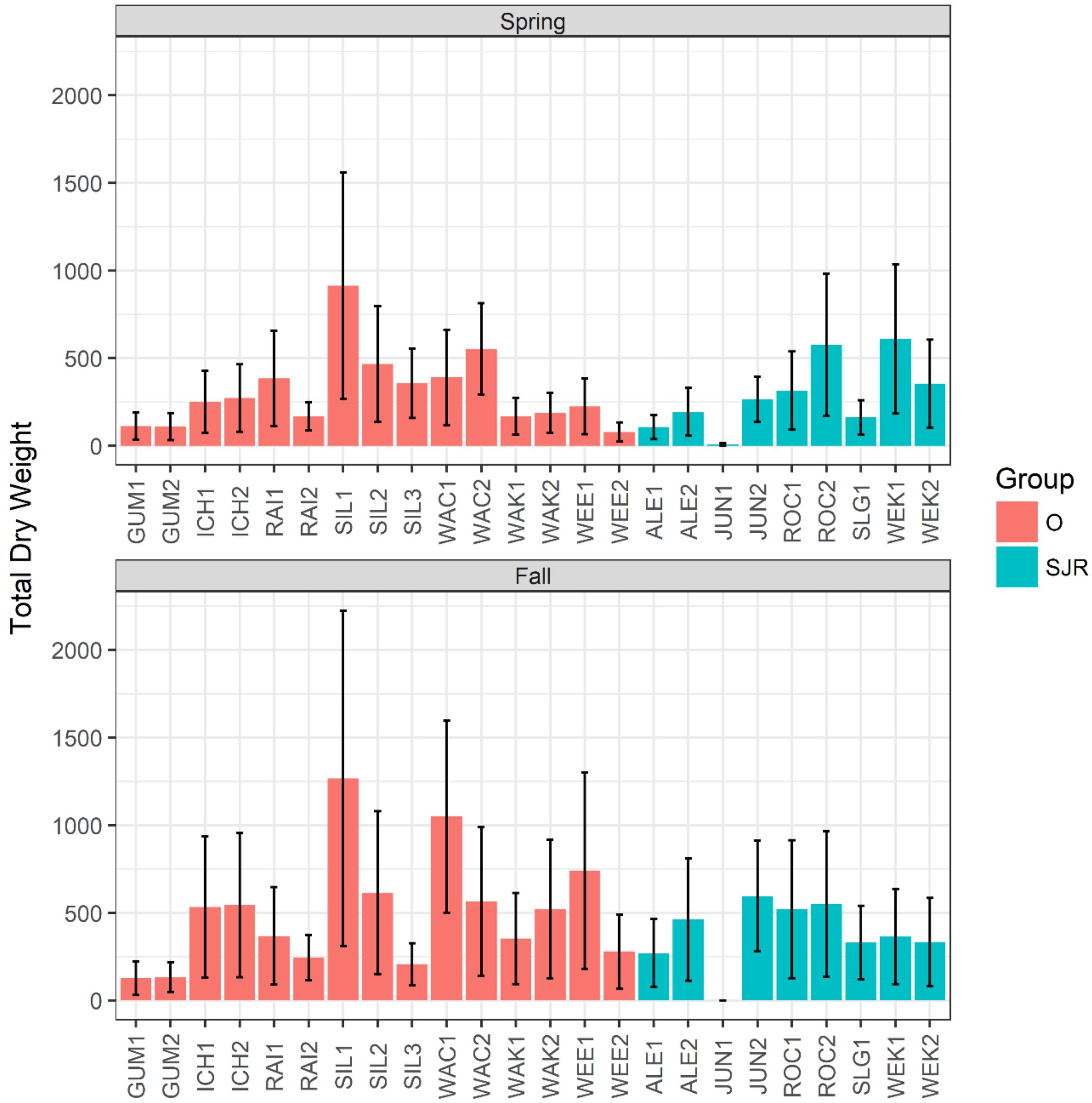
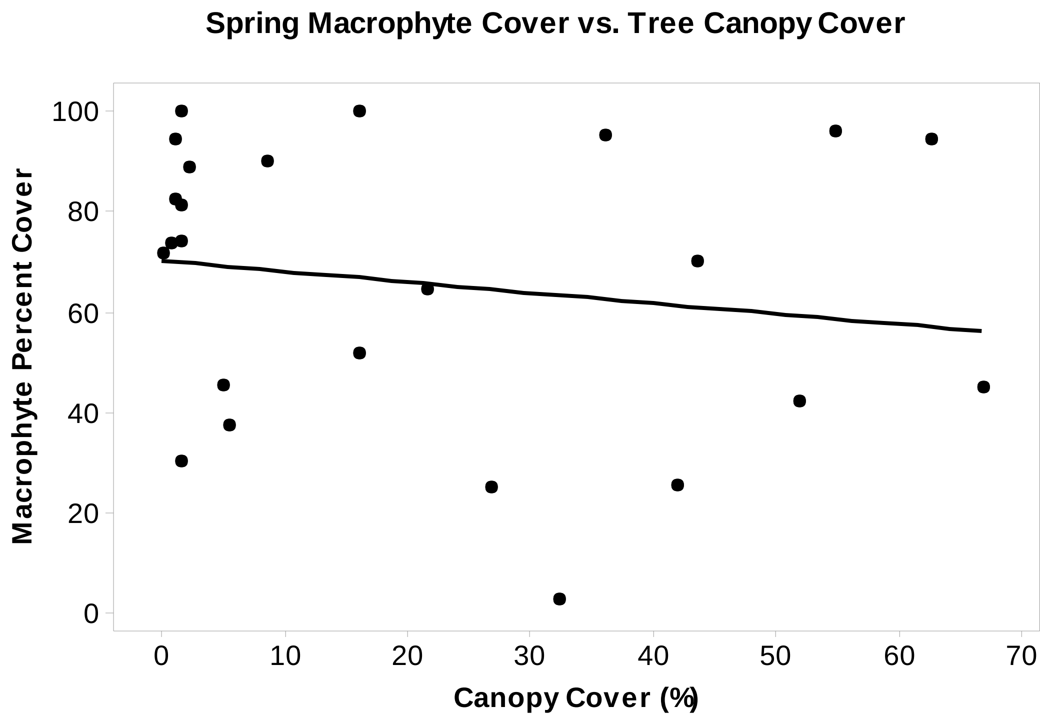



Figure 15. Mean total dry weight standing crop (g/m$^2$, $\pm$ 2 standard deviations) during spring and fall. Compare with Table 5. SJR=St. Johns River Streams; O=Other streams.



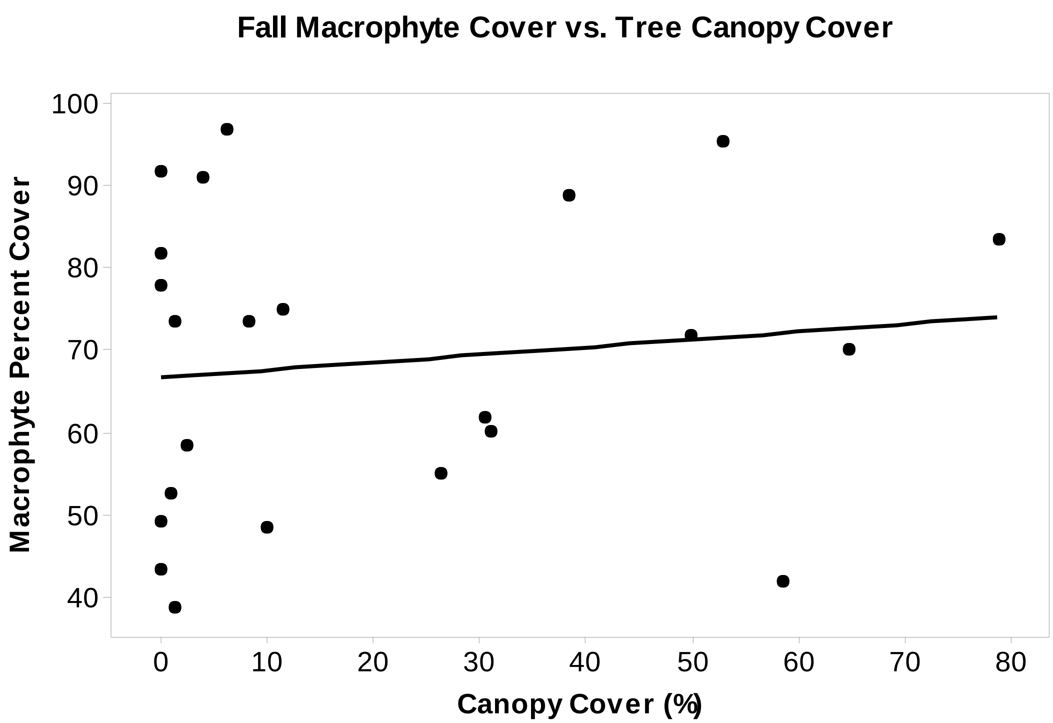
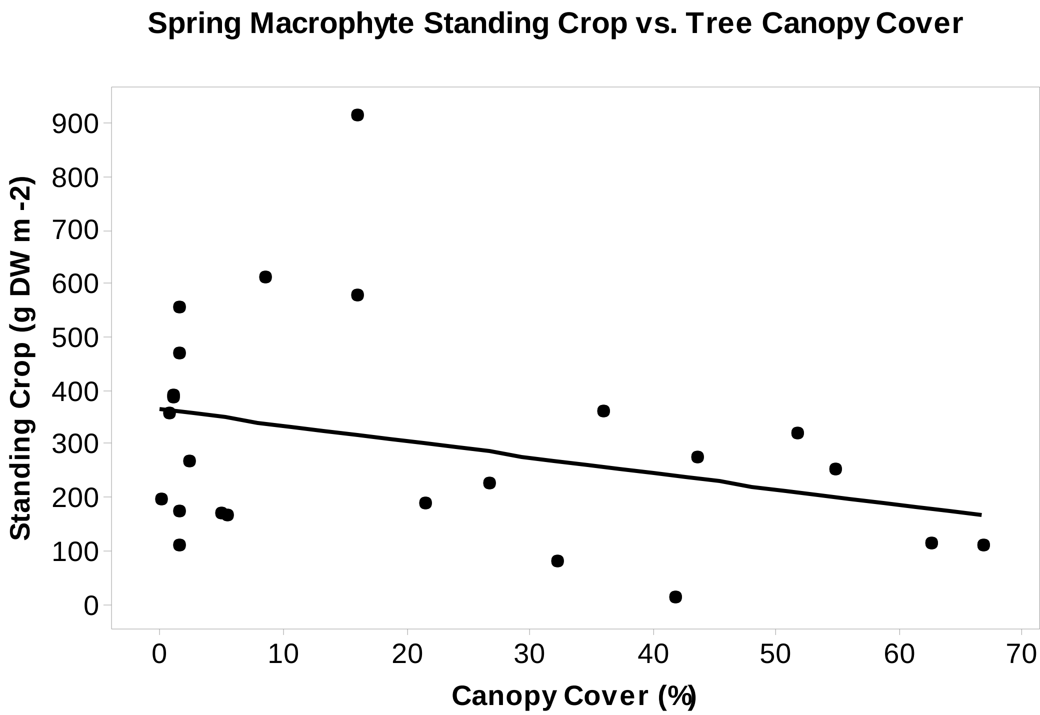




Figure 16. Plots of submerged macrophyte percent cover versus tree canopy cover over the stream channel (%) in spring (top) and fall (bottom). Trend line plotted for exploratory purposes.



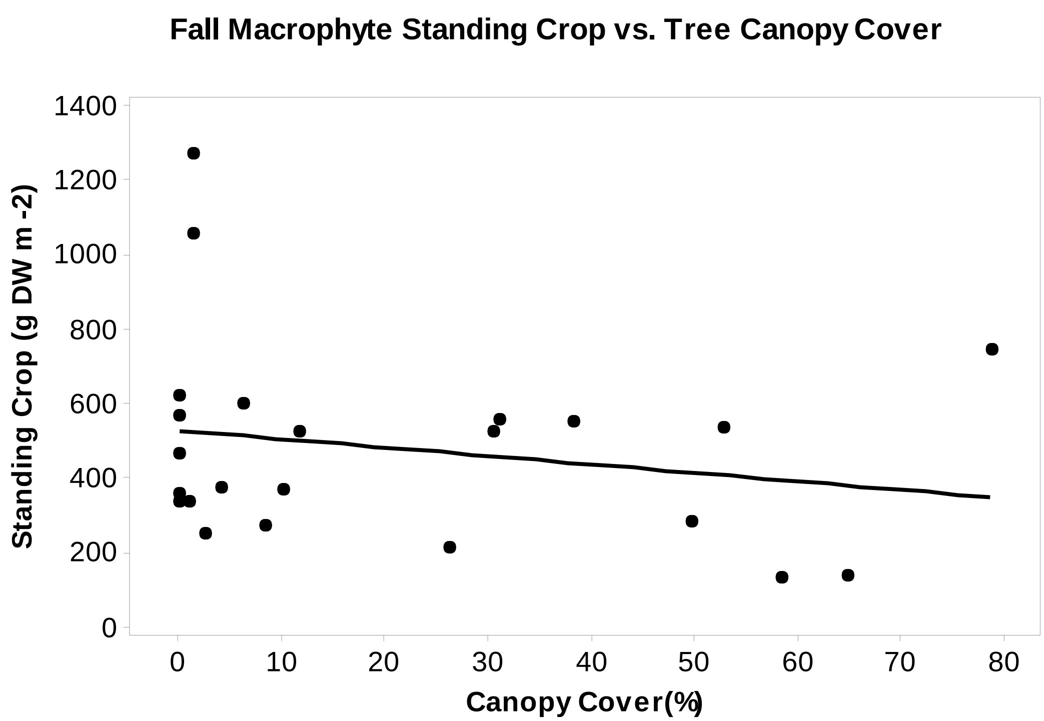



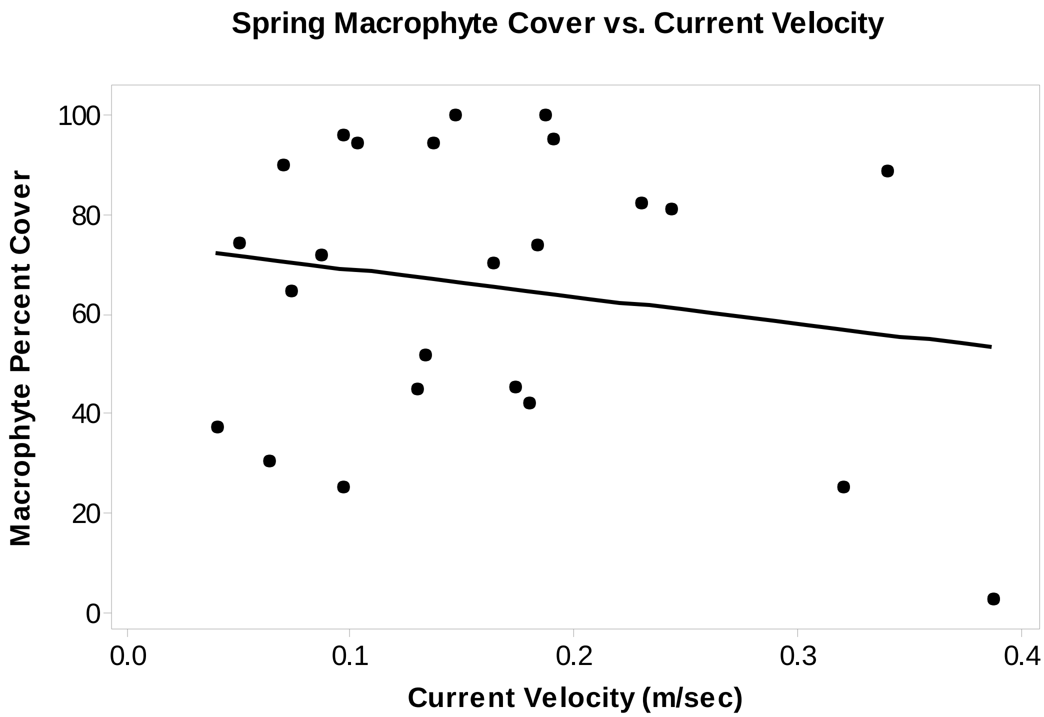

Figure 17. Plots of submerged macrophyte standing crop (g dry weight/m$^2$) versus tree canopy cover over the stream channel (%) in spring (top) and fall (bottom). Trend line plotted for exploratory purposes.

(but weak) negative relationship was seen between standing crop and canopy cover (Figure 17), but as with the macrophyte cover data, these relationships were very weak. Scatter plots of spring and fall stream channel width versus the respective spring and fall macrophyte cover and standing crop were also created and examined and no or very weak positive relationships were seen between channel width and macrophyte abundance (cover and standing crop), so these were not shown in this report.

The results of this study would tend to suggest that light is not a major factor influencing submerged macrophyte abundance in spring-run streams. Our data showed very weak negative relationships between canopy cover and macrophyte abundance (spring percent cover and spring and fall standing crop vs. canopy cover), and weak positive relationships between stream width and canopy cover (not shown). PBS&J and UF (2003) likewise saw poor correlation between macrophyte standing crop and canopy cover in the Ichetucknee River. In contrast, Duarte and Canfield (1990) saw a strong and significant relationship between canopy cover and macrophyte standing crop in Florida spring-run streams. The prior study estimated stream canopy cover visually using two independent observers. We used a spherical densiometer to measure canopy cover accurately, without subjectivity, which may explain the different conclusions. Differences in sampling location in these streams may be another reason for the different results. Duarte and Canfield (1990) also eliminated springs with very low DO (<1.0 mg/L), but we had no springs with DO that low supporting macrophytes, and they eliminated spring-run streams where they knew herbicide control of aquatic plants was conducted. To our knowledge, herbicide application is only done on the Wekiva River, so we do not feel that strongly influences our overall results. Szafraniec (2014) showed experimentally that light is a significant influence on macrophytes in spring-run streams. The BEST analysis of macrophyte cover in this study identified tree canopy as a weak explanatory variable.

Butcher (1933) and Hynes (1970) emphasized the importance of current velocity in influencing rooted macrophyte communities. Velocity exerts direct physical effects on the plants, straining plant tissues. Velocity effects may also be mediated through the interaction of velocity and stream bottom substratum type (rock, sand, mud, etc.). In this study, spring and fall macrophyte cover were compared to stream current velocity (Figure 18). A very weak negative relationship between cover and velocity was seen in spring, while almost no relationship between cover and velocity was seen in the fall. Macrophyte standing crop also exhibited weak to no relationships to current velocity (Figure 19). Spring standing crop exhibited a weak negative relationship (Figure 19), while fall standing crop exhibited almost no relationship.

Current velocities measured in this study were all <0.5 m/sec, with most measurements <0.3 m/sec. According to Butcher (1933), currents of <0.3 m/sec are generally associated with a sand, silt or mud bottom substratum (which all our study streams exhibit). The lack of strong relationships between macrophyte abundance and current velocity in our study is likely due to the small range of (generally low) velocities exhibited in the 12 streams sampled in this study. One effect of current velocity that does have a demonstrated effect on the submerged macrophyte communities of spring-run streams is flood events. Wetland Solutions, Inc (2005)



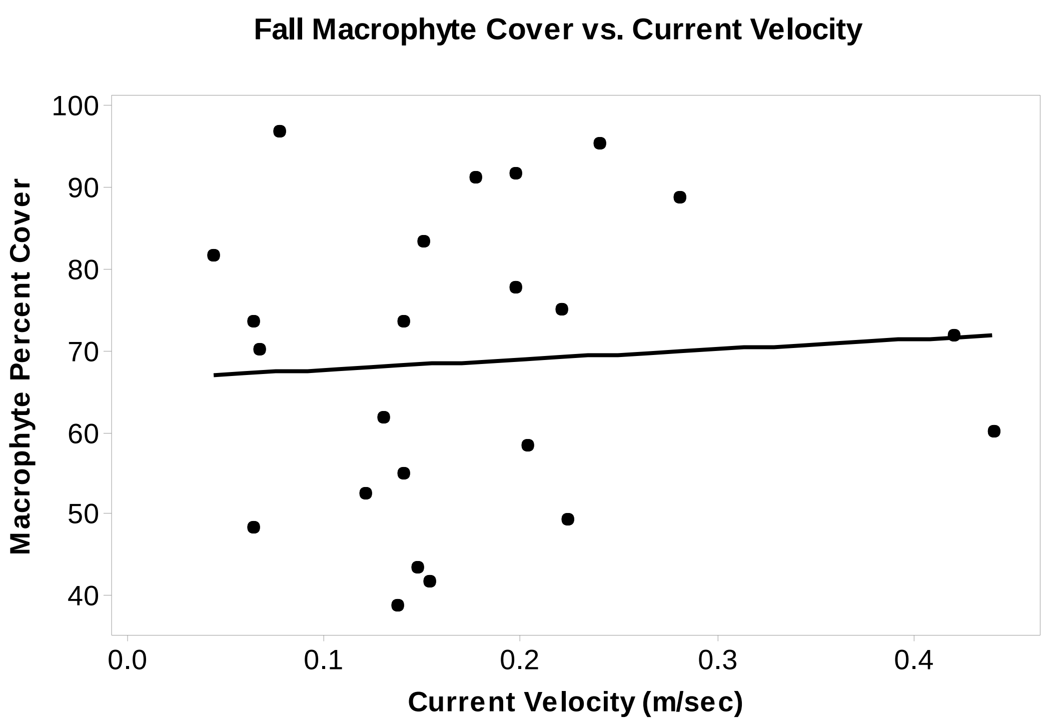
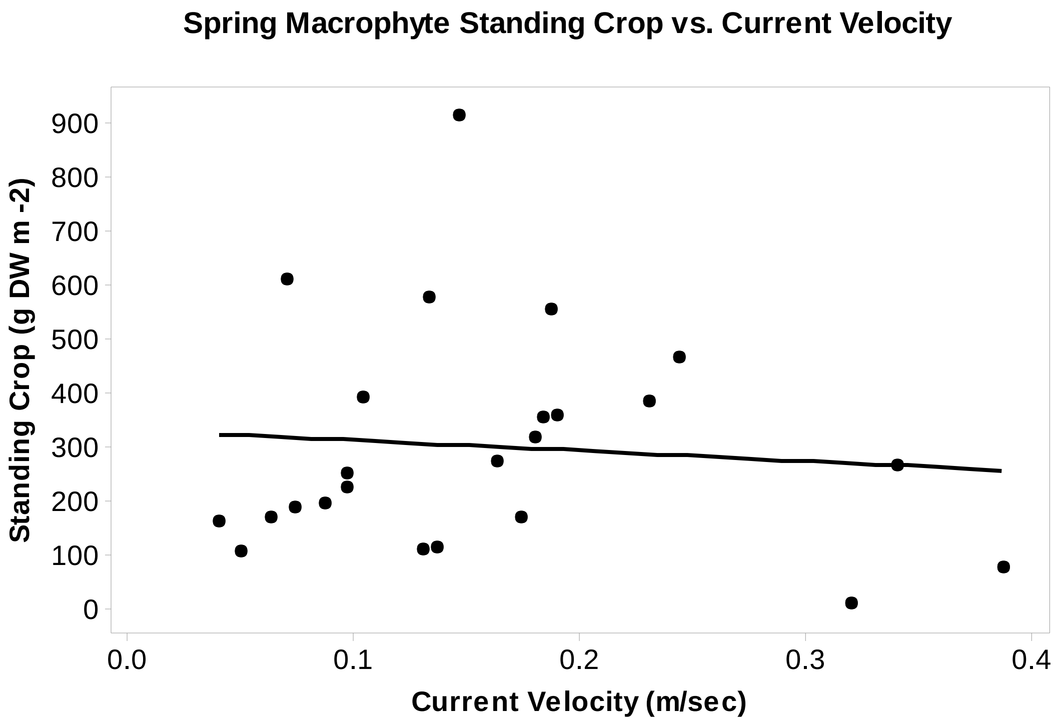




Figure 18. Plots of submerged macrophyte percent cover versus current velocity (m/sec) in spring (top) and fall (bottom). Trend line plotted for exploratory purposes.



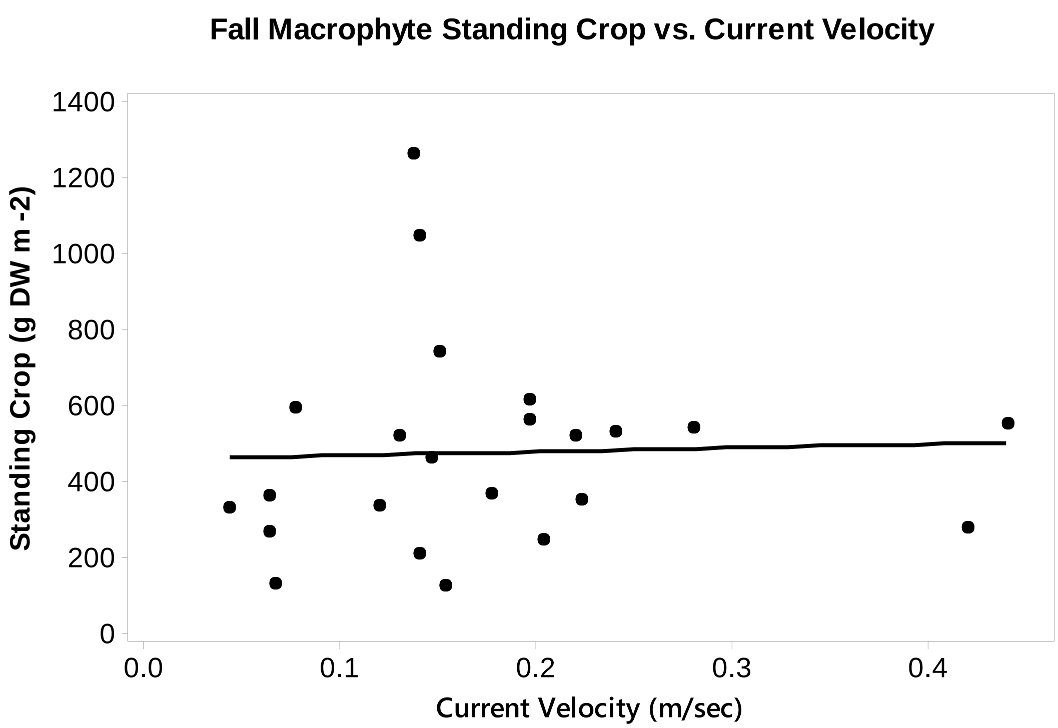




Figure 19. Plots of submerged macrophyte standing crop (g dry weight/$m^2$) versus current velocity (m/sec) in spring (top) and fall (bottom). Trend line plotted for exploratory purposes.

measured substantially lower macrophyte cover in Juniper Creek, Rock Springs Run, and the Wekiva River in 2005 compared to the cover levels measured in this study (see comparative results in the next Section). Their work was conducted following multiple major flood events which occurred on those streams following the passage of Hurricanes Charley, Frances, and Jeanne across the Florida peninsula in 2004 and un-named tropical storm events in 2005. Following the passage of Hurricane Irma in September 2017, surveys of submerged macrophytes in spring of 2018 in many of the St. Johns River spring-run streams sampled in this study found substantial losses of submerged macrophytes in most of these streams (R.A. Mattson, pers. observation). Flood events scour away plant beds and sediments (Butcher 1933) resulting in reductions in submerged macrophyte plant cover and standing crop. High water levels and high water color and/or turbidity can also have a negative effect on SAV communities during floods.

Examining Figures 16-19, macrophyte cover did not appear to be affected by tree canopy (Figure 16) or current velocity (Figure 18), in that both high and low cover values were generally seen throughout the range of both variables. Macrophyte standing crop did appear to be more affected by tree canopy cover and current velocity. For macrophyte standing crop, highest values were seen at canopy cover values <20% (Figure 17) and current velocities <0.2 m/sec (Figure 19) while lowest values of both macrophyte abundance measures were generally seen at highest canopy cover and velocity. This suggests that macrophyte standing crop is not responding to the mean of tree cover or velocity, but possibly to the extreme values (e.g., Gaines and Denny 1993). Duarte and Canfield (1990; their Figure 1), found a distinctly non-linear relationship between macrophyte standing crop and canopy cover, with highest standing crop at canopy cover values <20%, similar to what was found in this study.

To explore these associations more fully, quantile regression was used to examine relationships between macrophyte abundance (cover and standing crop) and canopy cover and stream velocity by looking at component parts of the distribution of the predictor and response variables (Cade and Noon 2003). Analysis of macrophyte cover vs. tree canopy cover is shown in Figure 20. The relationships (as indicated by visual inspection of the slopes of the fitted lines) generally did not appear to be much stronger than the "standard" regression line fitted through the median of the data (compare with Figure 16). A fairly strong positive relationship between macrophyte cover during the fall and tree canopy cover was seen in the 25$^{th}$ percentile of the data (Figure 20). Similar relationships were seen when comparing macrophyte cover and current velocity (Figure 21); again, not much stronger than the standard fitted line (compare Figures 18 and 21). Stronger relationships (positive) between cover and velocity were seen at lower quantiles (the 10$^{th}$ and 25$^{th}$ percentiles – Figure 21), suggesting that lower levels of canopy cover and current velocity may be more influential on macrophyte cover.

Relationships between macrophyte dry weight and canopy cover and current velocity were also explored with quantile regression. Standing crop versus canopy cover is shown in Figure 22. Based on visual examination of the fitted line slopes, there appeared to be a slightly stronger relationship between canopy and standing crop at higher quantiles (particularly the 90$^{th}$ quantile), which suggests that macrophyte standing crop is responding to the higher levels of canopy cover (lower standing crop at substantially higher canopy cover), most likely due to

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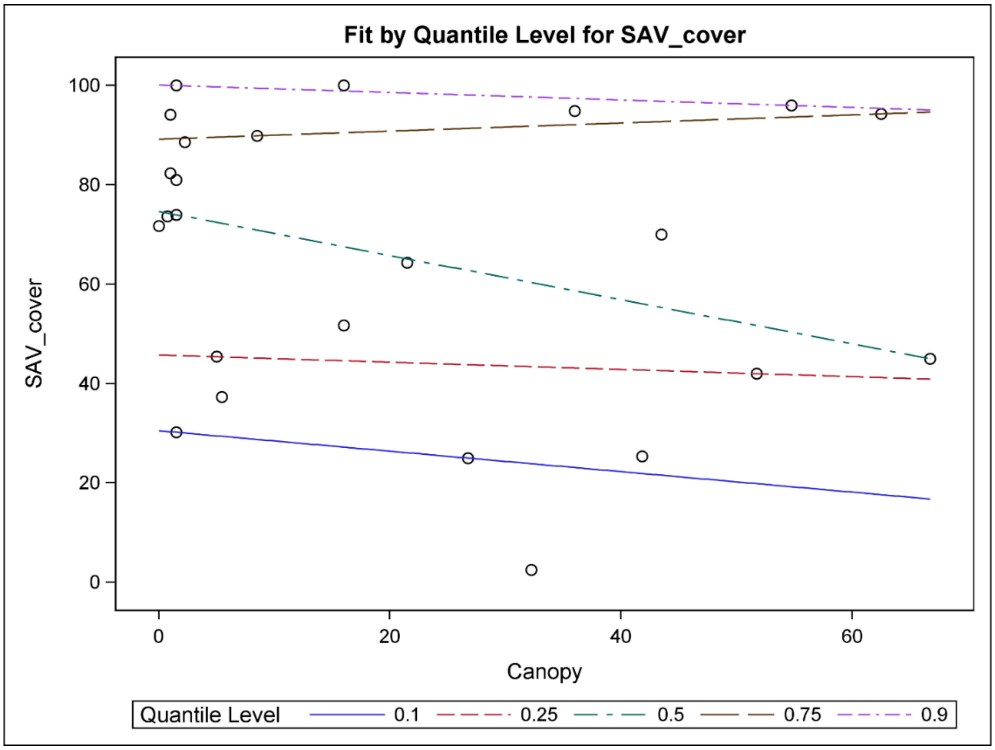


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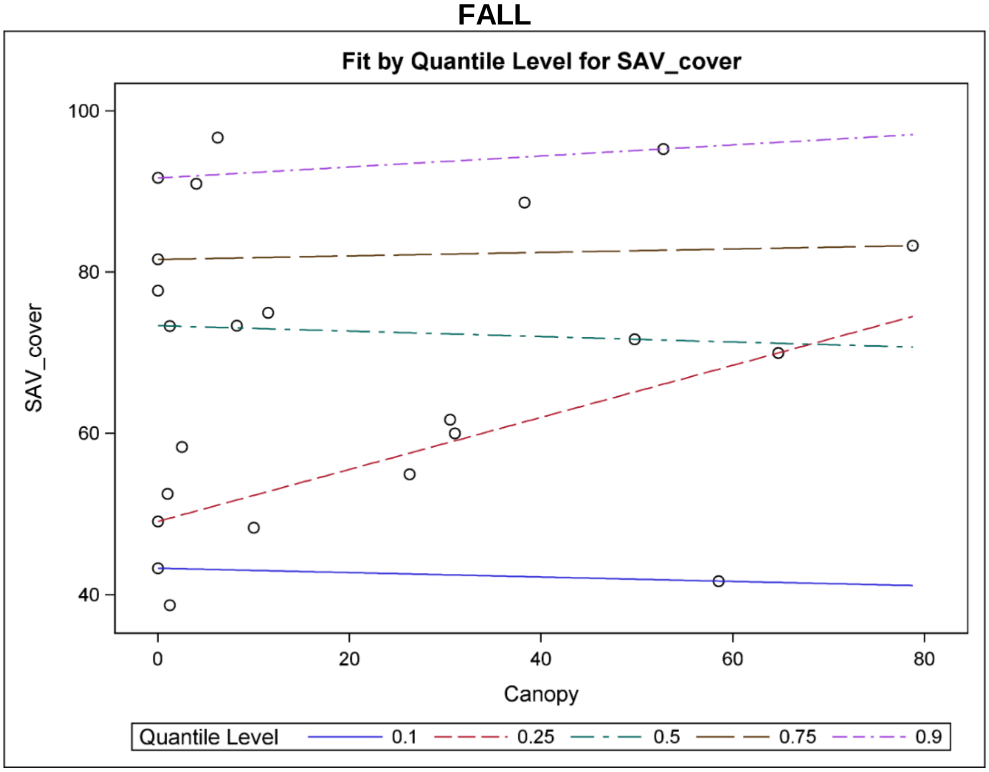


Figure 20. Quantile regression plots of macrophyte cover vs. tree canopy cover in spring and fall.

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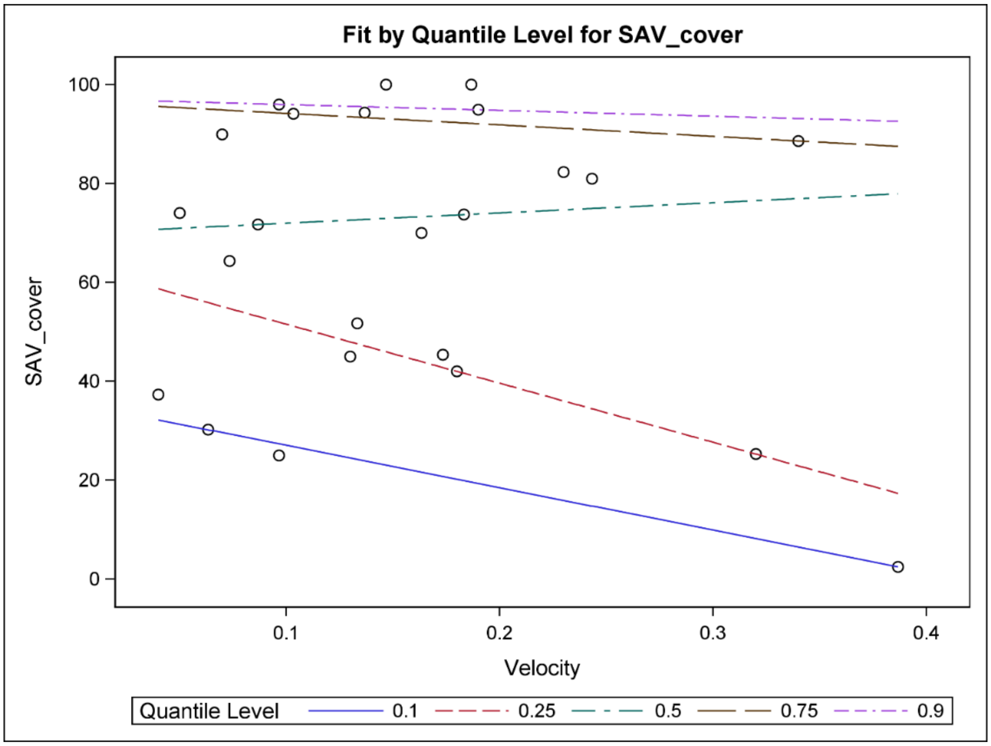


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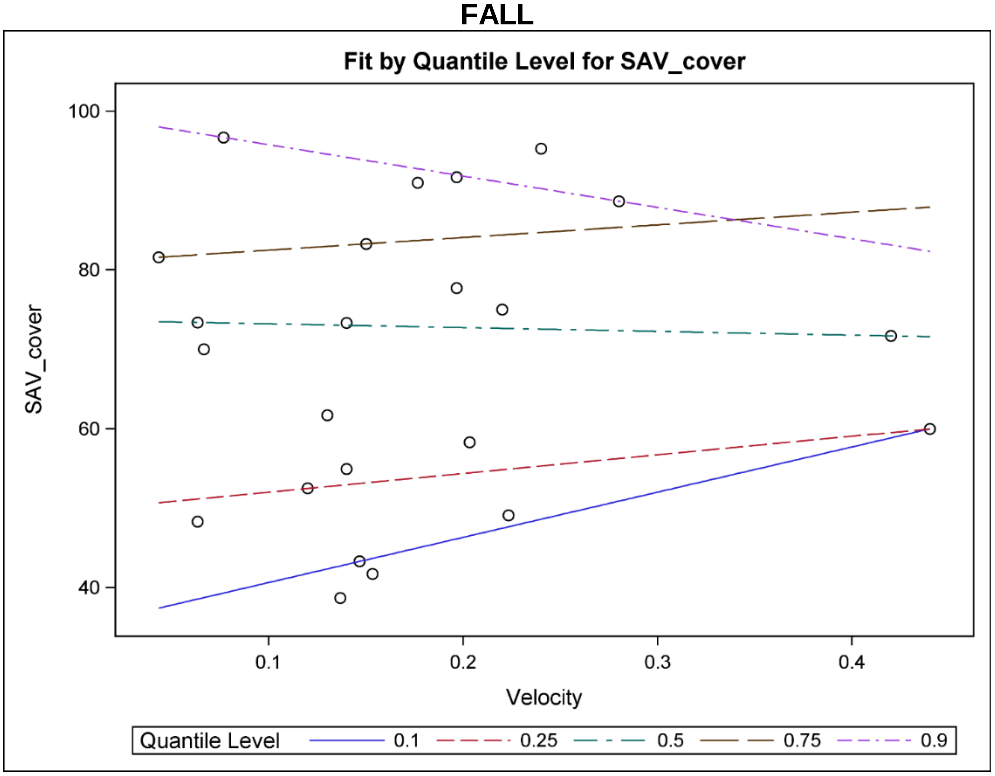


Figure 21. Quantile regression plots of macrophyte cover vs. current velocity in spring and fall.

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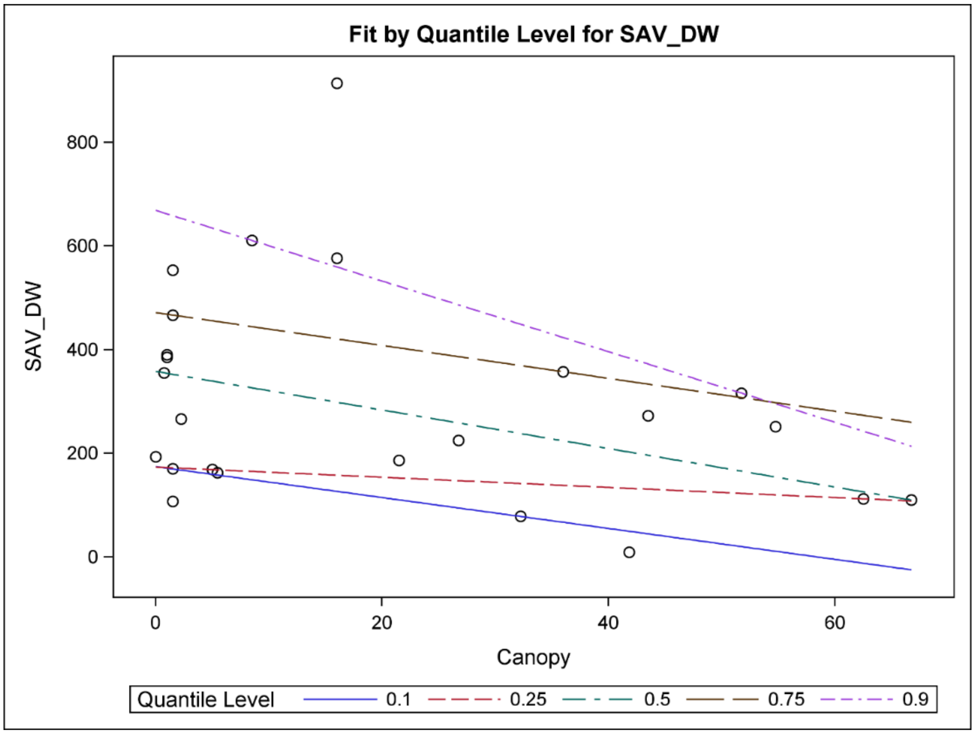


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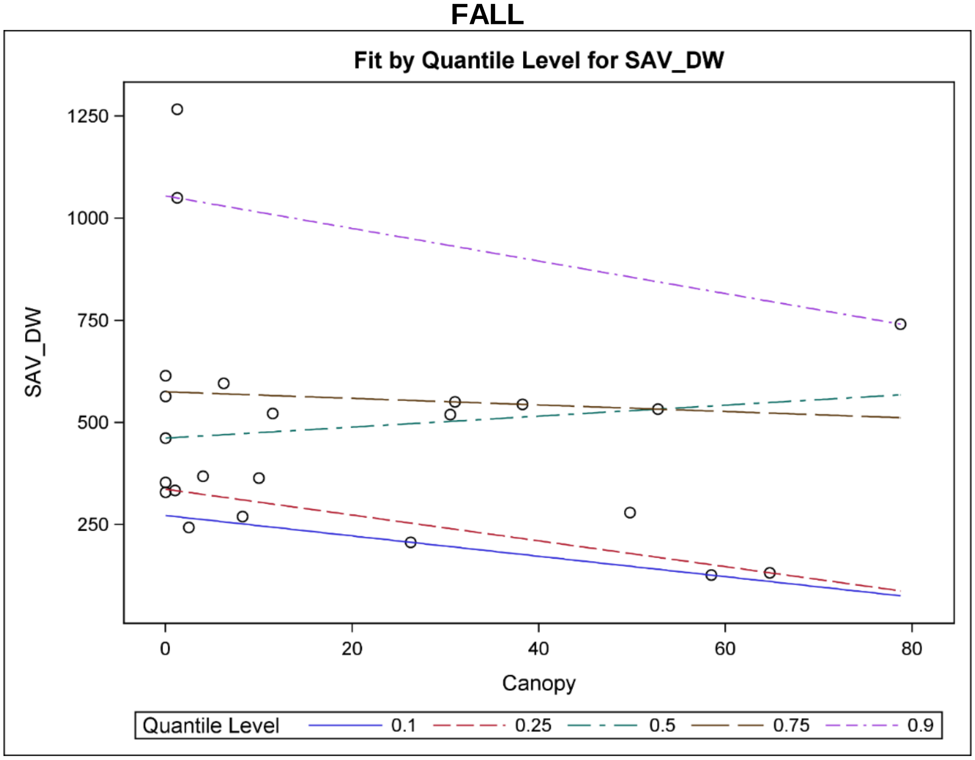


Figure 22. Quantile regression plots of macrophyte dry weight standing crop vs. tree canopy cover in spring and fall.

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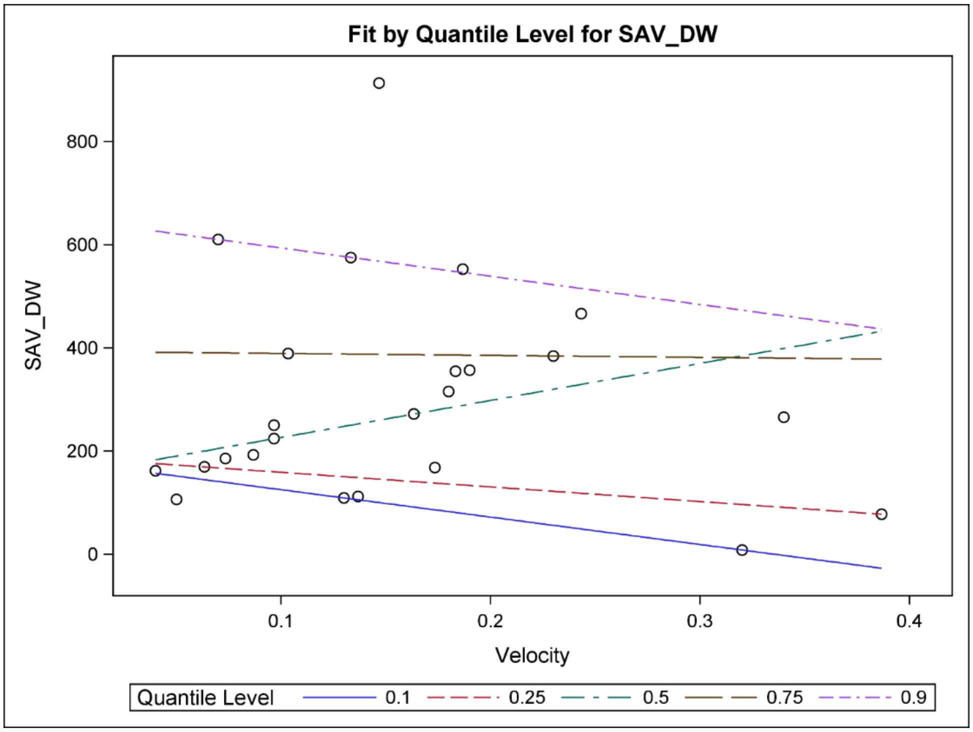


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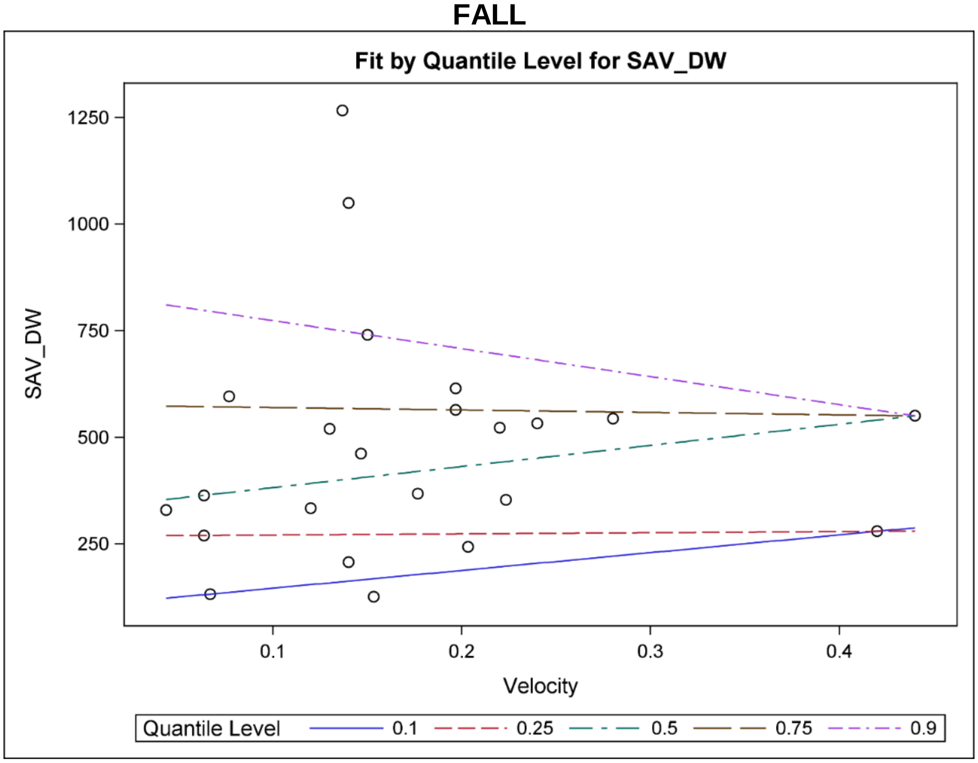



Figure 23. Quantile regression plots of macrophyte dry weight standing crop vs. current velocity in spring and fall.

light limitation. Comparisons of standing crop with current velocity (Figure 23) similarly indicated slightly stronger relationships (in terms of the slope of the fitted line) between the 90$^{th}$ quantile fit and the standard line fit (compare Figures 19 and 23), again suggesting that it is the higher current velocities that may be more influential on standing crop.

For the water quality variables measured during biological sampling, scatter plots were generated comparing spring and fall cover and standing crop with their respective DO, conductivity, pH, turbidity, and water temperature (measured at the time of macrophyte sampling). Visual inspection of the plots indicated very weak to no relationships between the macrophyte and all physicochemical variables, and therefore these results are not shown in this report. Butcher (1933) believed that temperature was not a major factor influencing the overall submerged macrophyte community, although it might be a factor affecting seasonal changes in British streams (although this was confounded with higher flows in the winter). Factors related to the degree of mineralization of the water (pH, conductivity) can be a factor (Butcher 1933; Hynes 1970), in that macrophyte communities of soft, poorly mineralized water have a different species composition than hard water systems, but this does not appear to affect abundance (cover or standing crop). All the spring-run streams sampled in this study may be considered hard water systems, and all had a relatively similar suite of macrophyte species.

A final factor that has generated much discussion is the effects of nutrients (nitrogen and phosphorus) on macrophyte growth in streams. Canfield and Hoyer (1988) and Duarte and Canfield (1990) concluded that nutrients were not a factor in growth/abundance of submerged macrophytes in Florida streams and spring-run streams, respectively. Butcher (1933) and Hynes (1970) note that moderate sewage enrichment of streams may increase macrophyte growth. "Traditionally" it was believed that rooted macrophytes obtain most of their nutrients from the sediment via their roots, but it has subsequently been shown that leaf absorption of nutrients directly from the water column also occurs in submerged macrophytes (Hynes 1970; Osborne et al. 2017a). Nitrogen and phosphorus data were obtained from existing water quality stations on the study streams and means for 2010-2015 period were calculated. Scatter plots of macrophyte cover and standing crop versus mean NOx-N and TP were generated and visually inspected. Weak to no relationships were observed between both of these nutrients and macrophyte abundance, and so these were not shown in this report.

One other "nutrient-related" effect on macrophytes is nitrate inhibition of plant growth. This has been observed in field and laboratory-based studies of freshwater and estuarine macrophytes (Osborne et al. 2017a). Excess ("luxury") foliar uptake of nitrate at elevated concentrations may lead to growth inhibition via a variety of physiological and morphological effects (Osborne et al. 2017a). Recent mesocosm experiments with *Vallisneria* and *Sagittaria* collected from the Silver River, however, failed to detect any significant negative effects of nitrate enrichment on the growth or physiology of these macrophytes (Osborne et al. 2017b).

## COMPARISON WITH PRIOR STUDIES OF FLORIDA SPRING-RUN STREAMS

The data from this study were compared to previous surveys of submerged macrophyte vegetation in Florida spring-run streams. Where possible, we attempted to compare data collected at similar locations in the same stream, but in some cases the locations of the sampling sites in the previous studies were not known. In other cases, the site locations were not comparable. However, some type of comparison to prior work can give a general indication of potential trends/changes over time in these streams.

A contractor for the Suwannee River Water Management District (PBS&J and UF 2003) sampled macrophytes in April 2003 at 31 sites on the Ichetucknee River. Two of their sites were in locations near to ICH1 and ICH2, and they measured similar cover compared to the spring 2015 samples (Table 6). In 2005, a contractor for SJRWMD (Wetland Solutions, Inc. 2005) conducted studies in Alexander Springs Creek, Juniper Creek, Rock Springs Run and the Wekiva River. They measured mostly lower cover values than measured in this study. A study funded by the Florida Fish and Wildlife Conservation Commission (Wetland Solutions, Inc 2010) conducted ecological surveys in 12 springs throughout Florida, five of these were sampled in this study, and generally similar cover values were measured at similar locations. The Florida Springs Institute (FSI 2012) conducted submerged macrophyte surveys in Silver River in 2011-2012, and their measurements of total vegetation cover were similar to those measured in this study at similar locations. Overall, a main conclusion drawn from this comparison is that submerged macrophyte cover appears to have remained generally stable in these spring-run streams over the last 10–15 years.

Some of the above-mentioned and other submerged vegetation studies in Florida spring-run streams measured macrophyte standing crop. Some of these studies measured standing crop as wet weight in $kg/m^2$. These data were converted to $g/m^2$ and then converted to dry weight by multiplying by 0.061 (after Odum 1957b). Table 7 compares these data based on an average for a whole stream. Odum (1957b) measured macrophyte standing crop in the upper 1,200 meters of Silver River and obtained a dry weight value similar to the overall mean in this study. Duarte and Canfield (1990) sampled submerged macrophytes at several locations in Silver River, and the mean of their values is also similar to the overall mean in this study. Munch et al. (2006) found that macrophyte standing crop in the summer in Silver River in 2004–2005 did not differ from what Odum measured in the 1950s but winter standing crop was lower than what Odum measured. In the Ichetucknee River, measurements of standing crop by Duarte and Canfield (1990) and PBS&J and UF (2003; 2004) were all generally within the range measured in this study. Duarte and Canfield (1990) measured macrophyte standing crop at four stations on Alexander Springs Creek, and the mean of those is similar to the mean in this study. Overall, these results indicated that submerged macrophyte cover and standing crop on these streams has remained relatively stable over the last 15–30 years, but that flood events can reduce macrophyte abundance (as cover and/or standing crop).

However, for several streams (Ichetucknee River, Silver Glen Run, Rainbow River, Wacissa River, and Weeki Wachee River) it appears macrophyte standing crop has declined from historic levels. Dutoit (1979) measured substantially higher standing crop in the Ichetucknee River in 1978 compared to more recent data (Table 7). Duarte and Canfield (1990) measured generally higher standing crops in Rainbow River, Silver Glen Run, Wacissa River, and Weeki Wachee River than measured in this and other recent studies (Table 7). Dry weight standing crop in Silver Glen was considerably higher in the 1990 study.

Table 6. Comparison of mean submerged macrophyte total percent cover from various spring-run stream studies. Note that sampling locations in the different studies may or may not be similar.

| | Transect | This study spring 2015 | This study fall 2015 | PBS&J and UF 2003[a] | PBS&J and UF 2004[a] | WSI 2005[b] | WSI 2010[c] | FSI 2012[d] | Szafraniec 2014[e] |
|---|---|---|---|---|---|---|---|---|---|
| Alexander Springs Crk | ALE1 | 74 | 73.4 | | | | | | |
| | ALE2 | 71.7 | 43.3 | | | 48.6 | | | |
| Ichetucknee River | ICH1 | 96 | 95.3 | 61 | 100 | | | | |
| | ICH2 | 70 | 88.67 | 70 | 86 | | 80 | | |
| Juniper Creek | JUN1 | 25.3 | 0 | | | | | | |
| | JUN2 | 88.6 | 96.7 | | | 4.2 | | | |
| Rainbow River | RAI1 | 82.3 | 91 | | | | 80 | | 71 |
| | RAI2 | 45.4 | 58.31 | | | | | | 36 |
| Rock Springs Run | ROC1 | 42 | 61.7 | | | 4.5 | | | |
| | ROC2 | 51.7 | 60 | | | | | | |
| Silver River | SIL1 | 100 | 38.7 | | | | | 75 | |
| | SIL2 | 81 | 77.7 | | | | 75 | 100 | |
| | SIL3 | 94.9 | 54.94 | | | | | 91 | |
| Silver Glen Run | SLG1 | 37.3 | 81.6 | | | | 63 | | |
| Weeki Wachee River | WEE1 | 25 | 83.3 | | | | 16 | | 36 |
| | WEE2 | 2.5 | 71.7 | | | | | | 3 |
| Wekiva River | WEK1 | 89.9 | 48.3 | | | 1.5 | | | |
| | WEK2 | 73.7 | 52.5 | | | 27.9 | | | |

a – sampled April 2003 and 2004
b – sampled April–May 2005
c – sampled February–July 2009
d – sampled April–May 2011
e – sampled March, May, August, and October–December 2011

Table 7. Comparison of mean submerged macrophyte total standing crop (g dry weight/m$^2$) from various spring-run stream studies. Data are means of variable number of stations for whole stream unless indicated otherwise. Note that sampling locations in the different studies may or may not be similar.

| | **Year** | **1956** | **1978** | **1990** | **1998-2000** | **2003** | **2004** | **2004** | **2003-2005** | **2011** | **2015** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alexander Springs Crk | | | | 286.7 | | | | | | | 258.1 |
| Ichetucknee River | | | 2,476.8 | 562.2 | | 284.3 | 323.3 | | | | 400.2 |
| Rainbow River | | | | 899.8 | | | | | | 128.6 | 291.3 |
| Silver River | | 621.0 | | 427.8 | | | | 493.5 | | | 637.9 |
| Silver Glen Run | | | | 1,032.7 | | | | | | | 246.1 |
| Wacissa River | | | | 1,561.6 | | | | | | | 639.3 |
| Weeki Wachee River | | | | 1,120.6 | 192.2 | | | | 37.8 | 16.4 | 330.8 |
| Wekiva River | | | | 36.6 | | | | | | | 415.9 |
| | Source | Odum 1957b[a] | Dutoit 1979[b] | Duarte and Canfield 1990[c] | Frazer et al 2006[d] | PBS&J and UF 2003[e] | PBS&J and UF 2004 [e] | Quinlan et al. 2008[f] | Frazer et al. 2006[d] | Szafraniec 2014[g] | This Study |

a – average dry weight for the headspring reach (upper 1,200 meters)
b – mean total dry weight for all macrophytes collected at multiple stations
c – average of multiple stations; sampled June–July 1987
d – river-wide average; sampled in August each year
e – sampled April 2003 and 2004
f – sampled winter 2003–04 and summer 2004
g – sampled March, May, August, and October–December 2011

**Macrophyte Communities of Florida Spring-Run Streams – Historical Perspective**

A major impetus behind this study, as well as the broader SPIS (Introduction Section) was the observation of significant increases in the abundance of benthic filamentous algal mats in many springs, in some cases accompanied by loss of macrophytes (Figure 24). There exist few historical data to enable quantitative assessment of these trends, other than what was discussed above. Obviously, Weeki Wachee Spring (the headspring) has lost its historic macrophyte cover (and the Southwest Florida Water Management District has conducted extensive restoration efforts to try to replace this habitat). Sketches of Wekiwa and Rock Springs made in the 1950s by a co-worker of H.T. Odum show small beds of *Najas* in Wekiwa Springs and beds of *Ceratophyllum* and "*Sagittaria*" (possibly *Vallisneria*?) in Rock Springs (Wetland Solutions, Inc 2007). *Vallisneria* persists in the run and swim area of Rock Springs in Kelly Park today, but Wekiwa Spring supports no submerged macrophytes (R.A. Mattson, pers. observation). A complicating factor in these two springs is trampling damage from heavy recreational use by swimmers, which can denude macrophytes (Dutoit 1979), but swimmer access to Weeki Wachee Spring has always been restricted due to the existence of the mermaid attraction. Recent data collected in Silver Glen Spring from 2009–2017 have shown the disappearance of beds of *Vallisneria* in the headspring in water much too deep for trampling damage (SJRWMD unpublished data).

Loss of macrophyte cover in entire spring-run streams has also been a concern. Anecdotal observations from credible sources indicate extensive loss of submerged macrophyte beds in the lower Santa Fe River (a largely spring-fed stream) and its associated springs (Karst Environmental Services 2017). Macrophyte beds have also disappeared from the Homosassa River (Frazer et al. 2006; Camp et al. 2014) and largely disappeared from the "Wekiwa Springs Run", the area of stream channel between Wekiwa Springs and the confluence with Rock Springs Run (SJRWMD unpublished data and Deborah Shelley, Wekiva River Aquatic Preserve, pers. comm.), although at least one bed extensive enough to be sampled was present in this study. Manatee Spring Run, which did not support any submerged macrophytes in this study, historically did support beds of *Vallisneria*, and possibly other macrophyte taxa, in the 1990s (R.A. Mattson, pers. observation). Blue Spring Run also did not support macrophytes in this study, but it did historically (Thompson 1968). Using the data from the studies cited in Table 7, graphs comparing macrophyte standing crop over time were constructed (Figure 25). We recognize that sampling methods, number of stations and sampling events, etc. differed between these studies, but these graphs provide a general indication of changes in macrophyte abundance in these streams over time.

In contrast to the above observations, some of the results of this study do show persistence of moderate to extensive beds of submerged macrophytes in many major spring-run streams, including Silver River, Wekiva River, Rainbow River, Wacissa River, Rock Springs Run, and Alexander Springs Creek. Figure 26 shows macrophyte standing crop in Silver River over time from the studies cited in Table 7. As seen by Quinlan et al. (2008), macrophyte standing crop has remained at similar levels in this river from the 1950s to current. However, macrophyte abundance could change. Since the mid-1990s, mapping of submerged macrophytes has been conducted in the Rainbow River at roughly 5 to 6-year intervals. From

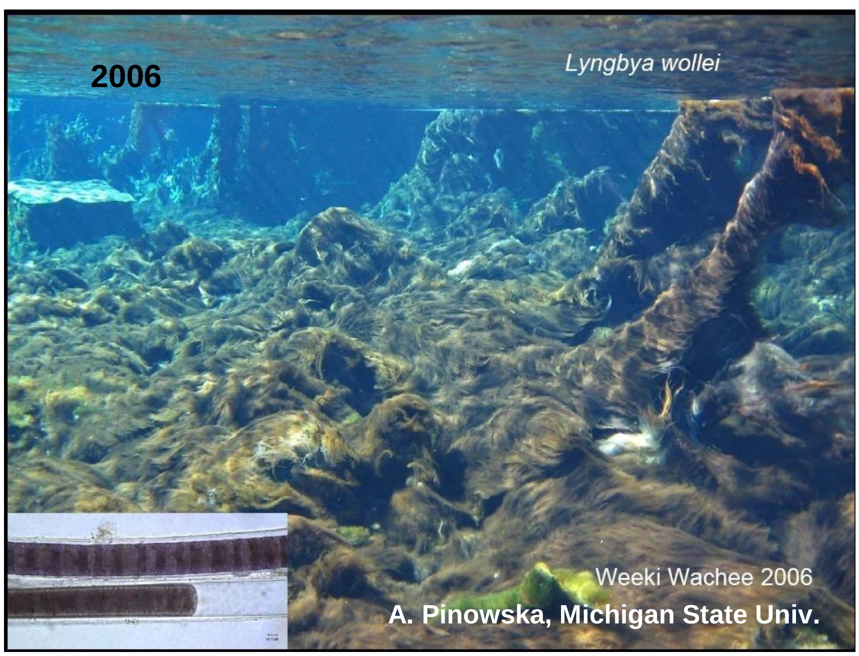
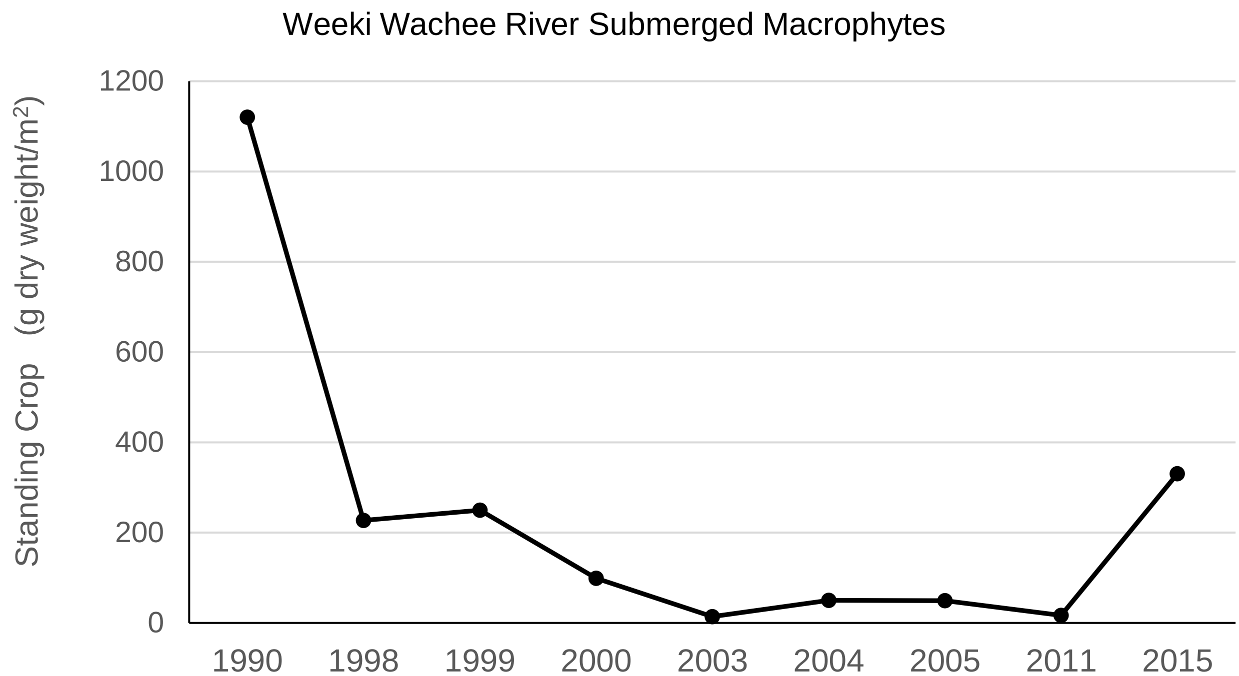




Figure 24. Photographs of Weeki Wachee Spring in 1951 (top) and 2006 (bottom), showing general changes in submerged aquatic plant communities.



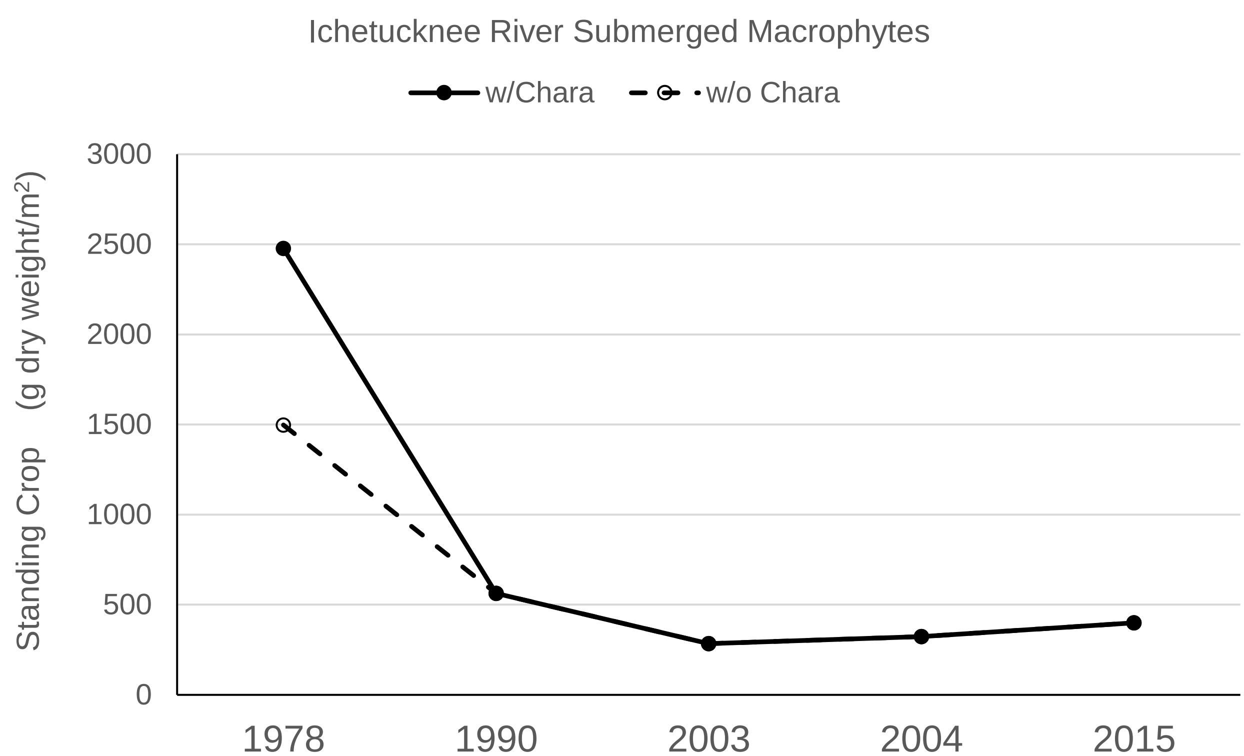




Figure 25. Plots of submerged macrophyte dry weight standing crop (g/m$^2$) over time in the Weeki Wachee and Ichetucknee Rivers.

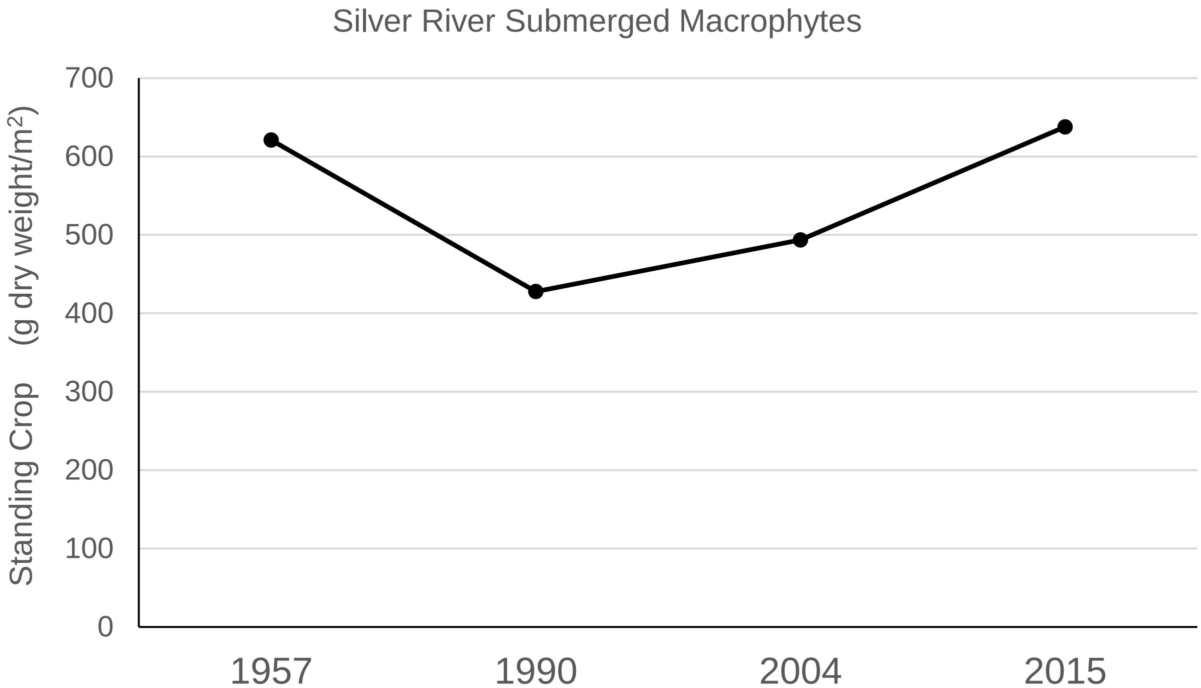



Figure 26. Plot of submerged macrophyte dry weight standing crop (g/m$^2$) over time in the Silver River.

1996 to 2005 submerged macrophyte cover remained relatively constant at 125-130 acres (Atkins NA and Woithe 2012), but in 2011, macrophyte acreage declined to about 100 acres, a ~20% decline in a six-year period.

Based on existing evidence (anecdotal and limited quantitative), there appears to be no question that Florida springs and spring-run streams are experiencing ecological changes in their vegetation communities (Florida Springs Task Force 2000; Jacoby et al. 2008; Karst Environmental Services 2017). Loss of submerged macrophyte communities and their replacement with benthic filamentous algal mats appears to be a growing problem in aquatic ecosystems worldwide (Duarte 1995; Hudon et al. 2014; Camp et al. 2014). While much attention has focused on loss of macrophytes (= seagrasses) in estuarine and coastal ecosystems, not as much attention has focused on loss of macrophytes in freshwater ecosystems. As noted above, Frazer et al. (2006) documented reductions in the submerged macrophyte community in the freshwater reach of the Homosassa River, and increases in filamentous algal mats. Quinlan et al. (2008), as part of a comprehensive "retrospective" study of the upper Silver River (comparing conditions measured by Odum and coworkers in the 1950s with current conditions), found that macrophyte communities (primarily *Sagittaria*) had remained relatively unchanged, while benthic and epiphytic algae had significantly increased in abundance and cover. Hudon et al. (2014) called attention to the proliferation of blooms (mats) of the benthic filamentous cyanobacterium *Lyngbya* (*Microseira*) *wollei* in freshwater ecosystems worldwide, including Florida spring-run streams. In many cases this was associated with declines in abundance of submerged macrophytes. Causes of this proliferation were primarily linked to this organism's wide range of environmental tolerance to multiple environmental factors and resulting adaptability to conditions in a variety of aquatic ecosystems (Hudon et al. 2014).

Considering the above, what currently stymies Florida springs ecologists and managers is the lack of a definitive determination of what environmental drivers/factors are responsible for these plant community changes, and what activities should be undertaken to ameliorate and reverse these effects in order to restore spring-run stream plant communities to a more historical condition. Conversely, what enables the persistence of reasonably intact beds of submerged macrophytes in spring-run stream systems experiencing demonstrably increased nitrate loads (Silver River, Wekiva River, Rock Springs Run, upper Rainbow River) or other stresses? Light (Odum 1957a, 1957b; Duarte and Canfield 1990; Szafraniec 2014), stream current velocity (Butcher 1933; King 2014), water quality conditions (conductivity, DO, nutrients; Hynes 1970; Stevenson et al. 2007), and grazer effects (Leibowitz et al. 2014; Karst Environmental Services 2017) may all be important to a greater or lesser extent, and depending upon the specific spring-run stream. None of these physicochemical variables had a significant influence on submerged macrophyte abundance (cover or standing crop) in this study. However, historic impacts (prior flood events, hurricanes, etc.) are a factor affecting changes in macrophyte abundance.

Springs and their spring-run streams have historically been viewed as "steady-state" systems (Odum 1957b), with relatively constant physicochemical conditions and related stable biological communities (Jacoby et al. 2008). Springs and their spring-run streams in fact exhibit a considerable amount of natural variability, both among springs and within a given spring-run stream ecosystem (Jacoby et a. 2008). All the studies carried out in recent decades that examined multiple springs and spring-run streams indicate considerable variation among springs in discharge and water chemistry (Woodruff 1993; Scott et al. 2004; Copeland et al. 2009), ecological communities (this study, Duarte and Canfield 1990; Stevenson et al. 2007; Jacoby et al. 2008; Walsh et al. 2009; WSI 2010; Szafraniec 2014; Mattson et al. 2018), and biological responses to physicochemical drivers (Table 1 in Jacoby et al. 2008, GreenWater Labs 2010, SJRWMD unpublished data).

Individual springs and their spring-run streams may also exhibit high variability within the system. Some springs exhibit wide variation in concentrations of basic dissolved constituents (Copeland et al. 2009; Marzolf and Mattson 2012) indicating "water age" (length of time in the limestone aquifer matrix) and "saline indicators" (depth source from the Floridan Aquifer), but this variation is driven by spring discharge (Copeland et al. 2009). Certain springs exhibit a high degree of variation in NOx concentration, that is also related to discharge (Upchurch et al. 2008; Marzolf and Mattson 2012). Depending upon rainfall amounts, some spring-run streams (Wekiva River, Rock Springs Run, Alexander Springs Creek, lower Santa Fe River) can vary from a clear, groundwater-dominated system to a highly colored stream dominated by surface water runoff, thereby greatly affecting the quality and quantity of light reaching the SAV communities on the bottom (R.A. Mattson, pers. observation). This variation introduces a layer of complexity requiring a "multiple lines of evidence" approach including highly targeted research, such as was done in the "CRISPS" study in Silver River (Reddy et al. 2017) and long-term monitoring of spring discharge, water quality, light regime and related biological measures to evaluate the various environmental and biological drivers responsible for plant community structure and function. From this understanding, effective management approaches can be developed, and the effectiveness of management and restoration efforts can be assessed.

Layered on top of this natural variability in spring-run stream ecosystems are multiple additional sources of variation:

- the periodic disturbance from flood events associated with tropical weather systems (hurricanes, tropical storms, and unnamed storm events);
- other climate-related effects, including droughts and effects associated with cyclic phenomena such as the El-Niño Southern Oscillation (ENSO) and Atlantic Multi-Decadal Oscillation (AMO);
- human-caused changes in spring discharge and water chemistry (e.g., increased nitrate concentrations as NOx);
- physical disruption of macrophyte beds from human recreational use/disturbance; and,
- climate change and its effects on hydrology and physicochemical conditions

These drivers may introduce extremes which exceed the environmental “boundaries” that spring-run stream ecosystems have adapted to over the past centuries; and these extremes may be more influential than “average” conditions (Gaines and Denny 1993). Given these conditions of variability, long-term monitoring, especially biological monitoring, can help better understand the effects of these “event” type disturbances and formulate management accordingly. In a comprehensive review of the scientific literature on effects of nutrients on Florida spring-run streams, Brown et al. (2008) recommended long-term monitoring of multiple spring ecosystems as an important management tool. They recommended using the same methodology across all streams, similar to what was done in this study. These monitoring data would be very valuable in understanding spatial and temporal variation in stressors and impacts. Monitoring of submerged macrophyte communities, given the odd combination of their stability and vulnerability, is recommended as one component of a long-term biological monitoring effort in Florida spring-run streams.

# CONCLUSIONS AND RECOMMENDATIONS

Fourteen springs and their associated spring-run streams in north and central Florida were intensively sampled in 2015 for selected physicochemical characteristics and quantitative measurement of submerged aquatic vegetation (SAV – macrophytes and algae) and SAV-associated macroinvertebrates. Of these 14, 12 of these streams supported submerged macrophytes in the SAV communities. This report focused on the submerged macrophyte data.

Florida springs and their associated spring-run stream exhibit a wide range of flow and water chemistry characteristics (dissolved solids, nutrient concentrations, etc.). Springs along the mainstem of the St. Johns River system tend to be “saltier” springs than those located elsewhere in central and north Florida.

Nine species/taxa of macrophytes were collected in two sampling events (spring and fall 2015). The dominant three species, by frequency of occurrence and abundance (percent cover and dry weight standing crop) were *Vallisneria americana* (eelgrass), *Sagittaria kurziana* (spring tape), and *Hydrilla verticillata* (hydrilla). Highest *Vallisneria* cover (%) was generally seen at the downstream transect on the Ichetucknee River, both Rock Springs Run transects, the downstream Wakulla River transect, and one or both transects on the Weeki Wachee River or Wekiva River. Highest *Vallisneria* standing crop (dry weight as $g/m^2$) was seen at the downstream transect on the Ichetucknee River, both Rock Springs Run transects, and at least one transect on the Wacissa, Wakulla, Weeki Wachee and Wekiva Rivers. Highest *Sagittaria* cover was seen at the upstream transects on Gum Slough, the Ichetucknee River, Rainbow River, Silver River and Wakulla River and both transects on the Wacissa River. Highest *Sagittaria* standing crop was seen at the upstream transects on the Ichetucknee River, Rainbow River, Silver River, Wacissa River and Wakulla River. Highest *Hydrilla* cover and standing crop were mostly seen on Silver Glen Run. Spring-run streams on the St. Johns River (SJR) were dominated by *Vallisneria*, while *Sagittaria* was generally dominant on spring-run streams not on the St. Johns River (O). Where the two plant species occurred in the same stream, *Sagittaria* was generally more abundant at upstream transects, while *Vallisneria* was more abundanct at downstream transects.

The sampling design used in this study precluded use of conventional parametric or non-parametric statistical tools to evaluate differences. Comparisons were made using visual inspection of tabular and graphical summaries of the data to identify general patterns and relationships. Multivariate analysis of the data generally indicated significant differences in macrophyte abundance among the sampling transects and delineated two major groupings of springs; those on the St. Johns River mainstem, generally dominated by *Vallisneria*, and those not on the St. Johns mainstem, generally dominated by *Sagittaria*.

Graphical comparison of physicochemical variables with total macrophyte cover and standing crop (using “standard” correlation graphs and quantile regression graphical comparisons) and multivariate comparison using the BEST procedure detected weak relationships between physicochemical conditions and macrophyte abundance as cover or standing crop. Prior studies have indicated that light levels (primarily influenced by tree canopy cover over the stream channel and water clarity) and current velocity may exert strong effects on macrophyte abundance, but this study failed to find any strong or significant relationships between physicochemistry and macrophyte abundance.

Comparison of the results of this study (macrophyte cover and standing crop) was made to prior studies of submerged macrophyte communities of Florida spring-run streams dating back to the 1950s. This comparison indicated similar cover and/or standing crop in some spring-run streams in the current study compared to prior studies (e.g., Silver River). A few spring-run streams (Silver Glen Run, Wacissa River, and Weeki Wachee River) did exhibit higher standing crop in historical surveys than measured in this study. Anecdotal and some quantitative historical data indicate increased algal abundance in some springs and spring-run streams, in some cases accompanied by loss of macrophytes. A summary and analysis of the algal sampling data from this study will be presented in a future technical report

The main recommendation from this study is that biological monitoring in springs and spring-run streams should be conducted to complement the existing discharge and water quality monitoring that is done in these systems. Long-term biological data, including consistent monitoring of submerged macrophyte communities, is an important tool to generate the data to better understand the drivers influencing submerged aquatic plant communities (macrophytes and algae) in spring-run streams.

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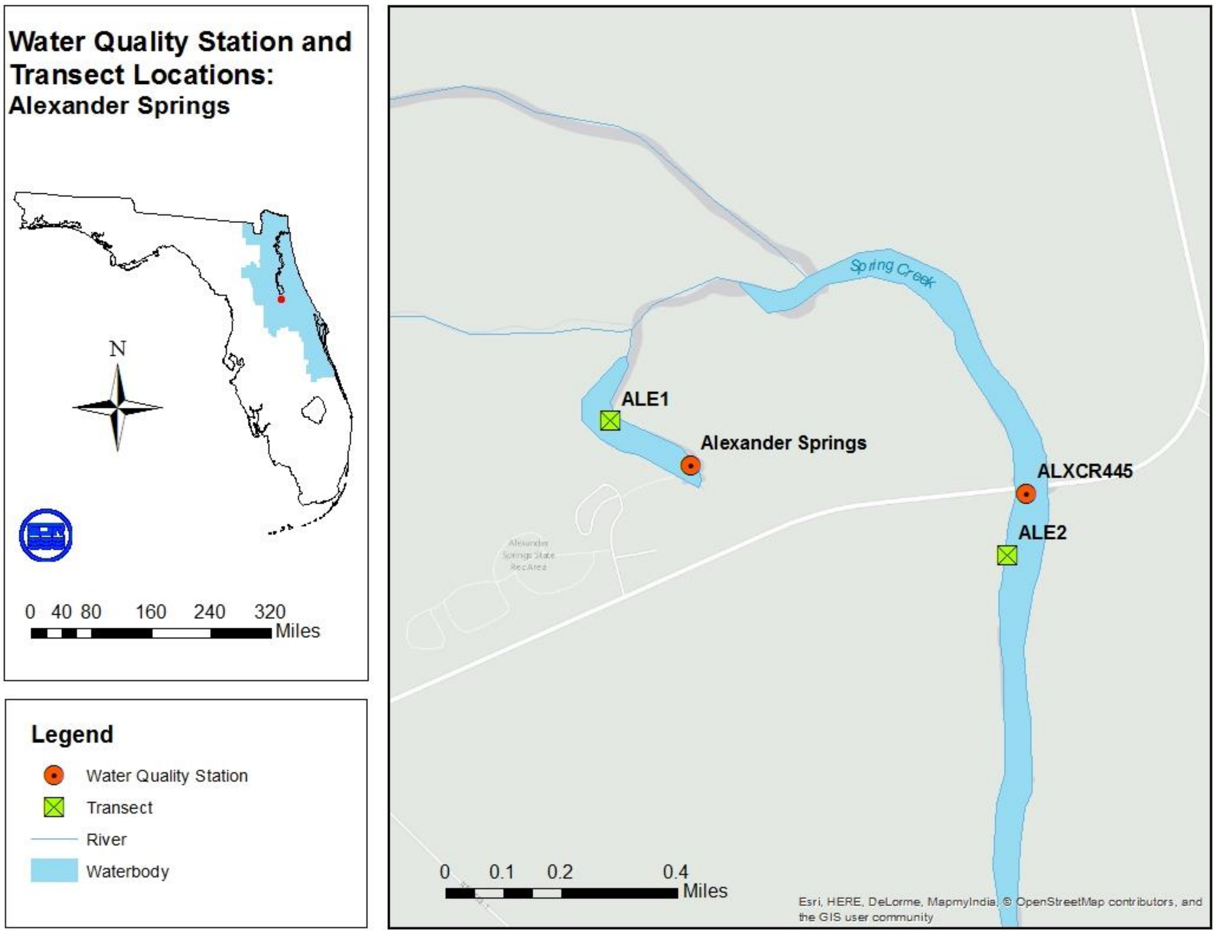
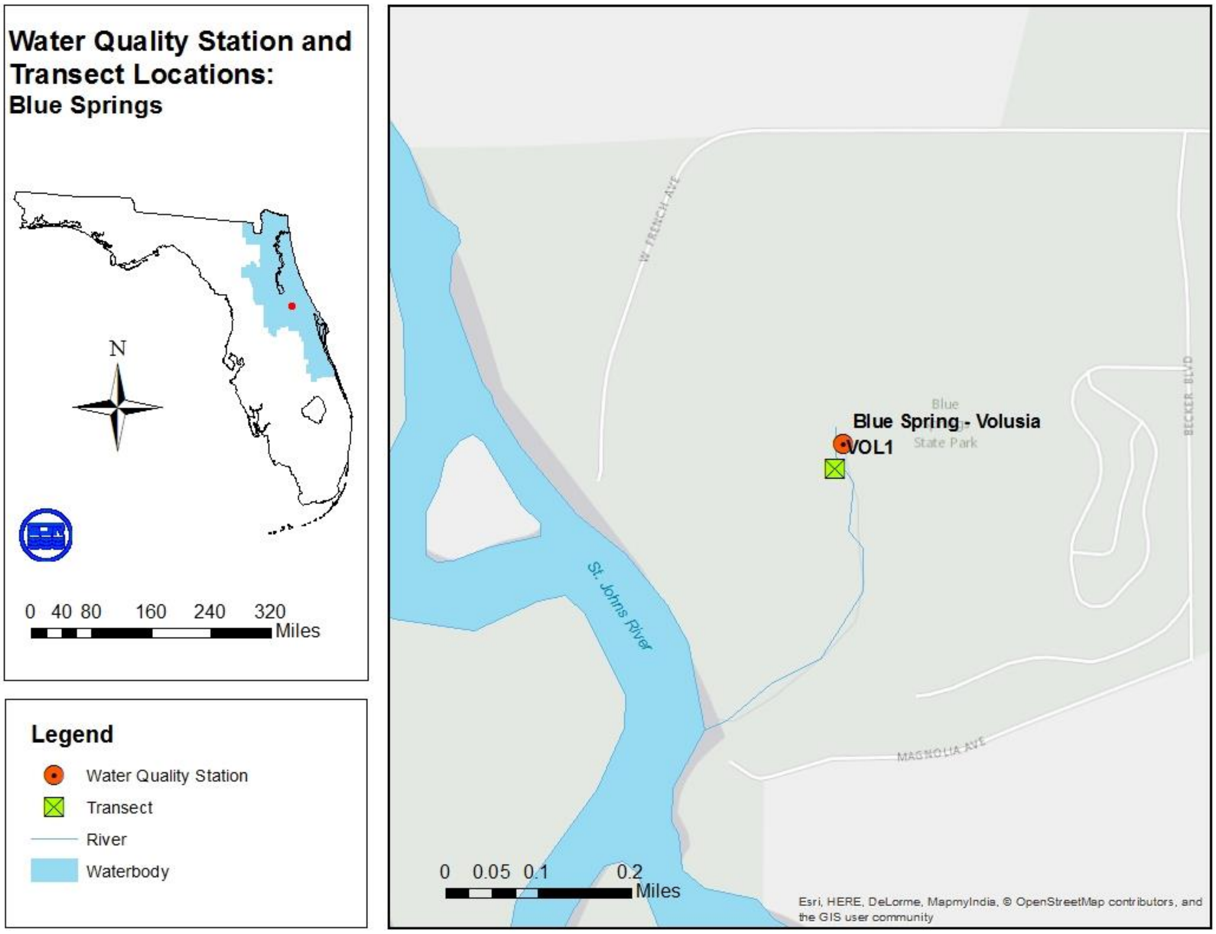
# APPENDIX A—TABLE OF ST. JOHNS RIVER SPRINGS DISCHARGE DATA

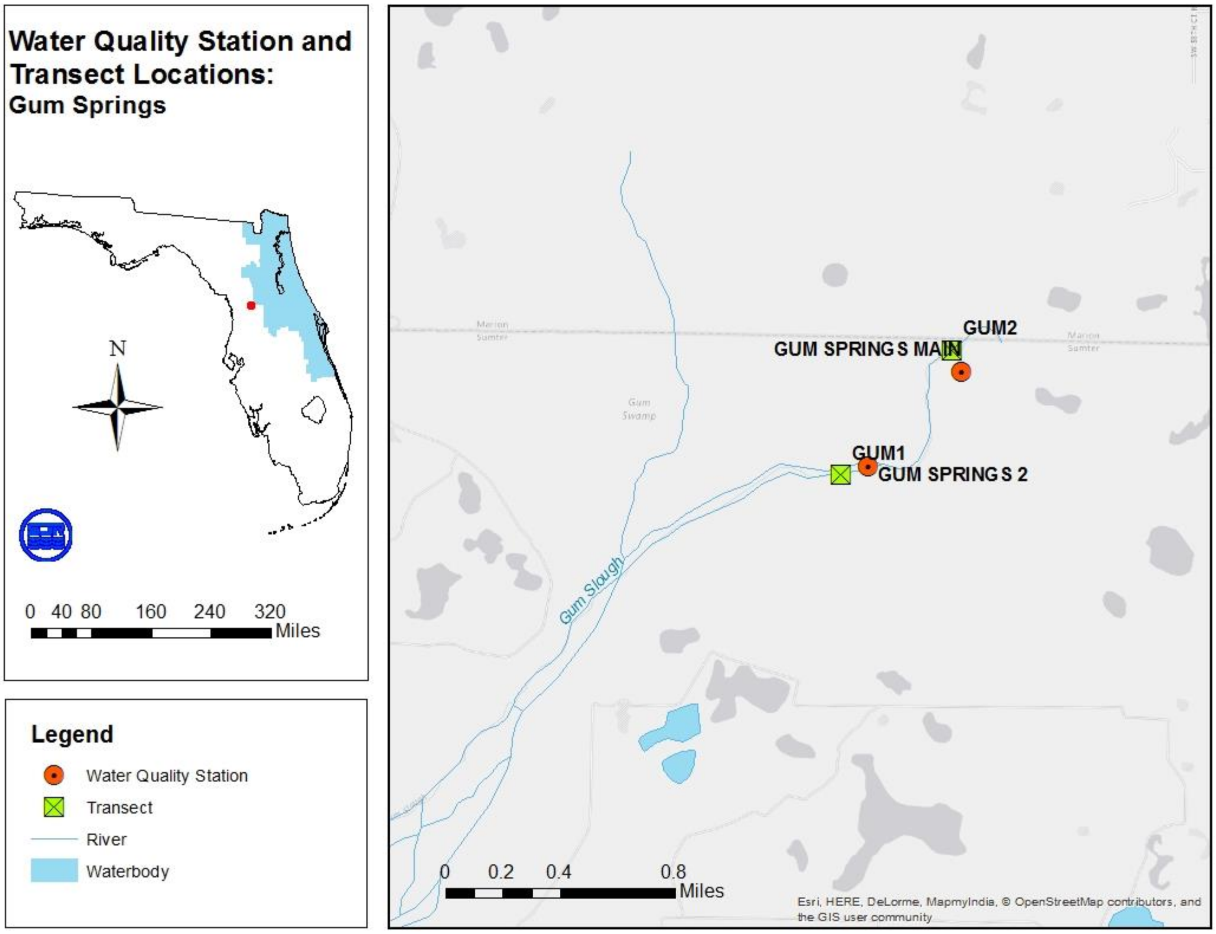
Appendix A Table1. Average discharge rate, magnitude, and data period of record of 25 springs in SJRWMD. Shading indicates first-, second-, and third-magnitude. Data from SJRWMD databases and table from Di and Mattson (unpublished report).

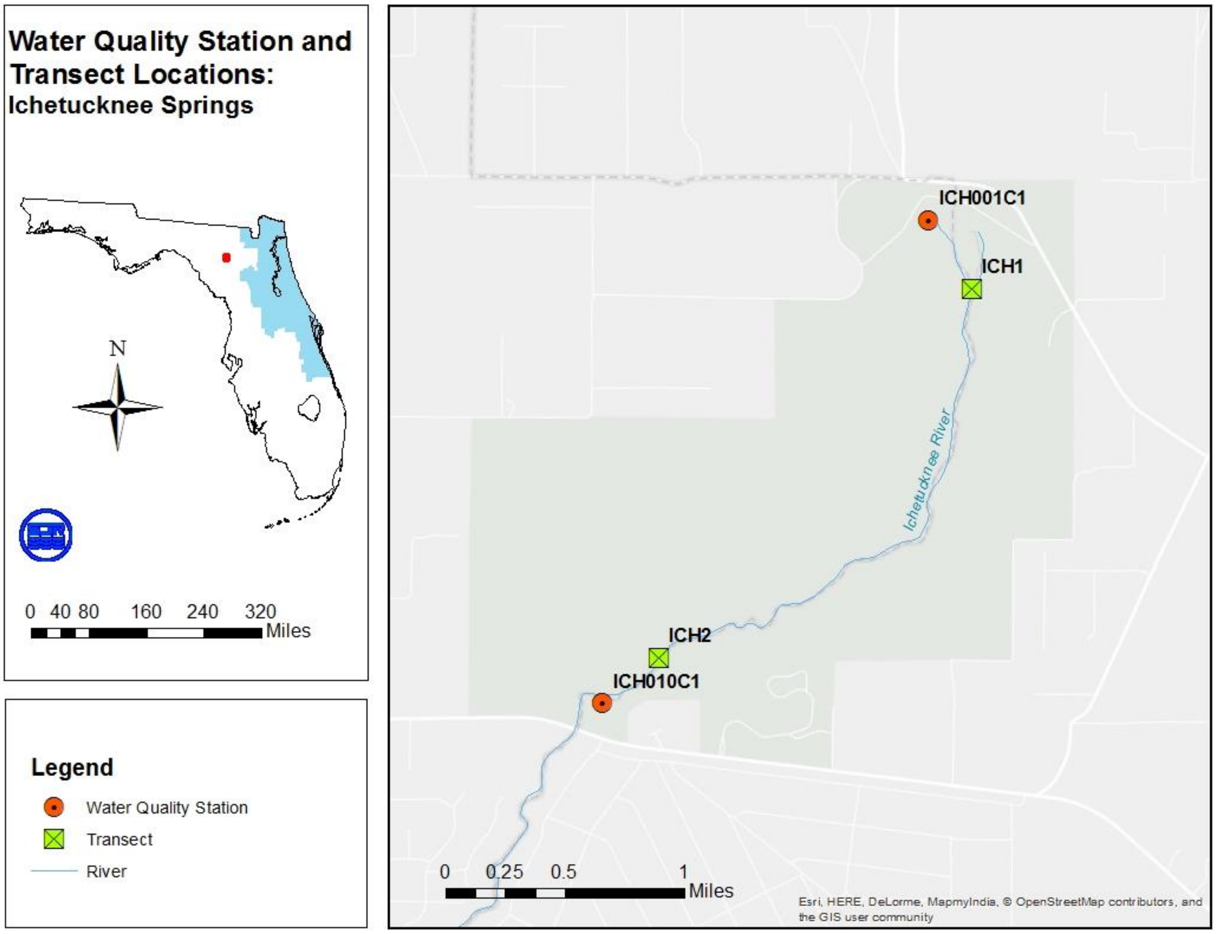
| Spring | Mean Discharge (cfs) | Magnitude | Start | End* |
|---|---|---|---|---|
| Silver Springs | 714 | First | 10/1932 | 04/2014 |
| Blue Spring - Volusia | 144 | First | 03/1932 | 09/2013 |
| Alexander Springs | 102 | First | 02/1931 | 04/2014 |
| Silver Glen Springs | 101 | First | 03/1931 | 09/2011 |
| Salt Springs | 79 | Second | 02/1929 | 06/2014 |
| Croaker Hole Spring | 69 | Second | 07/1998 | 03/2014 |
| Wekiwa Springs | 62 | Second | 03/1932 | 03/2014 |
| Rock Springs | 54 | Second | 02/1931 | 05/2014 |
| Apopka Spring | 25 | Second | 05/1971 | 03/2014 |
| Ponce De Leon Springs | 23 | Second | 02/1983 | 06/2014 |
| Sanlando Springs | 19 | Second | 11/1941 | 05/2014 |
| Sweetwater Springs | 13 | Second | 11/1980 | 06/2014 |
| Starbuck Spring | 12 | Second | 07/1944 | 05/2014 |
| Bugg Spring Run | 11 | Second | 03/1990 | 10/2013 |
| Fern Hammock Springs | 11 | Second | 12/1935 | 04/2014 |
| Juniper Springs | 11 | Second | 04/1935 | 04/2014 |
| Gemini Springs | 10 | Second | 04/1972 | 05/2014 |
| Palm Springs - Seminole | 6 | Third | 11/1941 | 05/2014 |
| Miami Springs | 5 | Third | 08/1945 | 05/2014 |
| Orange Spring | 3 | Third | 09/1972 | 06/2014 |
| Holiday Springs Dstm | 3 | Third | 04/1946 | 10/2011 |
| Green Cove Spring | 3 | Third | 02/1929 | 06/2014 |
| Blue Spring Yal Run | 3 | Third | 01/2002 | 10/2011 |
| Double Run Spring | 2 | Third | 10/1991 | 10/2011 |
| Green Springs | 1 | Third | 04/1972 | 05/2014 |

# APPENDIX B—MAPS OF SAMPLING SITES


Water Quality Station and
Transect Locations:
Alexander Springs
N
0 40 80 160 240 320
Miles
Legend
Water Quality Station
Transect
River
Waterbody
Spring Creek
ALE1
Alexander Springs
ALXCR445
ALE2
0 0.1 0.2 0.4
Miles
Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community


Water Quality Station and Transect Locations:
Blue Springs
N
0 40 80 160 240 320
Miles
Legend
Water Quality Station
Transect
River
Waterbody
W. FRENCH AVE
Blue Spring - Volusia
VOL1
Blue
State Park
St. Johns River
MAGNOLIA AVE
0 0.05 0.1 0.2
Miles
Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community


Water Quality Station and
Transect Locations:
Gum Springs
N
0 40 80 160 240 320
Miles
Legend
Water Quality Station
Transect
River
Waterbody
GUM2
GUM SPRINGS MAIN
GUM1
GUM SPRINGS 2
Gum Slough
0 0.2 0.4 0.8
Miles
Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community


Water Quality Station and Transect Locations:
Ichetucknee Springs
N
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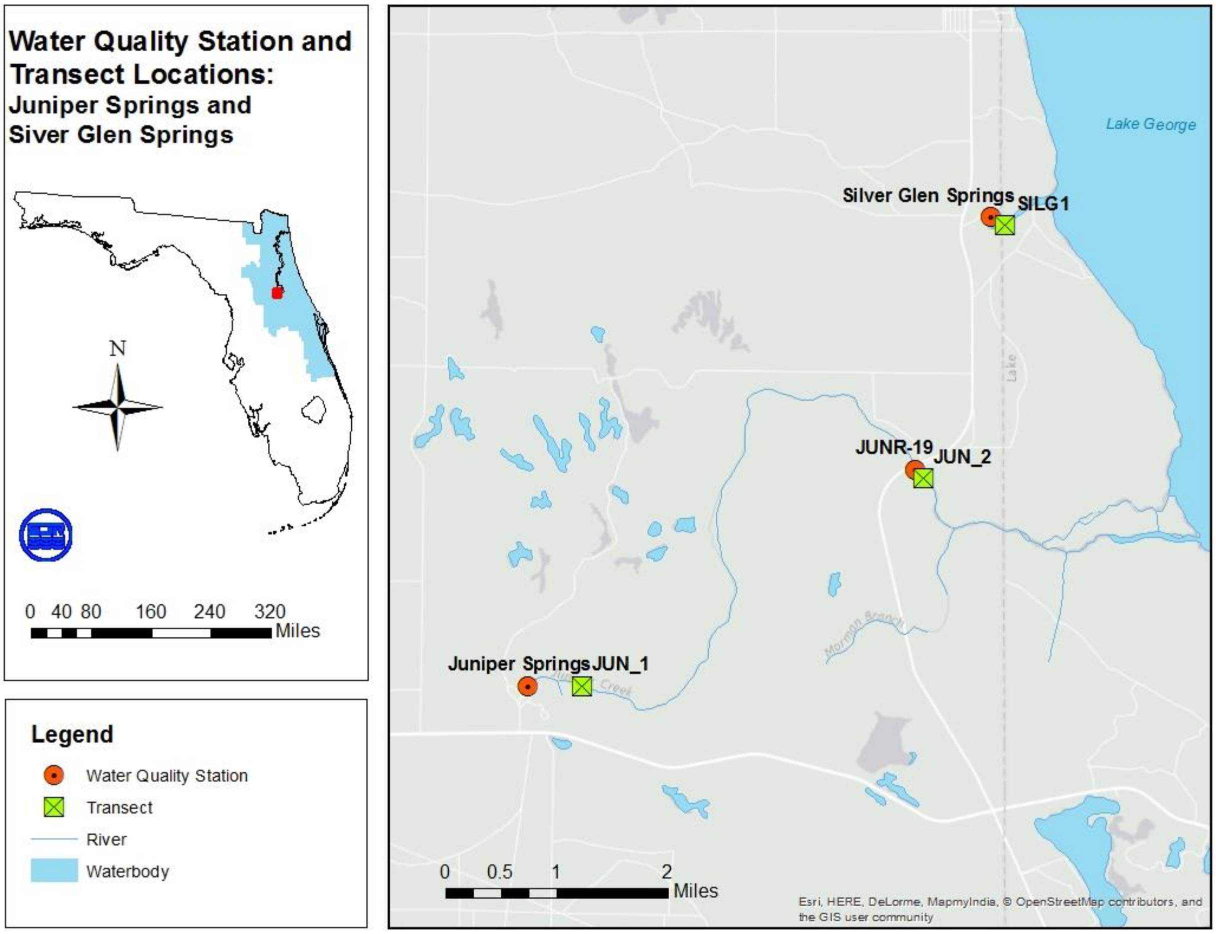
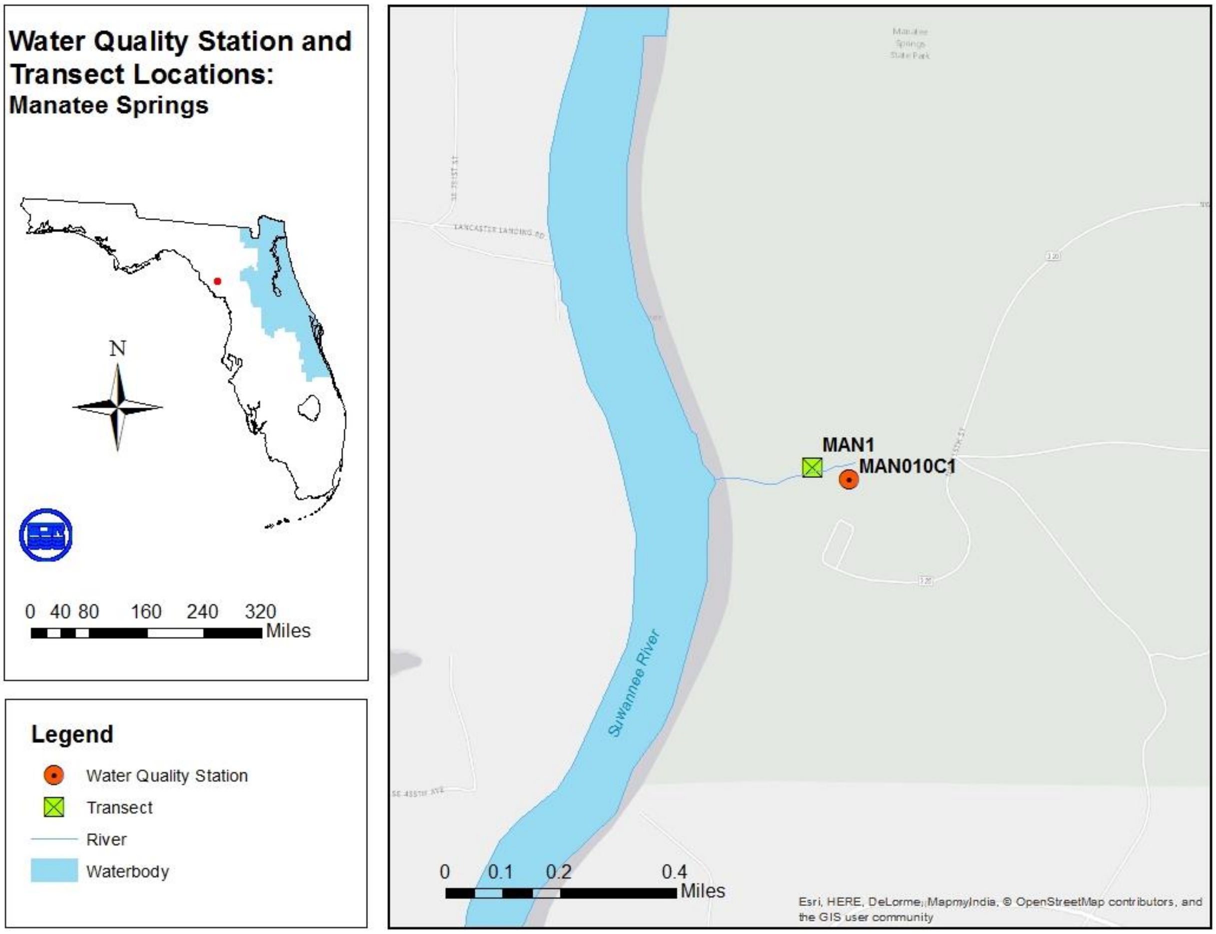
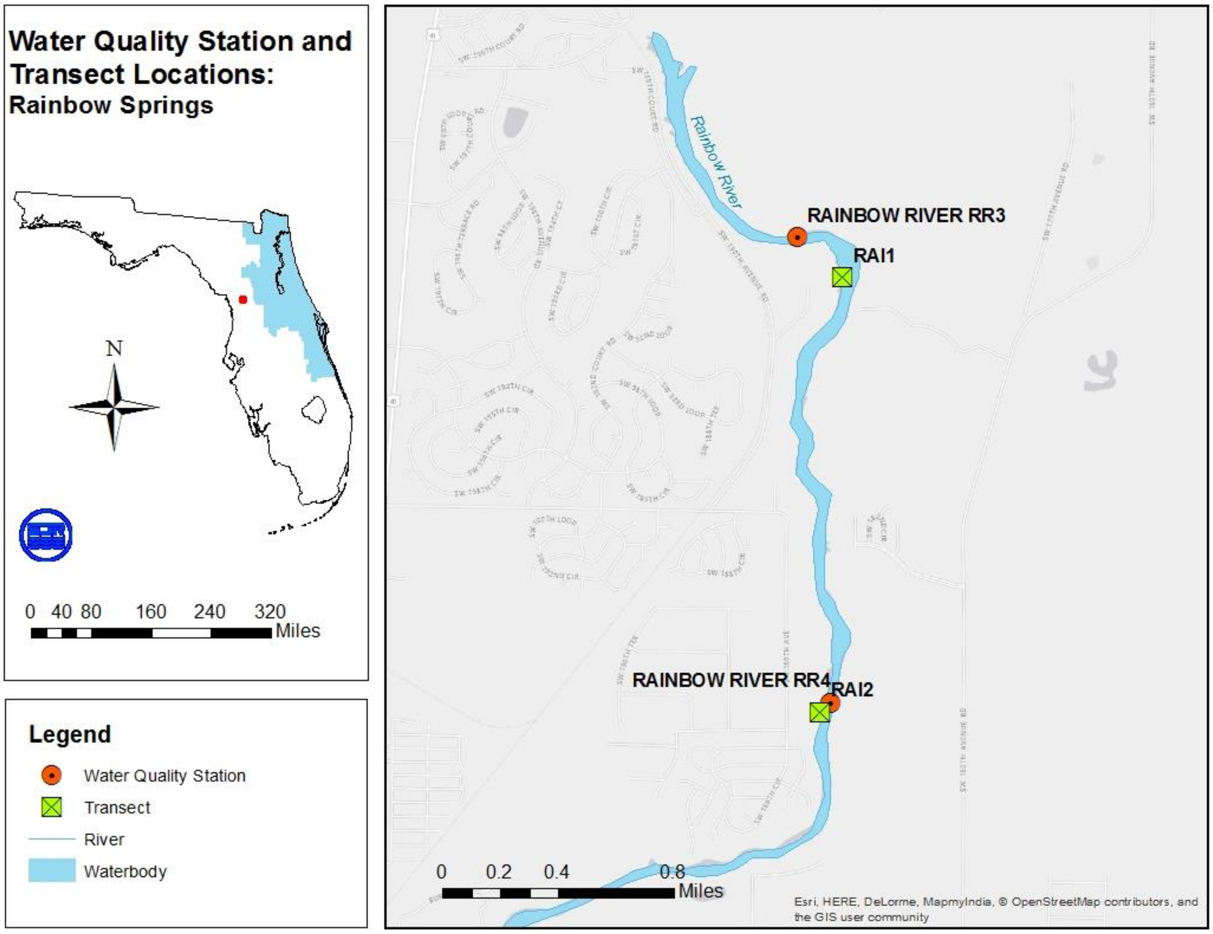
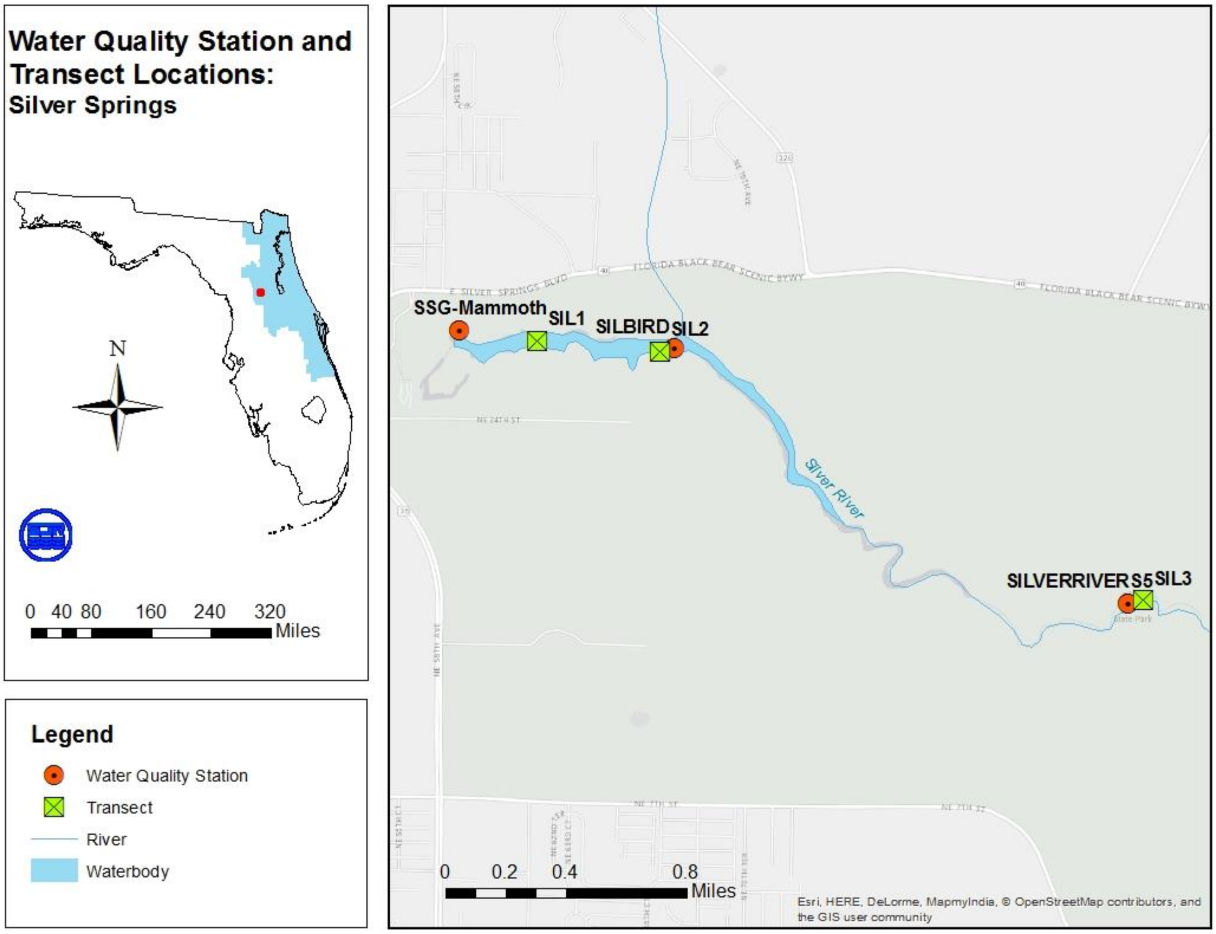
Miles
Legend
Water Quality Station
Transect
River
ICH001C1
ICH1
Ichetucknee River
ICH2
ICH010C1
0 0.25 0.5 1
Miles
Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

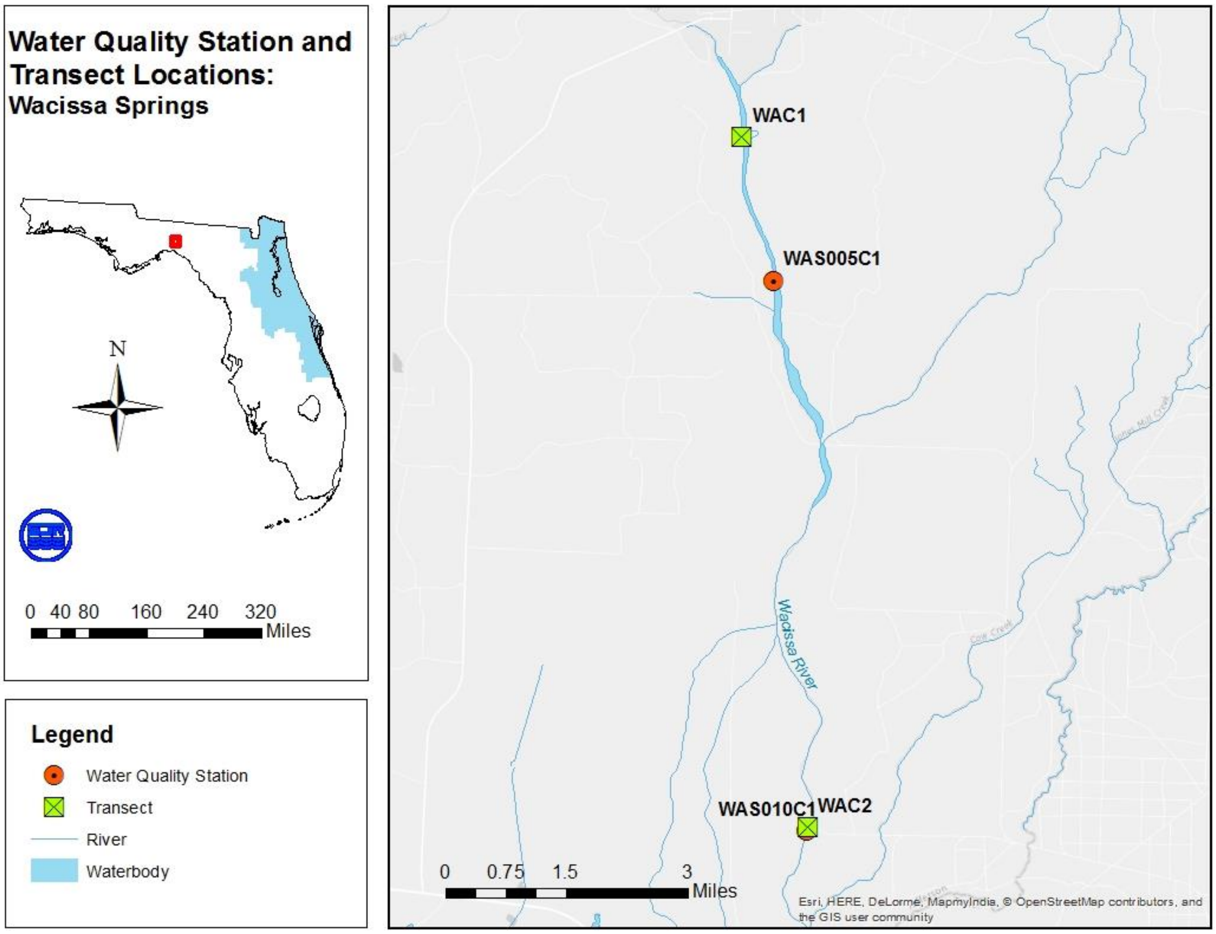

Water Quality Station and
Transect Locations:
Juniper Springs and
Siver Glen Springs
N
0 40 80 160 240 320
Miles
Legend
Water Quality Station
Transect
River
Waterbody
Lake George
Silver Glen Springs
SILG1
JUNR-19
JUN_2
Juniper Springs
JUN_1
0 0.5 1 2
Miles
Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

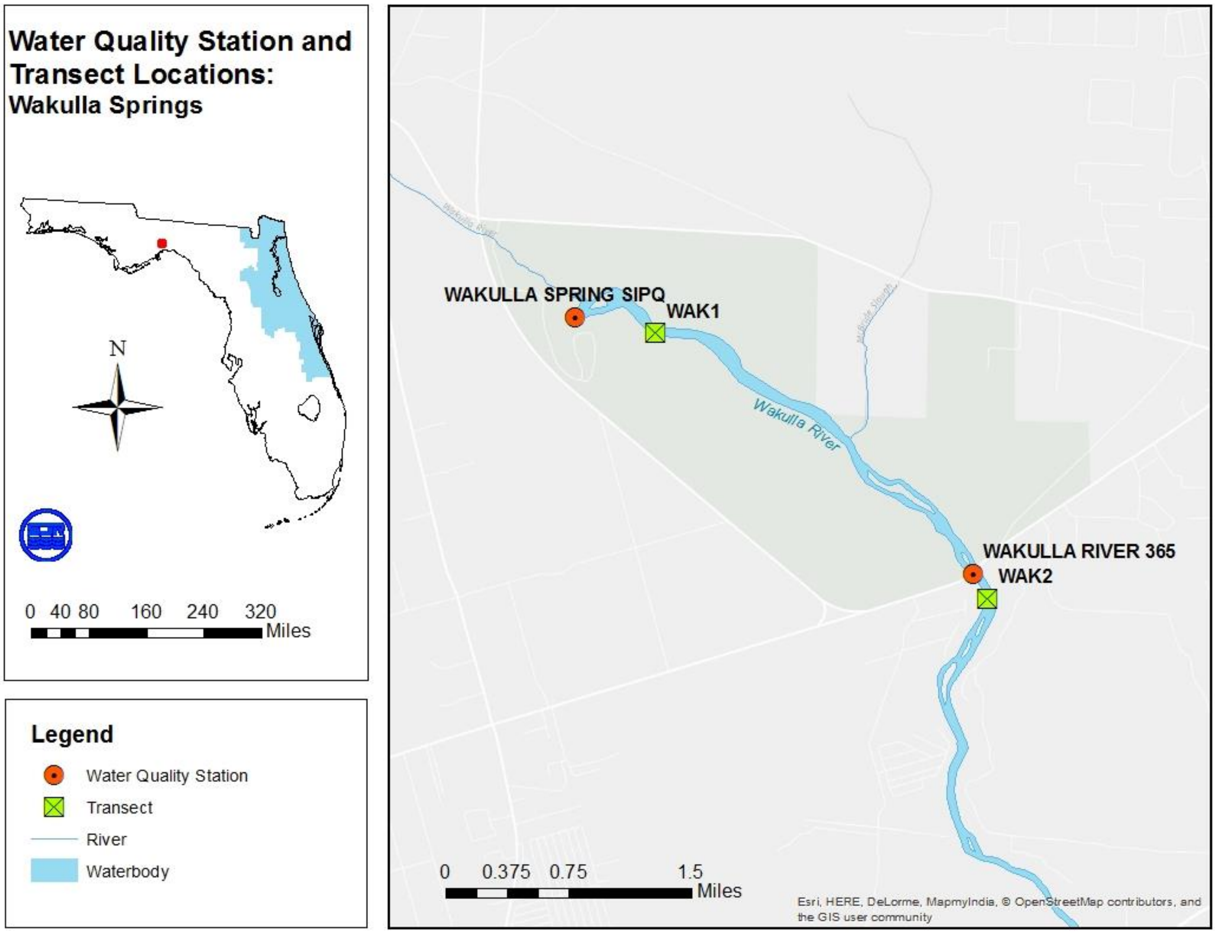

Water Quality Station and
Transect Locations:
Manatee Springs
N
0 40 80 160 240 320
Miles
Legend
Water Quality Station
Transect
River
Waterbody
MAN1
MAN010C1
Suwannee River
0 0.1 0.2 0.4
Miles
Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

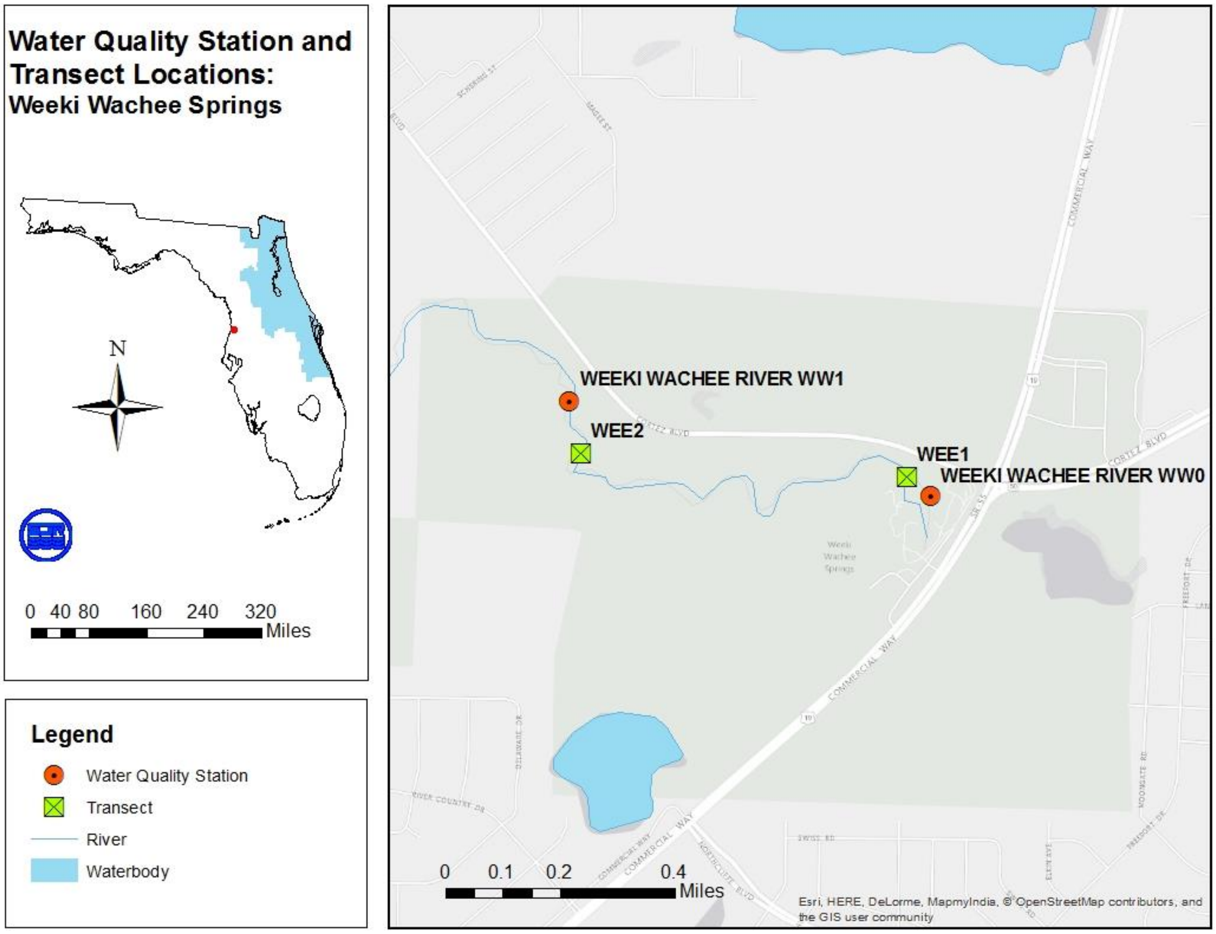

Water Quality Station and Transect Locations:
Rainbow Springs
N
0 40 80 160 240 320
Miles
Legend
Water Quality Station
Transect
River
Waterbody
Rainbow River
RAINBOW RIVER RR3
RAI1
RAINBOW RIVER RR4
RAI2
0 0.2 0.4 0.8
Miles
Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community



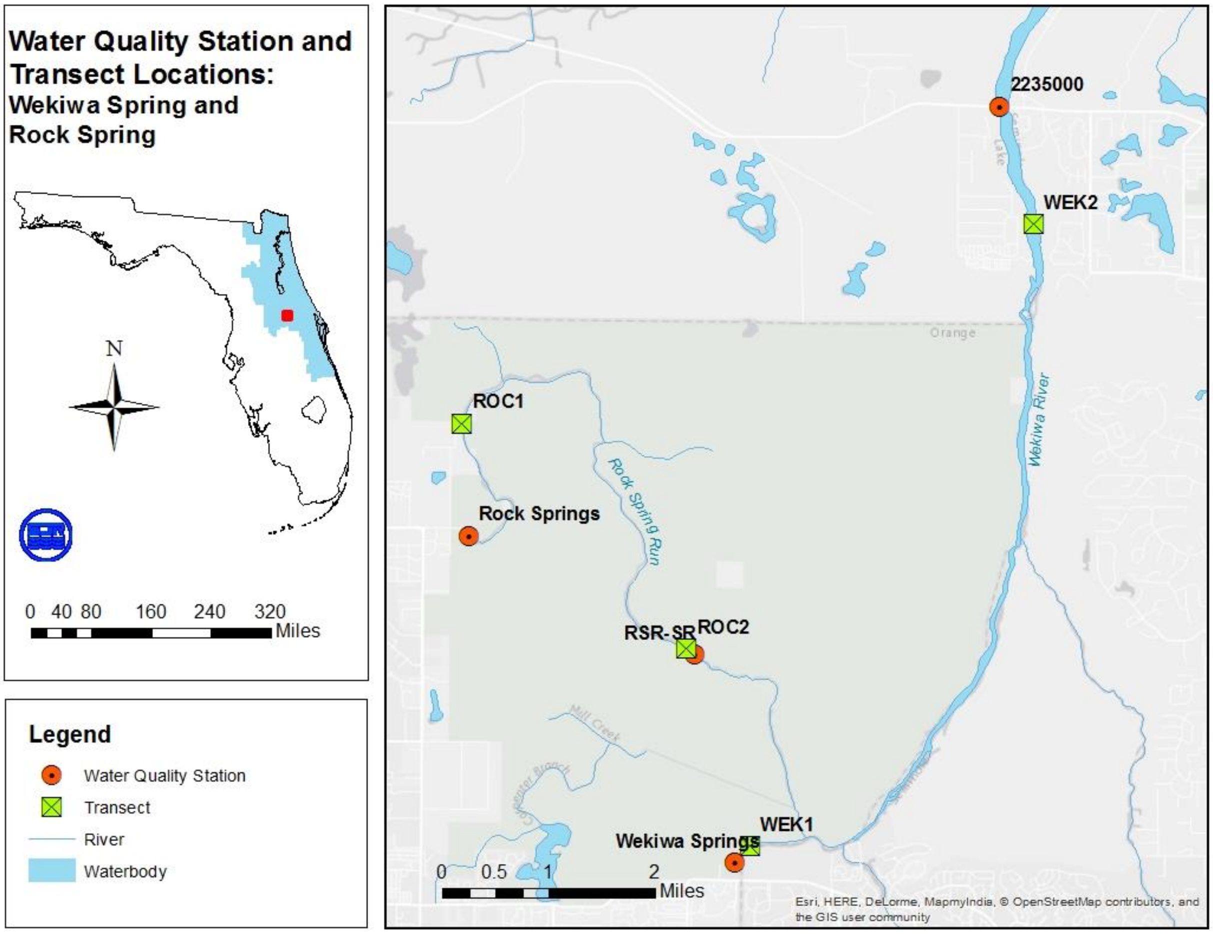
Water Quality Station and
Transect Locations:
Silver Springs
N
0 40 80 160 240 320
Miles
Legend
Water Quality Station
Transect
River
Waterbody
SSG-Mammoth
SIL1
SILBIRD
SIL2
Silver River
SILVERRIVERS5
SIL3
FLORIDA BLACK BEAR SCENIC BYWY
0 0.2 0.4 0.8
Miles
Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community


Water Quality Station and Transect Locations:
Wacissa Springs
N
0 40 80 160 240 320
Miles
Legend
Water Quality Station
Transect
River
Waterbody
WAC1
WAS005C1
Wacissa River
WAS010C1
WAC2
0 0.75 1.5 3
Miles
Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community


Water Quality Station and Transect Locations:
Wakulla Springs
N
0 40 80 160 240 320
Miles
Legend
Water Quality Station
Transect
River
Waterbody
WAKULLA SPRING SIPQ
WAK1
Wakulla River
WAKULLA RIVER 365
WAK2
0 0.375 0.75 1.5
Miles
Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community



Water Quality Station and Transect Locations:
Weeki Wachee Springs
N
0 40 80 160 240 320 Miles
Legend
Water Quality Station
Transect
River
Waterbody
WEEKI WACHEE RIVER WW1
WEE2
WEE1
WEEKI WACHEE RIVER WW0
0 0.1 0.2 0.4 Miles
Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community



Water Quality Station and Transect Locations:
Wekiwa Spring and Rock Spring
N
0 40 80 160 240 320
Miles
Legend
Water Quality Station
Transect
River
Waterbody
2235000
WEK2
Orange
Wekiwa River
ROC1
Rock Spring Run
Rock Springs
RSR-SR
ROC2
Mill Creek
WEK1
Wekiwa Springs
0 0.5 1 2
Miles
Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

# APPENDIX C—SUMMARY TABLES OF MACROPHYTE COVER AND DRY WEIGHT

Column Headings in Tables

MEAN – mean value
SE – Standard error
SD – Standard deviation
MIN – Minimum value
25 %ile – $25^{th}$ Percentile value
MEDIAN – Median value
75 %ile – $75^{th}$ Percentile value
MAX – Maximum value

Appendix C Table 1. Summary statistics for *Vallisneria americana* percent cover during spring 2015. Refer to Table 2 for definitions of transect labels.

| TRANSECT | MEAN | SE | SD | MIN | 25 %ile | MEDIAN | 75 %ile | MAX |
|---|---|---|---|---|---|---|---|---|
| ALE1 | 60.0 | 30.3 | 52.4 | 0 | 0 | 83.0 | 97.0 | 97.0 |
| ALE2 | 71.7 | 24.2 | 42.3 | 23.0 | 23.0 | 92.0 | 100 | 100 |
| GUM1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| GUM2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ICH1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ICH2 | 70.0 | 30.0 | 52.0 | 10.0 | 10.0 | 100 | 100 | 100 |
| JUN1 | 25.33 | 7.84 | 13.58 | 17.0 | 17.0 | 18.0 | 41.0 | 41.0 |
| JUN2 | 33.3 | 33.3 | 57.7 | 0 | 0 | 0 | 100 | 100 |
| RAI1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| RAI2 | 11.8 | 10.6 | 18.4 | 0 | 0 | 2.5 | 33.0 | 33.0 |
| ROC1 | 42.0 | 5.3 | 9.2 | 34.0 | 34.0 | 40.0 | 52.0 | 52.0 |
| ROC2 | 51.7 | 12.0 | 20.7 | 33.0 | 33.0 | 48.0 | 74.0 | 74.0 |
| SIL1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIL2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIL3 | 24.2 | 22.9 | 39.7 | 0 | 0 | 2.5 | 70.0 | 70.0 |
| SLG1 | 20.0 | 13.1 | 22.6 | 5.0 | 5.0 | 9.0 | 46.0 | 46.0 |
| WAC1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAC2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAK1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAK2 | 48.3 | 27.4 | 47.5 | 0 | 0 | 50.0 | 95.0 | 95.0 |
| WEE1 | 25.0 | 22.5 | 39.0 | 2.5 | 2.5 | 2.5 | 70.0 | 70.0 |
| WEE2 | 2.5 | 0 | 0 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| WEK1 | 69.67 | 5.24 | 9.07 | 60.0 | 60.0 | 71.0 | 78.0 | 78.0 |
| WEK2 | 73.7 | 21.9 | 37.8 | 30.0 | 30.0 | 94.0 | 97.0 | 97.0 |

Appendix C Table 2. Summary statistics for *Sagittaria kurziana* percent cover during spring 2015. Refer to Table 2 for definitions of transect labels.

| TRANSECT | MEAN | SE | SD | MIN | 25 %ile | MEDIAN | 75 %ile | MAX |
|---|---|---|---|---|---|---|---|---|
| ALE1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ALE2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| GUM1 | 93.3 | 2.7 | 4.6 | 88.0 | 88.0 | 96.0 | 96.0 | 96.0 |
| GUM2 | 45.0 | 5.0 | 8.7 | 35.0 | 35.0 | 50.0 | 50.0 | 50.0 |
| ICH1 | 96.0 | 2.0 | 3.46 | 94.0 | 94.0 | 94.0 | 100 | 100 |
| ICH2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| JUN1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| JUN2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| RAI1 | 82.3 | 16.2 | 28.0 | 50.0 | 50.0 | 97.0 | 100 | 100 |
| RAI2 | 32.8 | 17.2 | 29.8 | 2.5 | 2.5 | 34.0 | 62.0 | 62.0 |
| ROC1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ROC2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIL1 | 100 | 0 | 0 | 100 | 1 | 100 | 100 | 100 |
| SIL2 | 81.0 | 12.3 | 21.3 | 58.0 | 58.0 | 85.0 | 100 | 100 |
| SIL3 | 70.7 | 29.3 | 50.8 | 12.0 | 12.0 | 100 | 100 | 100 |
| SLG1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAC1 | 93.3 | 1.7 | 2.9 | 90.0 | 90.0 | 95.0 | 95.0 | 95.0 |
| WAC2 | 71.0 | 29.0 | 50.2 | 13.0 | 13.0 | 100 | 100 | 100 |
| WAK1 | 11.5 | 10.3 | 17.8 | 0 | 0 | 2.5 | 32.0 | 32.0 |
| WAK2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEE1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEE2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEK1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEK2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Appendix C Table 3. Summary statistics for *Hydrilla verticillata* percent cover during spring 2015. Refer to Table 2 for definitions of transect labels.

| TRANSECT | MEAN | SE | SD | MIN | 25 %ile | MEDIAN | 75 %ile | MAX |
|---|---|---|---|---|---|---|---|---|
| ALE1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ALE2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| GUM1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| GUM2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ICH1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ICH2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| JUN1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| JUN2 | 0.3 | 0.3 | 0.6 | 0 | 0 | 0 | 1.0 | 1.0 |
| RAI1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| RAI2 | 0.8 | 0.8 | 1.4 | 0 | 0 | 0 | 2.5 | 2.5 |
| ROC1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ROC2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIL1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIL2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIL3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SLG1 | 17.3 | 16.3 | 28.3 | 0 | 0 | 2.0 | 50.0 | 50.0 |
| WAC1 | 0.8 | 0.8 | 1.4 | 0 | 0 | 0 | 2.5 | 2.5 |
| WAC2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAK1 | 18.7 | 11.6 | 20.1 | 0 | 0 | 16.0 | 40.0 | 40.0 |
| WAK2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEE1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEE2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEK1 | 2.5 | 0 | 0 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| WEK2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Appendix C Table 4. Summary statistics for percent cover of other SAV macrophyte taxa during spring 2015. Refer to Table 2 for definitions of transect labels.

| TRANSECT | MEAN | SE | SD | MIN | 25 %ile | MEDIAN | 75 %ile | MAX |
|---|---|---|---|---|---|---|---|---|
| *Ceratophyllum demersum* | | | | | | | | |
| GUM1 | 1.0 | 1.0 | 1.73 | 0 | 0 | 0 | 3.0 | 3.0 |
| | | | | | | | | |
| *Chara* sp. | | | | | | | | |
| WAK2 | 0.8 | 0.8 | 1.4 | 0 | 0 | 0 | 2.5 | 2.5 |
| | | | | | | | | |
| *Najas guadalupensis* | | | | | | | | |
| ALE1 | 14.0 | 14.0 | 24.2 | 0 | 0 | 0 | 42.0 | 42.0 |
| WAK2 | 16.0 | 16.0 | 27.7 | 0 | 0 | 0 | 48.0 | 48.0 |
| WEK1 | 17.7 | 4.4 | 7.6 | 9.0 | 9.0 | 21.0 | 23.0 | 23.0 |
| | | | | | | | | |
| *Potamogeton illinoensis* | | | | | | | | |
| WAC2 | 29.0 | 29.0 | 50.2 | 0 | 0 | 0 | 87.0 | 87.0 |
| | | | | | | | | |
| *Potamogeton pectinatus* | | | | | | | | |
| JUN2 | 55.0 | 29.3 | 50.7 | 0 | 0 | 65.0 | 100 | 100 |

Appendix C Table 5. Summary statistics for *Vallisneria americana* percent cover during fall 2015. Refer to Table 2 for definitions of transect labels.

| TRANSECT | MEAN | SE | SD | MIN | 25 %ile | MEDIAN | 75 %ile | MAX |
|---|---|---|---|---|---|---|---|---|
| ALE1 | 46.70 | 23.50 | 40.70 | 0 | 0 | 65.00 | 75.00 | 75.00 |
| ALE2 | 43.30 | 13.00 | 22.50 | 20.00 | 20.00 | 45.00 | 65.00 | 65.00 |
| GUM1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| GUM2 | 10.00 | 5.77 | 10.00 | 0 | 0 | 10.00 | 20.00 | 20.00 |
| ICH1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ICH2 | 88.67 | 8.95 | 15.50 | 71.00 | 71.00 | 95.00 | 100 | 100 |
| JUN1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| JUN2 | 71.70 | 28.30 | 49.10 | 15.00 | 15.00 | 100 | 100 | 100 |
| RAI1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| RAI2 | 1.67 | 0.83 | 1.44 | 0 | 0 | 2.50 | 2.50 | 2.50 |
| ROC1 | 61.67 | 4.41 | 7.64 | 55.00 | 55.00 | 60.00 | 70.00 | 70.00 |
| ROC2 | 60.00 | 10.40 | 18.00 | 45.00 | 45.00 | 55.00 | 80.00 | 80.00 |
| SIL1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIL2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIL3 | 4.67 | 4.67 | 8.08 | 0 | 0 | 0 | 14.00 | 14.00 |
| SLG1 | 48.30 | 19.20 | 33.30 | 10.00 | 10.00 | 65.00 | 70.00 | 70.00 |
| WAC1 | 26.70 | 26.70 | 46.20 | 0 | 0 | 0 | 80.00 | 80.00 |
| WAC2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAK1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAK2 | 75.00 | 2.89 | 5.00 | 70.00 | 70.00 | 75.00 | 80.00 | 80.00 |
| WEE1 | 83.33 | 7.26 | 12.58 | 70.00 | 70.00 | 85.00 | 95.00 | 95.00 |
| WEE2 | 71.67 | 7.26 | 12.58 | 60.00 | 60.00 | 70.00 | 85.00 | 85.00 |
| WEK1 | 45.00 | 12.60 | 21.80 | 20.00 | 20.00 | 55.00 | 60.00 | 60.00 |
| WEK2 | 51.67 | 4.41 | 7.64 | 45.00 | 45.00 | 50.00 | 60.00 | 60.00 |

Appendix C Table 6. Summary statistics for *Sagittaria kurziana* percent cover during fall 2015. Refer to Table 2 for definitions of transect labels.

| TRANSECT | MEAN | SE | SD | MIN | 25 %ile | MEDIAN | 75 %ile | MAX |
|---|---|---|---|---|---|---|---|---|
| ALE1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ALE2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| GUM1 | 41.70 | 14.20 | 24.70 | 25.00 | 25.00 | 30.00 | 70.00 | 70.00 |
| GUM2 | 40.00 | 25.20 | 43.60 | 10.00 | 10.00 | 20.00 | 90.00 | 90.00 |
| ICH1 | 95.33 | 1.86 | 3.21 | 93.00 | 93.00 | 94.00 | 99.00 | 99.00 |
| ICH2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| JUN1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| JUN2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| RAI1 | 91.00 | 5.57 | 9.64 | 80.00 | 80.00 | 95.00 | 98.00 | 98.00 |
| RAI2 | 48.30 | 24.60 | 42.50 | 0 | 0 | 65.00 | 80.00 | 80.00 |
| ROC1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ROC2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIL1 | 38.70 | 21.60 | 37.40 | 10.00 | 10.00 | 25.00 | 81.00 | 81.00 |
| SIL2 | 77.67 | 1.45 | 2.52 | 75.00 | 75.00 | 78.00 | 80.00 | 80.00 |
| SIL3 | 48.67 | 4.67 | 8.08 | 40.00 | 40.00 | 50.00 | 56.00 | 56.00 |
| SLG1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAC1 | 43.30 | 23.30 | 40.40 | 0 | 0 | 50.00 | 80.00 | 80.00 |
| WAC2 | 90.00 | 2.89 | 5.00 | 85.00 | 85.00 | 90.00 | 95.00 | 95.00 |
| WAK1 | 48.30 | 14.20 | 24.70 | 20.00 | 20.00 | 60.00 | 65.00 | 65.00 |
| WAK2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEE1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEE2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEK1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEK2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Appendix C Table 7. Summary statistics for *Hydrilla verticillata* percent cover during fall 2015. Refer to Table 2 for definitions of transect labels.

| TRANSECT | MEAN | SE | SD | MIN | 25 %ile | MEDIAN | 75 %ile | MAX |
|---|---|---|---|---|---|---|---|---|
| ALE1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ALE2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| GUM1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| GUM2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ICH1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ICH2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| JUN1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| JUN2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| RAI1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| RAI2 | 4.17 | 3.00 | 5.20 | 0 | 0 | 2.50 | 10.00 | 10.00 |
| ROC1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ROC2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIL1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIL2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIL3 | 0.83 | 0.83 | 1.44 | 0 | 0 | 0 | 2.50 | 2.50 |
| SLG1 | 33.30 | 24.00 | 41.60 | 0 | 0 | 20.00 | 80.00 | 80.00 |
| WAC1 | 1.67 | 0.83 | 1.44 | 0 | 0 | 2.50 | 2.50 | 2.50 |
| WAC2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAK1 | 0.83 | 0.83 | 1.44 | 0 | 0 | 0 | 2.50 | 2.50 |
| WAK2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEE1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEE2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEK1 | 3.33 | 1.67 | 2.89 | 0 | 0 | 5.00 | 5.00 | 5.00 |
| WEK2 | 0.83 | 0.83 | 1.44 | 0 | 0 | 0 | 2.50 | 2.50 |

Appendix C Table 8. Summary statistics for percent cover of other SAV macrophyte taxa during fall 2015. Refer to Table 2 for definitions of transect labels.

| TRANSECT | MEAN | SE | SD | MIN | 25 %ile | MEDIAN | 75 %ile | MAX |
|---|---|---|---|---|---|---|---|---|
| *Najas guadalupensis* | | | | | | | | |
| ALE1 | 26.70 | 26.70 | 46.20 | 0 | 0 | 0 | 80.00 | 80.00 |
| GUM2 | 20.00 | 20.00 | 34.60 | 0 | 0 | 0 | 60.00 | 60.00 |
| RAI2 | 4.17 | 3.00 | 5.20 | 0 | 0 | 2.50 | 10.00 | 10.00 |
| SIL3 | 0.83 | 0.83 | 1.44 | 0 | 0 | 0 | 2.50 | 2.50 |
| WAC1 | 1.67 | 0.83 | 1.44 | 0 | 0 | 2.50 | 2.50 | 2.50 |
| | | | | | | | | |
| *Potamogeton illinoensis* | | | | | | | | |
| WAC2 | 1.67 | 1.67 | 2.89 | 0 | 0 | 0 | 5.00 | 5.00 |
| | | | | | | | | |
| *Potamogeton pectinatus* | | | | | | | | |
| JUN2 | 25.00 | 25.00 | 43.30 | 0 | 0 | 0 | 75.00 | 75.00 |

Appendix C Table 9. Summary statistics for *Vallisneria americana* dry weight (g/$m^2$) during spring 2015. Refer to Table 2 for definitions of transect labels.

| TRANSECT | MEAN | SE | SD | MIN | 25 %ile | MEDIAN | 75 %ile | MAX |
|---|---|---|---|---|---|---|---|---|
| ALE1 | 98.4 | 51.4 | 89.1 | 0 | 0 | 121.9 | 173.4 | 173.4 |
| ALE2 | 193.2 | 53.9 | 93.4 | 115.6 | 115.6 | 167.2 | 296.9 | 296.9 |
| GUM1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| GUM2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ICH1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ICH2 | 272.4 | 93.7 | 162.3 | 143.8 | 143.8 | 218.8 | 454.7 | 454.7 |
| JUN1 | 8.8 | 3.9 | 6.7 | 2.4 | 2.4 | 8.03 | 15.8 | 15.8 |
| JUN2 | 92.2 | 92.2 | 159.7 | 0 | 0 | 0 | 276.6 | 276.6 |
| RAI1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| RAI2 | 59.3 | 57.9 | 100.2 | 0 | 0 | 2.8 | 175.0 | 175.0 |
| ROC1 | 316.0 | 114.0 | 198.0 | 128.0 | 128.0 | 297.0 | 522.0 | 522.0 |
| ROC2 | 576.0 | 260.0 | 451.0 | 216.0 | 216.0 | 430.0 | 1,081.0 | 1,081.0 |
| SIL1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIL2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIL3 | 75.5 | 72.4 | 125.4 | 0 | 0 | 6.2 | 220.3 | 220.3 |
| SLG1 | 140.1 | 18.5 | 32.1 | 103.1 | 103.1 | 156.3 | 160.9 | 160.9 |
| WAC1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAC2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAK1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAK2 | 163.0 | 115.0 | 199.0 | 0 | 0 | 105.0 | 384.0 | 384.0 |
| WEE1 | 224.5 | 62.8 | 108.7 | 159.4 | 159.4 | 164.1 | 350.0 | 350.0 |
| WEE2 | 78.1 | 17.3 | 29.9 | 43.8 | 43.8 | 92.2 | 98.4 | 98.4 |
| WEK1 | 604.0 | 232.0 | 402.0 | 330.0 | 330.0 | 417.0 | 1,066.0 | 1,066.0 |
| WEK2 | 355.2 | 24.4 | 42.2 | 314.1 | 314.1 | 353.1 | 398.4 | 398.4 |

Appendix C Table 10. Summary statistics for *Sagittaria kurziana* dry weight (g/m$^2$) during spring 2015. Refer to Table 2 for definitions of transect labels.

| TRANSECT | MEAN | SE | SD | MIN | 25 %ile | MEDIAN | 75 %ile | MAX |
|---|---|---|---|---|---|---|---|---|
| ALE1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ALE2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| GUM1 | 110.9 | 11.5 | 19.9 | 93.8 | 93.8 | 106.3 | 132.8 | 132.8 |
| GUM2 | 109.7 | 53.4 | 92.5 | 5.6 | 5.6 | 140.6 | 182.8 | 182.8 |
| ICH1 | 251.0 | 74.4 | 128.8 | 112.5 | 112.5 | 273.4 | 367.2 | 367.2 |
| ICH2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| JUN1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| JUN2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| RAI1 | 384.9 | 81.6 | 141.4 | 221.9 | 221.9 | 459.4 | 473.4 | 473.4 |
| RAI2 | 107.8 | 46.7 | 80.9 | 15.6 | 15.6 | 140.6 | 167.2 | 167.2 |
| ROC1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ROC2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIL1 | 914.0 | 207.0 | 359.0 | 616.0 | 616.0 | 814.0 | 1,313.0 | 1,313.0 |
| SIL2 | 466.7 | 90.5 | 156.7 | 329.7 | 329.7 | 432.8 | 637.5 | 637.5 |
| SIL3 | 281.8 | 81.4 | 140.9 | 135.9 | 135.9 | 292.2 | 417.2 | 417.2 |
| SLG1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAC1 | 386.5 | 18.6 | 32.3 | 364.1 | 364.1 | 371.9 | 423.4 | 423.4 |
| WAC2 | 231.0 | 104.0 | 181.0 | 41.0 | 41.0 | 252.0 | 400.0 | 400.0 |
| WAK1 | 149.5 | 90.0 | 155.8 | 0 | 0 | 137.5 | 310.9 | 310.9 |
| WAK2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEE1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEE2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEK1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEK2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Appendix C Table 11. Summary statistics for *Hydrilla verticillata* dry weight (g/m$^2$) during spring 2015. Refer to Table 2 for definitions of transect labels.

| TRANSECT | MEAN | SE | SD | MIN | 25 %ile | MEDIAN | 75 %ile | MAX |
|---|---|---|---|---|---|---|---|---|
| ALE1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ALE2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| GUM1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| GUM2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ICH1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ICH2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| JUN1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| JUN2 | 1.5 | 1.5 | 2.6 | 0 | 0 | 0 | 4.5 | 4.5 |
| RAI1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| RAI2 | 1.4 | 1.4 | 2.5 | 0 | 0 | 0 | 4.3 | 4.3 |
| ROC1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ROC2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIL1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIL2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIL3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SLG1 | 22.4 | 11.3 | 19.5 | 0 | 0 | 31.3 | 35.9 | 35.9 |
| WAC1 | 3.2 | 3.2 | 5.6 | 0 | 0 | 0 | 9.7 | 9.7 |
| WAC2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAK1 | 20.3 | 15.9 | 27.5 | 0 | 0 | 9.4 | 51.6 | 51.6 |
| WAK2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEE1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEE2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEK1 | 2.6 | 1.2 | 2.1 | 0.1 | 0.1 | 3.7 | 3.9 | 3.9 |
| WEK2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Appendix C Table 12. Summary statistics for dry weight (g/m$^2$) of other SAV macrophyte taxa during spring 2015. Refer to Table 2 for definitions of transect labels.

| TRANSECT | MEAN | SE | SD | MIN | 25 %ile | MEDIAN | 75 %ile | MAX |
|---|---|---|---|---|---|---|---|---|
| *Ceratophyllum demersum* | | | | | | | | |
| GUM1 | 1.3 | 1.3 | 2.3 | 0 | 0 | 0 | 4.0 | 4.0 |
| | | | | | | | | |
| *Chara* sp. | | | | | | | | |
| WAK2 | 1.6 | 1.6 | 2.7 | 0 | 0 | 0 | 4.7 | 4.7 |
| | | | | | | | | |
| *Najas guadalupensis* | | | | | | | | |
| ALE1 | 8.8 | 8.8 | 15.3 | 0 | 0 | 0 | 26.5 | 26.5 |
| WAK2 | 21.9 | 21.9 | 37.9 | 0 | 0 | 0 | 65.6 | 65.6 |
| WEK1 | 4.1 | 1.8 | 3.1 | 0.9 | 0.9 | 4.1 | 7.2 | 7.2 |
| | | | | | | | | |
| *Potamogeton illinoensis* | | | | | | | | |
| WAC2 | 322.0 | 322.0 | 558.0 | 0 | 0 | 0 | 967.0 | 967.0 |
| | | | | | | | | |
| *Potamogeton pectinatus* | | | | | | | | |
| JUN2 | 172.4 | 92.3 | 159.8 | 0 | 0 | 201.6 | 315.6 | 315.6 |

Appendix C Table 13. Summary statistics for *Vallisneria americana* dry weight (g/m$^2$) during fall 2015. Refer to Table 2 for definitions of transect labels.

| TRANSECT | MEAN | SE | SD | MIN | 25 %ile | MEDIAN | 75 %ile | MAX |
|---|---|---|---|---|---|---|---|---|
| ALE1 | 257.0 | 129.0 | 223.0 | 0 | 0 | 377.0 | 395.0 | 395.0 |
| ALE2 | 462.0 | 80.8 | 139.9 | 378.1 | 378.1 | 384.4 | 623.4 | 623.4 |
| GUM1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| GUM2 | 14.6 | 7.3 | 12.6 | 0 | 0 | 21.9 | 21.9 | 21.9 |
| ICH1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ICH2 | 544.3 | 90.4 | 156.5 | 426.6 | 426.6 | 484.4 | 721.9 | 721.9 |
| JUN1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| JUN2 | 404.0 | 185.0 | 321.0 | 47.0 | 47.0 | 495.0 | 669.0 | 669.0 |
| RAI1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| RAI2 | 69.3 | 59.4 | 102.9 | 0 | 0 | 20.3 | 187.5 | 187.5 |
| ROC1 | 520.0 | 175.0 | 302.0 | 289.0 | 289.0 | 409.0 | 863.0 | 863.0 |
| ROC2 | 550.5 | 57.6 | 99.7 | 439.1 | 439.1 | 581.3 | 631.3 | 631.3 |
| SIL1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIL2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIL3 | 46.4 | 46.4 | 80.3 | 0 | 0 | 0 | 139.1 | 139.1 |
| SLG1 | 281.8 | 22.4 | 38.7 | 246.9 | 246.9 | 275.0 | 323.4 | 323.4 |
| WAC1 | 702.0 | 702.0 | 1,215.0 | 0 | 0 | 0 | 2,105.0 | 2,105.0 |
| WAC2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAK1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAK2 | 522.4 | 32.2 | 55.7 | 464.1 | 464.1 | 528.1 | 575.0 | 575.0 |
| WEE1 | 741.0 | 240.0 | 415.0 | 384.0 | 384.0 | 642.0 | 1,197.0 | 1,197.0 |
| WEE2 | 279.7 | 31.0 | 53.7 | 221.9 | 221.9 | 289.1 | 328.1 | 328.1 |
| WEK1 | 360.0 | 118.0 | 204.0 | 205.0 | 205.0 | 284.0 | 591.0 | 591.0 |
| WEK2 | 332.3 | 69.0 | 119.5 | 201.6 | 201.6 | 359.4 | 435.9 | 435.9 |

Appendix C Table 14. Summary statistics for *Sagittaria kurziana* dry weight (g/m$^2$) during fall 2015. Refer to Table 2 for definitions of transect labels.

| TRANSECT | MEAN | SE | SD | MIN | 25 %ile | MEDIAN | 75 %ile | MAX |
|---|---|---|---|---|---|---|---|---|
| ALE1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ALE2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| GUM1 | 126.6 | 23.7 | 41.0 | 82.8 | 82.8 | 132.8 | 164.1 | 164.1 |
| GUM2 | 114.1 | 49.6 | 85.9 | 28.1 | 28.1 | 114.1 | 200.0 | 200.0 |
| ICH1 | 533.0 | 133.0 | 231.0 | 328.0 | 328.0 | 488.0 | 783.0 | 783.0 |
| ICH2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| JUN1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| JUN2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| RAI1 | 368.2 | 71.1 | 123.1 | 275.0 | 275.0 | 321.9 | 507.8 | 507.8 |
| RAI2 | 169.3 | 84.7 | 146.7 | 0 | 0 | 248.4 | 259.4 | 259.4 |
| ROC1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ROC2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIL1 | 1,267.0 | 468.0 | 811.0 | 347.0 | 347.0 | 1,580.0 | 1,875.0 | 1,875.0 |
| SIL2 | 615.1 | 77.1 | 133.5 | 467.2 | 467.2 | 651.6 | 726.6 | 726.6 |
| SIL3 | 158.3 | 46.3 | 80.2 | 90.6 | 90.6 | 137.5 | 246.9 | 246.9 |
| SLG1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAC1 | 341.0 | 172.0 | 298.0 | 0 | 0 | 472.0 | 550.0 | 550.0 |
| WAC2 | 563.0 | 204.0 | 353.0 | 211.0 | 211.0 | 561.0 | 917.0 | 917.0 |
| WAK1 | 346.0 | 114.0 | 197.0 | 120.0 | 120.0 | 430.0 | 488.0 | 488.0 |
| WAK2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEE1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEE2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEK1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEK2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Appendix C Table 15. Summary statistics for *Hydrilla verticillata* dry weight (g/m$^2$) during fall 2015. Refer to Table 2 for definitions of transect labels.

| TRANSECT | MEAN | SE | SD | MIN | 25 %ile | MEDIAN | 75 %ile | MAX |
|---|---|---|---|---|---|---|---|---|
| ALE1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ALE2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| GUM1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| GUM2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ICH1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ICH2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| JUN1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| JUN2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| RAI1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| RAI2 | 2.8 | 2.5 | 4.4 | 0 | 0 | 0.6 | 7.9 | 7.9 |
| ROC1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ROC2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIL1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIL2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SIL3 | 1.1 | 1.1 | 1.9 | 0 | 0 | 0 | 3.4 | 3.4 |
| SLG1 | 47.9 | 27.5 | 47.7 | 0 | 0 | 48.4 | 95.3 | 95.3 |
| WAC1 | 6.1 | 3.1 | 5.4 | 0 | 0 | 7.8 | 10.4 | 10.4 |
| WAC2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WAK1 | 7.3 | 7.3 | 12.6 | 0 | 0 | 0 | 21.9 | 21.9 |
| WAK2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEE1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEE2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEK1 | 4.1 | 2.8 | 4.8 | 0 | 0 | 3.0 | 9.4 | 9.4 |
| WEK2 | 1.4 | 1.4 | 2.4 | 0 | 0 | 0 | 4.2 | 4.2 |

Appendix C Table 16. Summary statistics for dry weight (g/m$^2$) of other SAV macrophyte taxa during fall 2015. Refer to Table 2 for definitions of transect labels.

| TRANSECT | MEAN | SE | SD | MIN | 25 %ile | MEDIAN | 75 %ile | MAX |
|---|---|---|---|---|---|---|---|---|
| UNID Charophyte | | | | | | | | |
| SIL3 | 0.2 | 0.2 | 0.4 | 0 | 0 | 0 | 0.7 | 0.7 |
| | | | | | | | | |
| *Najas guadalupensis* | | | | | | | | |
| ALE1 | 13.0 | 13.0 | 22.6 | 0 | 0 | 0 | 39.1 | 39.1 |
| GUM2 | 3.7 | 3.7 | 6.3 | 0 | 0 | 0 | 10.9 | 10.9 |
| RAI2 | 2.3 | 1.8 | 3.1 | 0 | 0 | 1.0 | 5.8 | 5.8 |
| SIL3 | 1.1 | 1.1 | 2.0 | 0 | 0 | 0 | 3.4 | 3.4 |
| WAC1 | 0.8 | 0.6 | 1.0 | 0 | 0 | 0.5 | 1.9 | 1.9 |
| | | | | | | | | |
| *Potamogeton illinoensis* | | | | | | | | |
| WAC2 | 1.5 | 1.5 | 2.5 | 0 | 0 | 0 | 4.4 | 4.4 |
| | | | | | | | | |
| *Potamogeton pectinatus* | | | | | | | | |
| JUN2 | 192.0 | 192.0 | 332.0 | 0 | 0 | 0 | 575.0 | 575.0 |