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RELATIONSHIPS BETWEEN BENTHIC ALGAE AND BENTHIC MACROINVERTEBRATE COMMUNITIES IN FLORIDA SPRING-RUN STREAMS

ST. JOHNS RIVER
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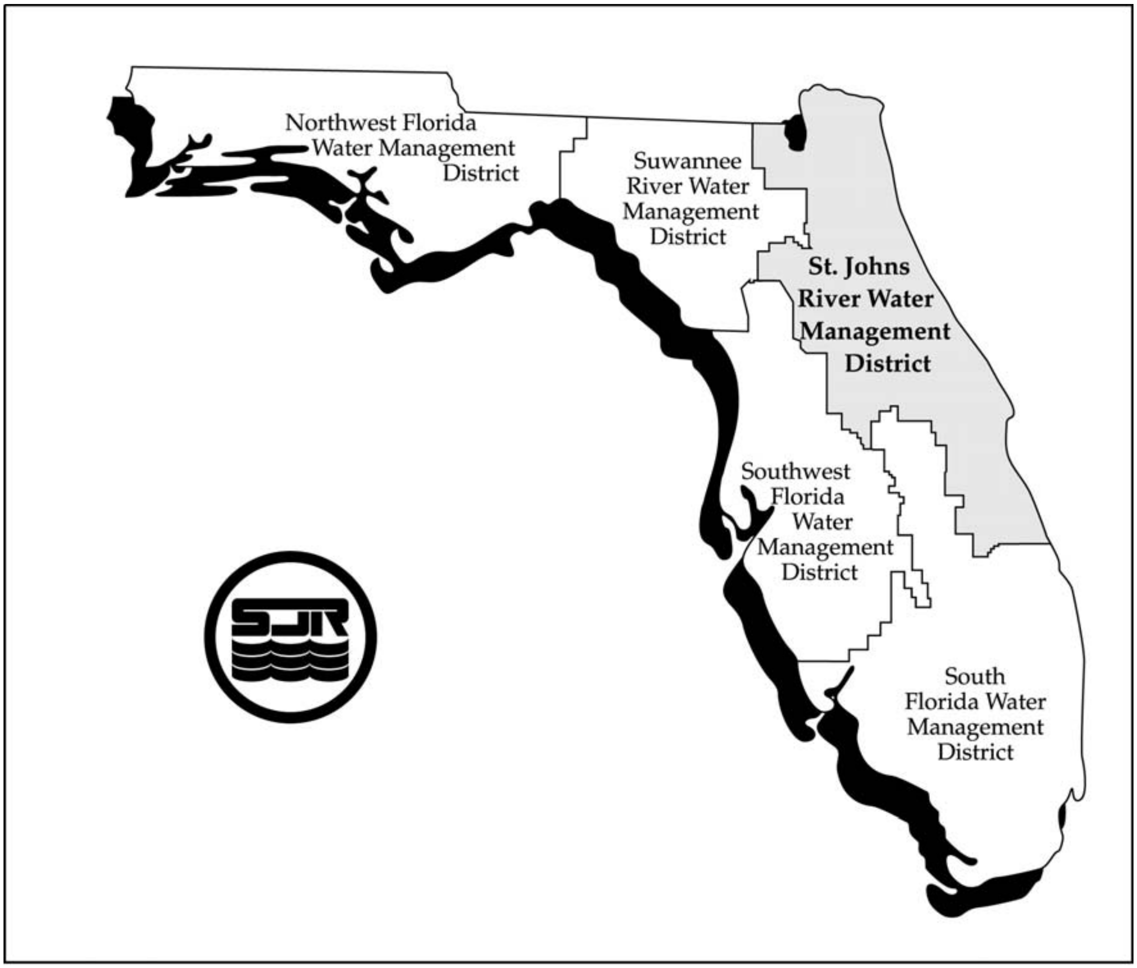
Palatka, Florida

2009



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ABSTRACT

Elevated levels of nutrients in Florida springs and spring-run streams, principally nitrate, are becoming increasingly linked to the proliferation of benthic algal populations. Changes include increased algal abundance (as biomass, cell density, and/or chlorophyll a) and alterations in algal community structure, from a microalgal/diatom-dominated community to one dominated more by filamentous macroalgae (including blue-green, green and yellow-green algae). To date, there has not been any examination of how these changes in algal communities may affect the fauna of springs and spring-run streams. Existing data from published studies of benthic algae and macroinvertebrates were analyzed to evaluate the existence of relationships. Increased algal abundance was associated with “positive” (increased invertebrate taxa richness and abundance) and “negative” changes (decreased evenness and diversity). Abundance of scraper taxa (those invertebrates that feed on algae) generally increases with algal abundance, as might be predicted. Significant reductions in taxa richness and Ephemeroptera/Plecoptera/Trichoptera (EPT) Scores and significantly increased contributions of % dominance with increased proportions of blue-green and green algae in the algal community suggest that changes in algal community structure from a periphyton/microalgal physiognomy to one dominated by filamentous macroalgae negatively affect macroinvertebrate community structure. These conclusions are preliminary, since the data used for this analysis were not collected with the intent to relate benthic algae and macroinvertebrate communities. Specific studies examining this question should be conducted.

INTRODUCTION

The karst geology of Florida is the basis for the widespread occurrence of springs in many areas of the state (Scott et al. 2004; Miller 1997). This geology results in a high degree of connection between surface- and groundwaters, with high potential for contamination of groundwater quality by land use activities in the area contributing groundwater to a spring, or “springshed” (after Copeland 2003). One of the principal pollutants of concern is nitrate-nitrite nitrogen (NO^3/NO^2-N, referred to in this paper as ‘nitrate’), which is the form of dissolved, oxidized nitrogen most commonly measured in surface- and groundwater monitoring programs. This constituent, highly mobile in aqueous solution, is one of the main forms of dissolved nitrogen available for uptake by plants and microbes in streams (Allan 1995).

Concentrations of nitrate in many Florida springs and the spring-run streams they create have been increasing over the past several decades (Scott et al. 2004; Figure 1). These elevated levels of nitrate, acting in conjunction with phosphorus, are being increasingly linked to proliferation of benthic algal populations and changes in algal community composition (Stevenson et al. 2004, 2007; Frazer et al., 2006; Mattson et al. 2006). In particular, changes in the algal community involve alteration from a microalgal/periphyton community, primarily

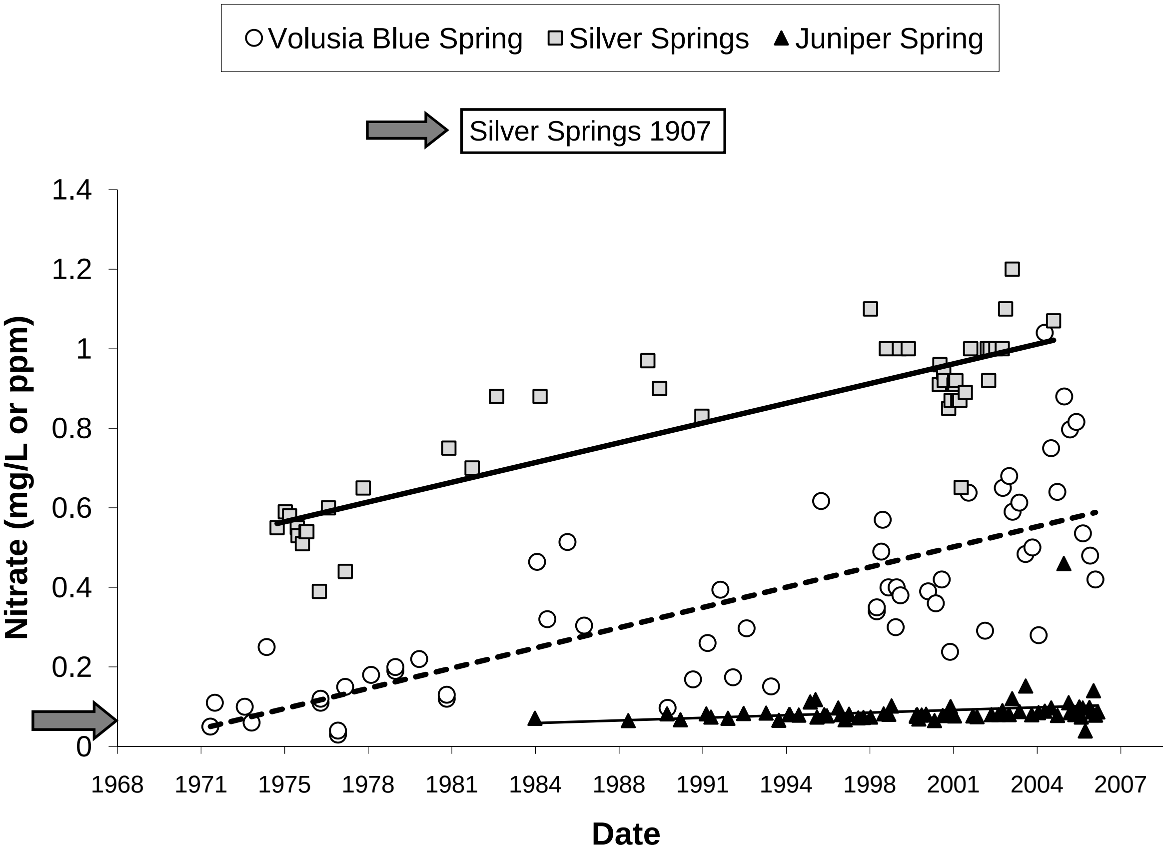


Figure 1. Trends in nitrate (NO_3/NO_2-N) levels in selected springs of the St. Johns River Water Management District, Fla. The arrow shows nitrate levels in Silver Springs in 1907 (from Collins and Howard 1928).

composed of diatoms (Bacillariophyceae), to a filamentous macroalgal community, dominated by species of blue-green algae (Cyanobacteria), green algae (Chlorophyta), and yellow-green algae (Xanthophyta).

While a number of efforts are still ongoing to better define the relationships between nutrients and algal communities in Florida spring-run streams, to date, no attempt has been made to examine how changes in spring-run algal communities may affect the fauna of these lotic ecosystems. In general, this subject has not received much attention in lotic ecology, although there has been extensive study of the impacts of benthic invertebrate herbivores on algal communities (Steinman 1996; chapter 8 in Allan 1995).

In this paper, I obtained existing data on benthic algal communities (taxa richness, abundance, biomass, and species composition) and similar data on benthic macroinvertebrate communities from studies conducted in springs and spring-run streams in Florida. I related these two sets of data using basic exploratory techniques (graphical and correlative statistical comparisons) to investigate whether relationships exist and discuss possible mechanisms for any identified relationships. The purpose of this effort was to conduct a preliminary analysis of the effects of increased benthic algal abundance and changes in algal community structure on benthic macroinvertebrate communities. From this preliminary analysis, I propose further questions that need to be investigated to better evaluate the impacts of nutrients on Florida spring ecosystems.

Effects of Benthic Algae on Benthic Macroinvertebrates

Dudley et al. (1986) indicate that effects of algae may be “positive” (increasing measures of macroinvertebrate communities or populations with increasing algae) or “negative” (decreasing macroinvertebrate community/population measures with increasing algae). Maasri et al. (2008) showed that algal abundance (as ash-free dry weight [AFDW] or chlorophyll a) and algal community structure (% diatoms, green algae, blue-green algae, etc.) are both important in explaining variation in chironomid community composition and the abundance of certain chironomid populations in Mediterranean streams.

Effects of benthic algae on macroinvertebrates may be summarized as follows.

Positive effects may include:

- Increased habitat structure (attachment space, predation refuges, etc.)
- Increased food resources (epiphytes or macroalgae; filamentous algal mats trap additional fine particulate organic matter)

Negative effects may include:

- Disruption of habitat (smothering); competition for space with invertebrates
- Interference with feeding or other behavior (direct physical effects; alteration of current flow patterns)
- Water quality changes (reduced dissolved oxygen [DO]; increased variation in water quality)
- Production of toxins (Cyanobacteria)

STREAM LITERATURE STUDIES

As noted above, there is extensive literature on the impacts of benthic invertebrate grazers on benthic algal communities, but very few studies looking at the opposite interaction: how changes in benthic algae affect invertebrate community characteristics. The main studies I found are summarized below.

Dudley et al. (1986) conducted manipulative studies in Rattlesnake Creek, California, examining how growth of the green alga *Cladophora glomerata* and the blue-green alga *Nostoc* sp. (both filamentous macroalgae) influence benthic macroinvertebrate populations. Experiments were conducted on the surface of a rock/concrete bridge structure in the stream to provide a uniform substrate. Algae was removed at various times of the year from defined areas of substrate, and the invertebrate communities that developed on the cleared areas (which were kept clear by removing newly colonizing algae) were compared with those on uncleared control plots. Both positive (increasing) and negative (decreasing) effects were observed. At a community level, the presence of macroalgae resulted in increased benthic invertebrate taxa richness and abundance. Three types of effects were identified at the level of species-specific macroinvertebrate populations:

(1) Negative effects on selected taxa (*Blepharicera* spp., large *Simulium* larvae) due to competition for space with algae. Decreased abundance of the affected invertebrate taxa was the main result.

(2) Positive effects on selected taxa (various caddisfly taxa, *Rheotanytarsus* spp.) due to the creation of additional structural habitat by filamentous algae. Increased abundance of invertebrate taxa resulted here.

(3) Positive effects on selected taxa (baetid mayflies, various chironomid taxa) due to a combination of additional habitat and food resources (either the macroalgae or attached epiphytes).

Power (1990) conducted manipulative studies in the Eel River, California, examining the differences between benthic turfs and floating mats of algae as habitat for stream macroinvertebrates. Her study stream was dominated by dense growths of the green alga *Cladophora glomerata* during the summer. Using clumps of floating, pre-cleaned (of invertebrates) algae attached to strings and paired with similar clumps affixed to the stream bottom, she examined differences in colonization and predation rates on stream macroinvertebrates, as well as macroinvertebrate sampling in existing, natural benthic turfs and floating mats of *Cladophora* in the study stream. Larval chironomids were 15–16 times more susceptible to fish predation in benthic algal turfs versus floating mats. Emergence of adult insects was significantly greater in floating mats. Differences were attributable to the protective habitat and additional food resources (denser epiphytic diatom growth) in floating mats versus turfs, and foraging behavioral preferences of the dominant fish predators. One observation I noted from her discussion is that she indicates that the dominant macroinvertebrates using the mats were chironomid larvae (principally *Pseudochironomus* spp.), which could tolerate the more widely varying temperature, pH, and DO conditions which occur in the algal mats. Less tolerant taxa such as stoneflies and mayflies were “uncommon” in the mats.

Maasri et al. (2008) evaluated the effects of nutrient enrichment and algal community changes on the benthic chironomid fauna in a Mediterranean stream. Three reaches were sampled, representing natural background, moderate nutrient enrichment, and high nutrient enrichment. Stones were collected from riffle habitats in each reach, and epilithon and chironomid abundance and community composition were analyzed. Algal cell density and biovolume were significantly higher in the most enriched reach. Diatom, green algal, and blue-green algal cell densities were highest in the most enriched reach. Significant positive correlations were found between algal cell density and biovolume and total chironomid abundance. Densities of the midge *Eukiefferiella claripennis* were strongly and significantly correlated (positive) with densities of diatoms, red algae (Rhodophyceae) and blue-green algae. *Cricotopus bicinctus* density was positively correlated with densities of diatoms and red algae; *Thienemanniella* density was positively correlated with densities of green algae. Densities of midges in the genus *Diamesa* were positively correlated with blue-green algae but negatively correlated with green algae, and densities of *Micropsectra* sp. were negatively correlated with densities of green algae and red algae.

Koksvik and Reinertsen (2008) sampled benthic algae and macroinvertebrates in the Alta River in Norway. Algae and invertebrates were collected using Surber samplers in winter. Benthic algal biomass exhibited a significant decline over an 8-year period at two sites that remained ice-free in winter. Concurrent with this trend, total benthic macroinvertebrate density declined significantly, and the correlation of mean invertebrate density and biomass with mean algal biomass was statistically significant. Chironomids made up the bulk of the relative abundance (69–86%), with Ephemeroptera and Trichoptera accounting for much of the remainder. The decline in total macroinvertebrate density was accompanied by shifts in relative abundance. Chironomids accounted for a lower fraction of relative abundance in the community during the latter part of the sampling period, when algal biomass was lowest. Ephemeroptera, Trichoptera, and Plecoptera all increased in relative abundance during this same period.

DATA SOURCES

Data used in the analyses in this paper were obtained from existing studies conducted in various springs and spring-run streams in Florida. Most of these were in the gray literature, consisting of government agency reports. Very little of this information has been published in the refereed literature.

Ichetucknee River—PBSJ. The PBSJ Corp. (2003) conducted a one-time sampling of submerged aquatic vegetation (SAV), epiphytes, and associated macroinvertebrate communities in April 2003 in the Ichetucknee River, a springfed tributary of the Santa Fe River in north-central Florida. They sampled SAV biomass in 0.25 square-meter (m^2) quadrats at 10 sites along the length of the river within Ichetucknee Springs State Park. At these 10 sites, epiphyte abundance was quantified on SAV by harvesting a subsample of the most abundant SAV species at a site (determined by field sampling). The samples were stored in bottles (in deionized water and kept chilled) and analyzed in the laboratory by using the method of Canfield and Hoyer (1988), that is, vigorously shaking each SAV sample in the sample bottle and decanting the resulting slurry. The process was repeated two additional times (for a total of three) and a predetermined subsample of the decanted supernatant was filtered through a Gelman-type glass fiber filter and subsequently analyzed for chlorophyll a. Epiphyte abundance was expressed as milligrams (mg) chlorophyll a per gram (/g) wet weight of host macrophyte.

Macroinvertebrates associated with SAV were sampled at the same 10 sites as SAV biomass and epiphytes by using a plankton net to enclose an area of SAV, which was then clipped at the sediment surface and rinsed into the net. All collected material (SAV and any material washed off and retained in the net) was preserved in 10% formalin solution. In the lab, SAV leaves in each sample were rinsed to remove macroinvertebrates, and all retained material was examined for additional invertebrates. Samples were sorted, and most major taxa of invertebrates were removed and stored in ethanol for subsequent identification and enumeration. Due to high abundance of oligochaetes and chironomids, a subsampling method was used for these groups, consisting of a modification of the technique used in the Florida Department of Environmental Protection (FDEP) Stream Bioassessment Program (Barbour et al. 1996): collected material with invertebrates was spread on a gridded pan, and individual grids were randomly selected and the invertebrates within the grid removed until a sample of 100 individual animals was counted. A correction factor was applied to these data to “scale up” the count of chironomids and oligochaetes to the entire sample.

Ichetucknee River—Steigerwalt. Steigerwalt (2005) sampled periphyton and macroinvertebrates at 24 sites on submerged wood (snag) habitat in the Ichetucknee River once in May/June 2004. Similar to PBSJ (above), her study was confined to the stretch of the river within Ichetucknee Springs State Park. Snags were collected by enclosing a piece of submerged wood in a plastic bag, sawing off the wood at the bag opening, and sealing the collected wood in the bag. Samples were preserved chilled and returned to the lab for analysis.

Periphyton was quantified by scraping algae from snags and obtaining wet weight. Dry weight was determined on a subsample of periphyton for determination of total periphyton dry weight on the snag sample. All macroinvertebrates were removed/sorted from the snag, identified and enumerated.

Wekiva River—FWCC. Staff with the Florida Fish and Wildlife Conservation Commission (FWCC; Warren et al. 2000) sampled benthic macroinvertebrate communities on various natural habitats (emergent, floating, and submerged aquatic vegetation, snags, and bottom sediments) at nine sites in three segments of the Wekiva River (upper, middle, and lower) at two intervals in 1999; a low-flow period and a higher-flow period. Methods specific to each habitat type were used to collect samples, which were returned to the laboratory, and all invertebrates were sorted from the samples, identified, and enumerated. No epiphyte or periphytic algal data were collected in this study.

Wekiva River—GreenWater. GreenWater Labs (2005) sampled attached algal communities on various natural substrates (emergent and submerged vegetation, wood, and rock) at 14 sites in the Wekiva River in winter of 2004 and summer of 2005. Samples of substratum were collected and returned to the laboratory, where algae were removed, the areas cleaned were measured, and various analyses were conducted. Subsamples were examined to identify the algal species present. Algal abundance was determined in multiple ways: subsamples from each habitat were analyzed for chlorophyll a

(mg/m^3), cell density (# $cells/cm^2$), ash-free dry weight (AFDW g/m^2), and biovolume ($\mu m^3/cm^2$). Biovolume data were not used in this analysis.

The invertebrate data of Warren et al. (2000) were compared with the algal data of GreenWater Labs (2005) by comparing the data from cognate or nearby stations sampled in each separate study. Geographic coordinates (latitude/longitude) for the study sites from each project were compared, and sites with similar locations were selected for analysis and comparison. The average distance between similar sites (141–1922 meters [m]) was 932 m. Low- and high-flow data from the invertebrate study and winter and summer data from the algal study were combined and compared.

Statewide—FDEP. Macroinvertebrate and algal data from the statewide stream bioassessment program of the Florida Department of Environmental Protection were obtained for springs and spring-run streams. The sampling period was from October 2000 to July 2006. Data were typically collected twice per year from each spring, although some were sampled once per year. The data were obtained from FDEP data files courtesy of the bioassessment program staff. A total of 14 spring-run streams from throughout the state were used in this analysis. Macroinvertebrate total taxa richness, Stream Condition Index (SCI) Score, Ephemeroptera/Plecoptera/Tricoptera (EPT) Score, and % dominance were used for the analysis. Benthic algae were sampled from various natural substrata in the spring runs; data reported were percent (by cell density) Cyanobacteria (blue-green algae), Chlorophyta (green algae), and Bacillariophyceae (diatoms) in the periphyton community.

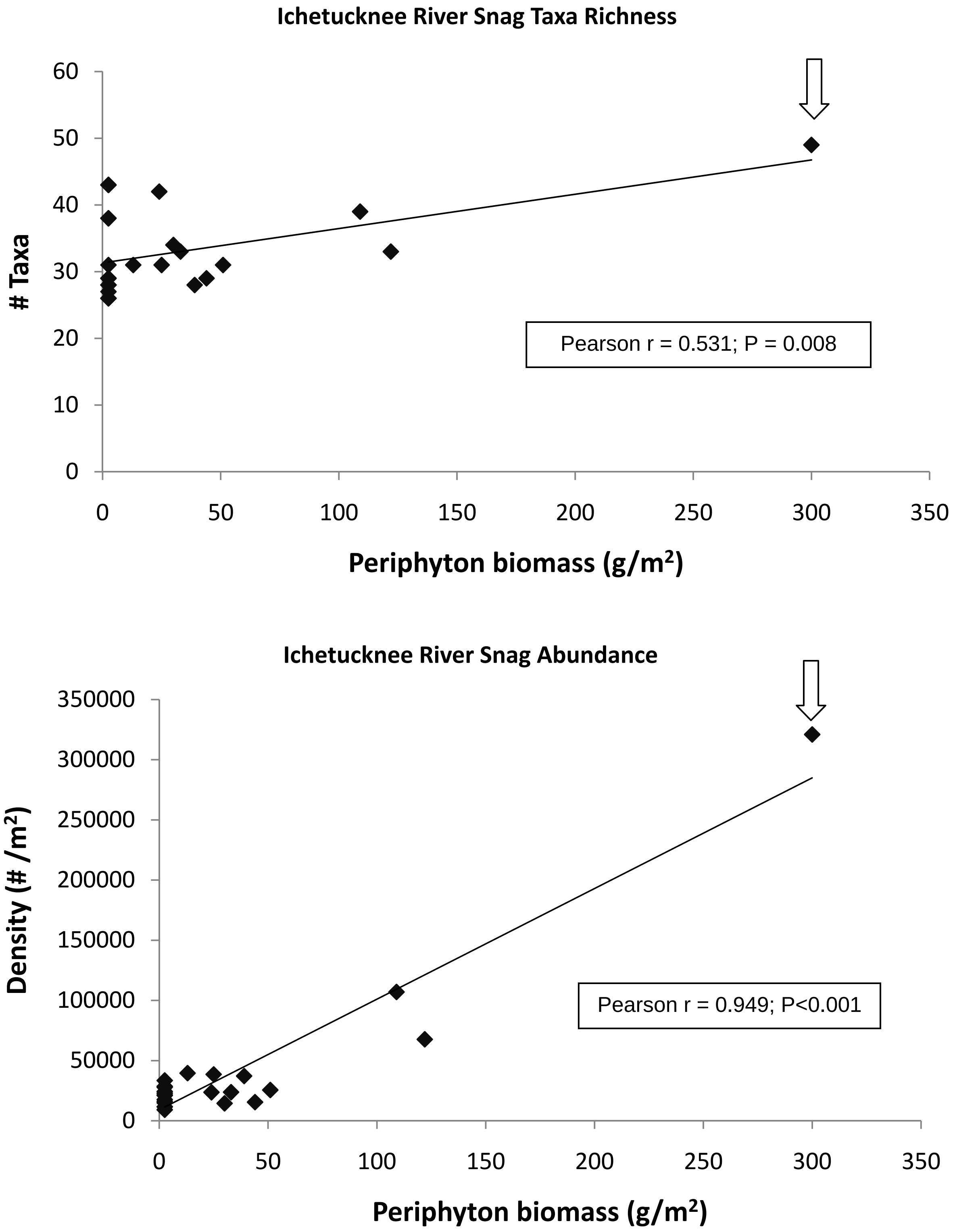
Statewide—UF. Researchers with University of Florida (UF; Canfield and Hoyer 1988) sampled epiphytic algae and drift macroinvertebrates in a number of stream systems in north and central Florida. Their data from spring-run streams (the lower Little Wekiva River, Alexander Spring Creek, Ichetucknee River, Rock Springs Run, and the Wekiva River) were extracted and analyzed. They collected epiphytes using the methodology described above for Ichetucknee River–PBSJ. Epiphyte abundance was expressed as: mg chlorophyll a/m^2 host plant. Macroinvertebrates were collected by using drift nets deployed in streams for 24 hours. Macroinvertebrate drift density (number of $individuals/m^3$) and biomass (g dry $weight/m^3$) were reported.

Analytical Methods. Graphical comparisons of various measures of algal abundance and community composition were made with invertebrate community metrics, with the algal data as the independent variable. Linear correlation analyses were used to assess the significance of the relationships observed, using SAS 9.1 or Minitab 15 documentation statistical software. In all cases, an α probability <0.05 was used as the threshold of statistical significance.

RESULTS AND DISCUSSION

Basic Community Measures. In the Ichetucknee River, invertebrate taxa richness and abundance were positively correlated with algal abundance (Figures 2 and 3) on both snags and SAV habitat. Correlations on snags were significant at $P < 0.05$ (labeled on the figures), but those on SAV were not statistically significant (although abundance was close to significant). Stronger correlations were seen between algal and invertebrate abundance than between algal abundance and invertebrate taxa richness on both snags and SAV. These results are consistent with those of Dudley et al. (1986), Maasri et al. (2008), and Koksvik and Reinertsen (2008), who found increased invertebrate taxa richness and/or abundance with increased amounts of algae. For the snag data, removal of the apparent outlier value renders the correlation between algal abundance and invertebrate taxa richness nonsignificant ($r = 0.158$; $P = 0.472$), while the correlation between invertebrate and algal abundance remains statistically significant.

Macroinvertebrate taxa richness in spring-run streams statewide (Figure 4; FDEP bioassessment data) was negatively correlated to % Cyanobacteria plus Chlorophyta in the

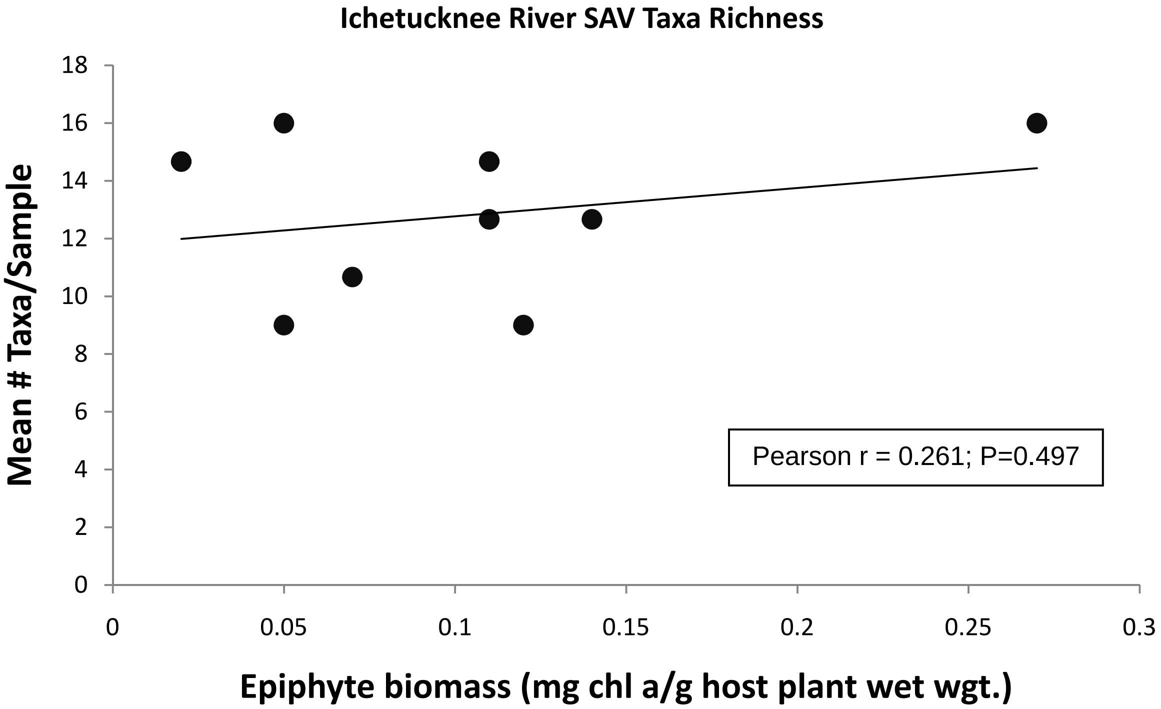

Ichetucknee River Snag Taxa Richness

Pearson r = 0.531; P = 0.008

Ichetucknee River Snag Abundance

Pearson r = 0.949; P<0.001

Figure 2. Benthic macroinvertebrate taxa richness and abundance in relation to periphyton biomass on snags in the Ichetucknee River (Steigerwalt 2005). Outlier values indicated with an arrow.



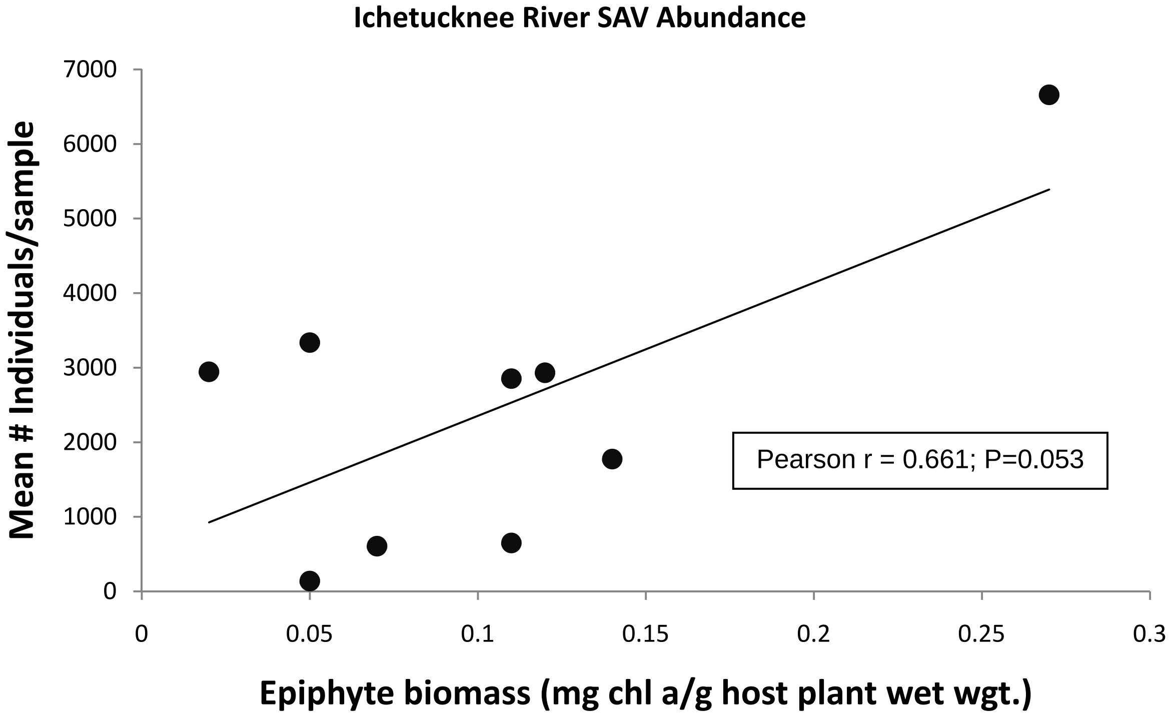


Figure 3. Benthic macroinvertebrate taxa richness and abundance on submerged aquatic vegetation (SAV) in the Ichetucknee River (PBSJ 2003)

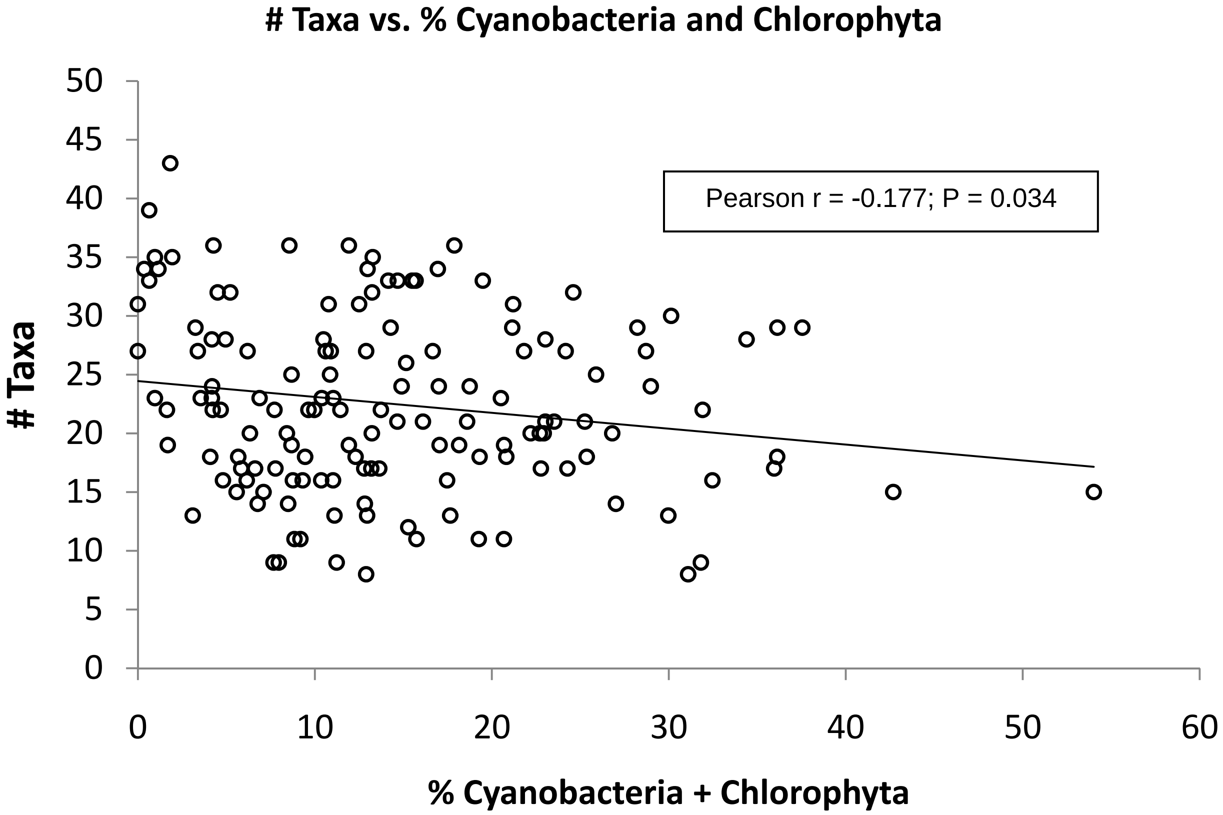


Figure 4. Macroinvertebrate taxa richness versus % Cyanobacteria and Chlorophyta in the periphyton community in 14 spring systems in Florida (Florida Department of Environmental Protection [FDEP] bioassessment data)

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periphyton (r = –0.177; P = 0.034). Dudley et al. (1986) found that the filamentous blue-green alga *Nostoc* sp. eventually replaces the green alga *Cladophora glomerata* in successional sequence. *Nostoc* provided structural habitat and had negative effects on some invertebrates (excluding them and/or their food resource from preferred substrate) but positive effects on others due to provision of additional habitat architecture. This alga did not support growths of epiphytic diatoms, as *Cladophora* did, and so increased food resources would not appear to be a factor here. Little is known about which invertebrates may consume filamentous blue-green algae directly. A recent study in Alabama (Camacho and Thacker 2006) found that the amphipod *Hyalella azteca* consumed both *Lyngbya wollei* (a blue-green alga) and *Rhizoclonium hieroglyphicum* (a green alga), but preferred the latter due to the presence of the mucilaginous sheath on the *Lyngbya*, which appeared to deter herbivory. This amphipod is abundant in the benthic invertebrate community in Florida spring-run streams.

Functional Feeding Group Measures. Because many freshwater invertebrates are omnivorous in food habits conventional descriptions of herbivores or carnivores are not applicable. Various modes of food acquisition have been described (Cummins and Merritt 1996) in the form of functional feeding groups (Table 1) which have been used to describe lotic invertebrate feeding habits, and have been used to assess ecosystem condition (Merritt et al. 1996). Steinman (1996) described a model of the

Table 1. Macroinvertebrate functional feeding groups commonly used in benthic community studies. Adapted from Cummins and Merritt (1996)

Functional Feeding Group	Dominant Food Types
Shredders	Coarse particulate organic matter (CPOM) as live and/or decaying plant tissue
Gathering collectors	Fine particulate organic material (FPOM) in sediments or settled on benthic surfaces; may include live or dead plant material or small fauna (microscopic or meifauna)
Filtering collectors	FPOM suspended in the water column and carried by currents; may include plant material (small decaying pieces or live algal cells) or zooplankton
Scrapers	Periphyton, including algae and other attached organisms (bacteria, protozoans, meiofauna)
Macrophyte piercers	Internal fluids of macrophytic algae or vascular plants
Predators	Live animals, either attack prey and engulf all or part or attack and pierce/suck body fluids (e.g., many Hemiptera)

possible relationships between algal community physiognomy and susceptibility/preference of different feeding groups (Figure 5). Most algal feeding invertebrates are in the scraper functional feeding group (FFG), with some in the shredder group. In general, as the algal community shifts from a microalgal/diatom dominated community to one dominated by more filamentous forms (which includes many blue-green, green, and yellow-green algae), the scraper feeding mode is less favored and other feeding modes (gathering collectors, shredders, piercers, etc.) may be more prevalent.

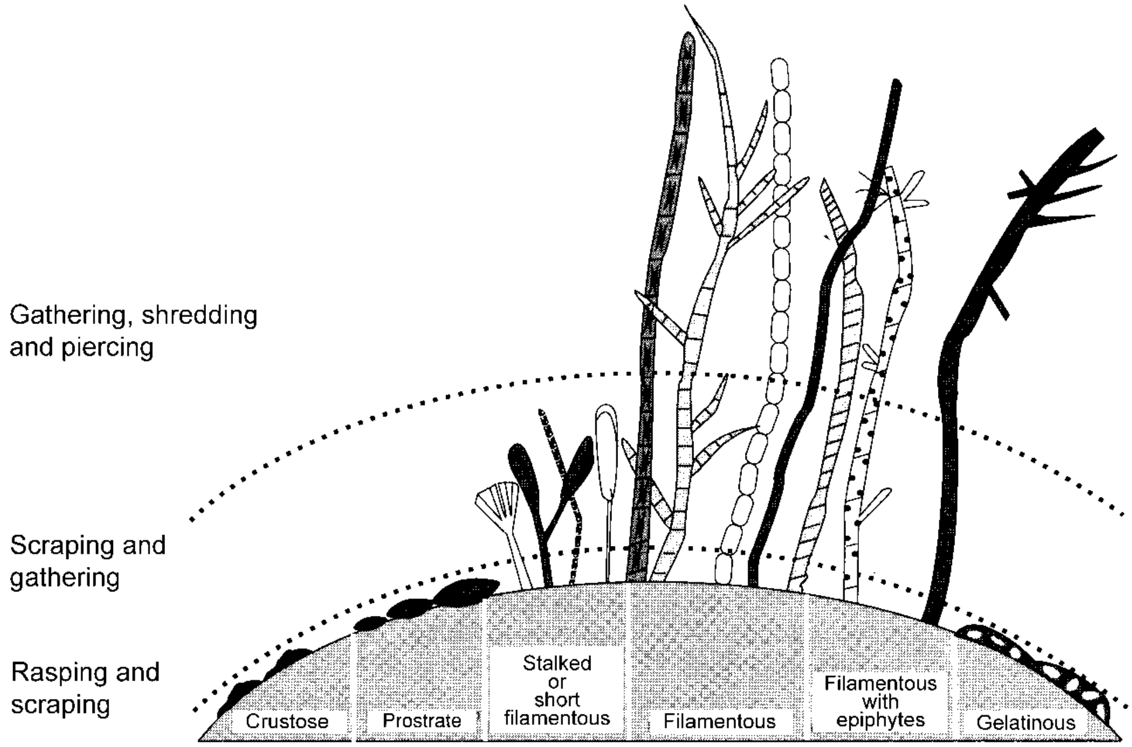


Figure 5. Attached algal community physiognomy in relation to preference by different macroinvertebrate functional feeding groups (adapted from Steinman 1996)

In the Ichetucknee River, relative abundance of scraper taxa on snag habitat was weakly positively correlated with periphyton biomass (Figure 6). This might be expected as algae would be their main food source (macroalgae and/or attached epiphytes). The correlation coefficient was actually quite strong (Pearson r = 0.874), but the relationship was not statistically significant, probably due to small sample size. Similar weak positive relationships were seen among periphyton biomass and abundance of filtering collectors, shredders, and predators. All were not statistically significant (Table 2). Gathering collectors exhibited a weak negative correlation with algal abundance (Table 2, Figure 6) and were also not significant.

An increase in shredders may reflect entrainment of course particulate organic matter in algal mats and filaments, or it may indicate that shredders are consuming macroalgae, as indicated in Figure 5. Increased predators may reflect an increase in prey resources on snags as reflected in higher invertebrate abundance with increasing amounts of algae (Figure 2). Dudley et al. (1986) noted that large hydropsychids and simuliids (filtering collectors) preferred macroalgal habitat, because it provided more secure attachment sites, which may explain the higher abundance of filtering collectors. The decline in abundance of gathering collectors is enigmatic, since it may be assumed that increased fine particulate organic matter would be available by being entrained in higher amounts of algae. Therefore, the apparent decline of this feeding guild may be due to algae interfering in some way with invertebrates that obtain their food via this mode.

In the Wekiva River, macroinvertebrate data collected in 1999 (Warren et al. 2000) were compared with benthic algae data collected in 2004 and 2005 (GreenWater Labs 2005). The percentage of scraper invertebrates in the community displayed weak positive or no correlation with various measures of algal abundance (chlorophyll a, AFDW biomass, and cell density; Figures 7 to 9 and Table 3). None of these relationships were statistically significant. Filtering collectors and predators displayed weak negative (nonsignificant) correlations with all measures of algal abundance (Figures 7 to 9 and Table 3). Gathering collectors and shredders displayed a mix (both positive and negative correlation), but again no statistically significant relationships (Figures 7 to 9 and Table 3). It appeared the strongest relationship was between % shredders and chlorophyll a and AFDW biomass (largest r coefficient and smallest P value – Table 3). This may indicate the shredders are responding to increased algal standing crop by feeding on algae. Of the three measures of algal abundance employed, the strongest correlations and lowest P values were seen for chlorophyll a.

Wekiva River results contrast somewhat from those seen on the Ichetucknee River. On the latter spring-run stream, most FFGs seemed to respond in a positive fashion (increased relative abundance) to increased algal standing crop, while in the Wekiva, some FFGs (filtering collectors and predators) appeared to respond with a negative trend, possibly indicating some type of “competition” among algae and macroinvertebrate communities. This may reflect differences in the types of algal communities on the two spring-run streams, but the data to examine this did not exist in the data sets used (the Ichetucknee study only collected algal biomass). Other reasons for the differences could be different hydrodynamics in the two spring-run stream systems (velocity and flow in the Ichetucknee are generally greater than in the Wekiva), or the difference could be a sampling artifact—the Ichetucknee algal and invertebrate data were collected concurrently, while the Wekiva algal and invertebrate data are from two different studies.

Composite Community Measures. Steigerwalt (2005) found that macroinvertebrate community diversity (Shannon-Wiener Index, H’) and community evenness (Pielou’s evenness, E) declined significantly with increasing algal biomass on Ichetucknee River snag habitat (Figure 10). Removal of the apparent outlier caused the relationship between algae and diversity to become nonsignificant (r = –0.368; P = 0.084), but the relationship with

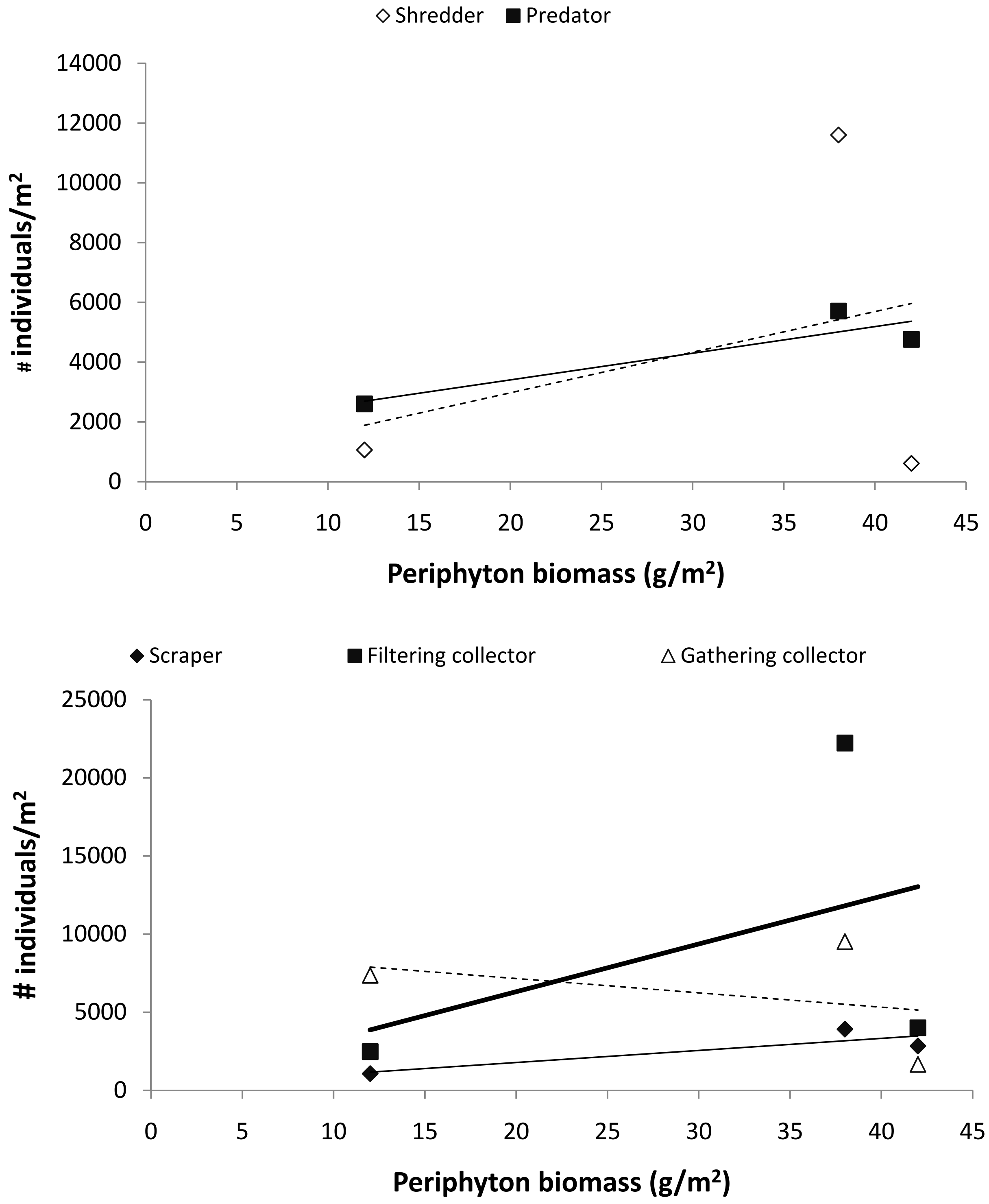
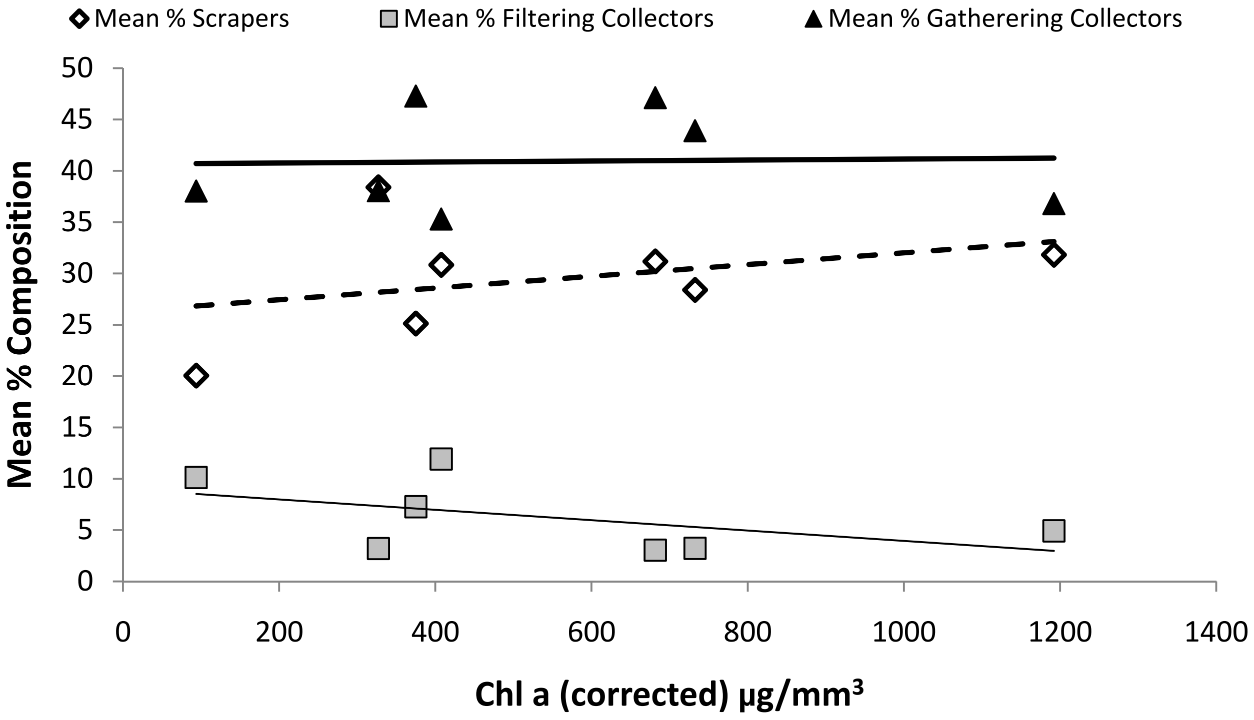


Figure 6. Total abundance of macroinvertebrate functional feeding groups versus periphyton biomass on snags in the Ichetucknee River (Steigerwalt 2005)



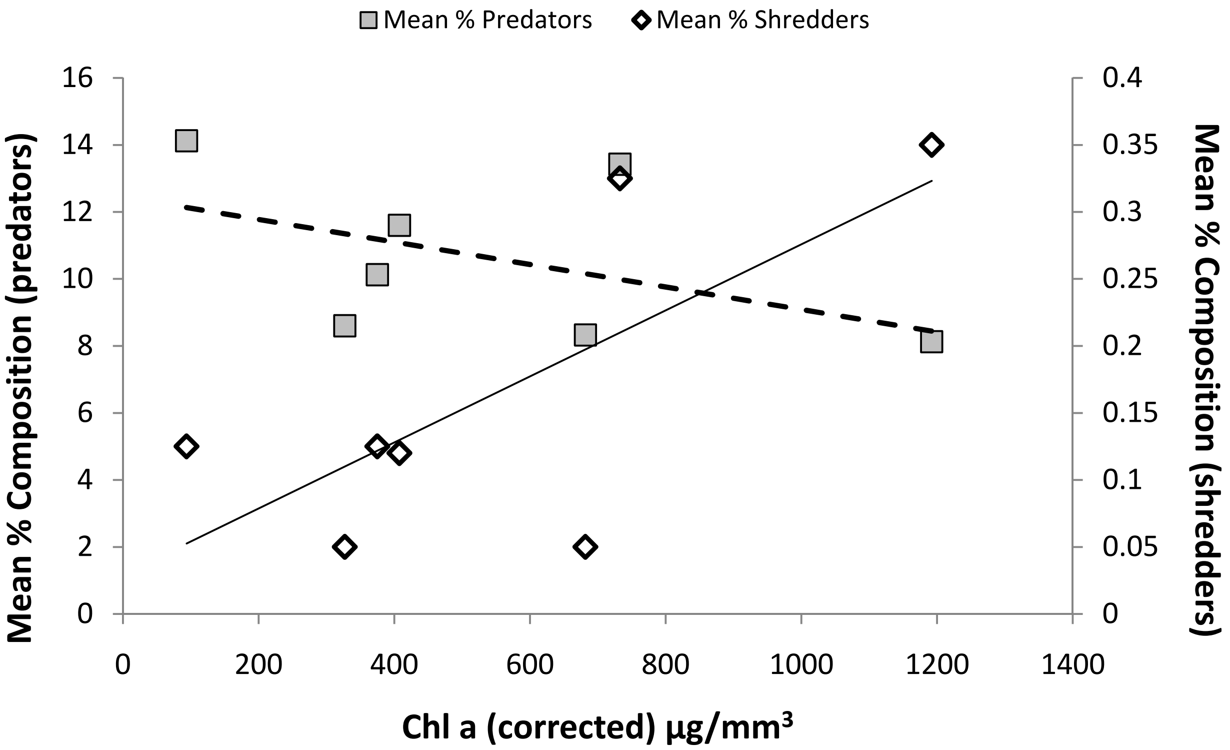
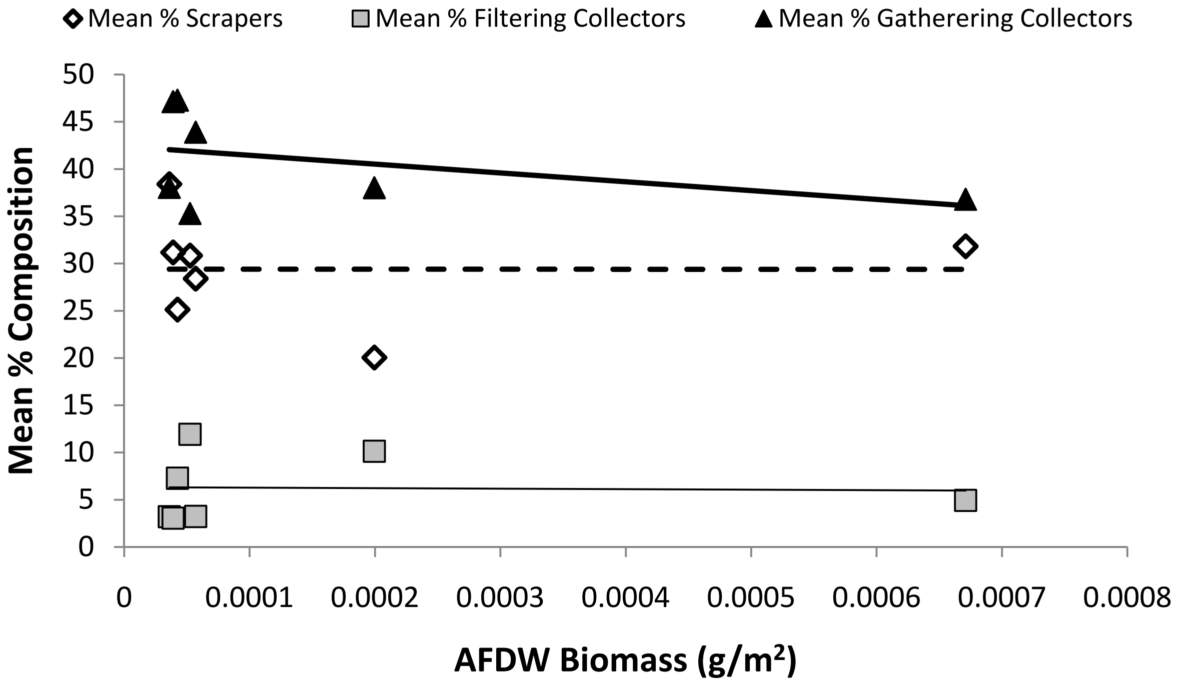


Figure 7. Mean % composition of macroinvertebrate functional feeding groups versus chlorophyll a in the Wekiva River (Warren et al. 2000 and GreenWater Labs 2005)



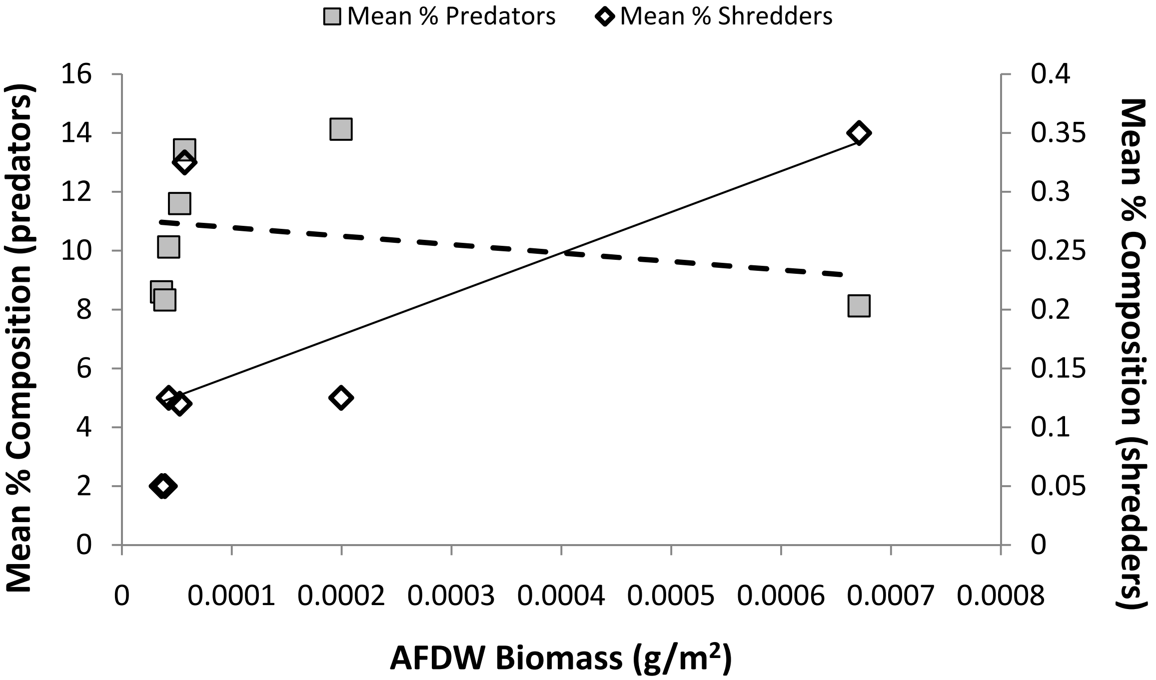
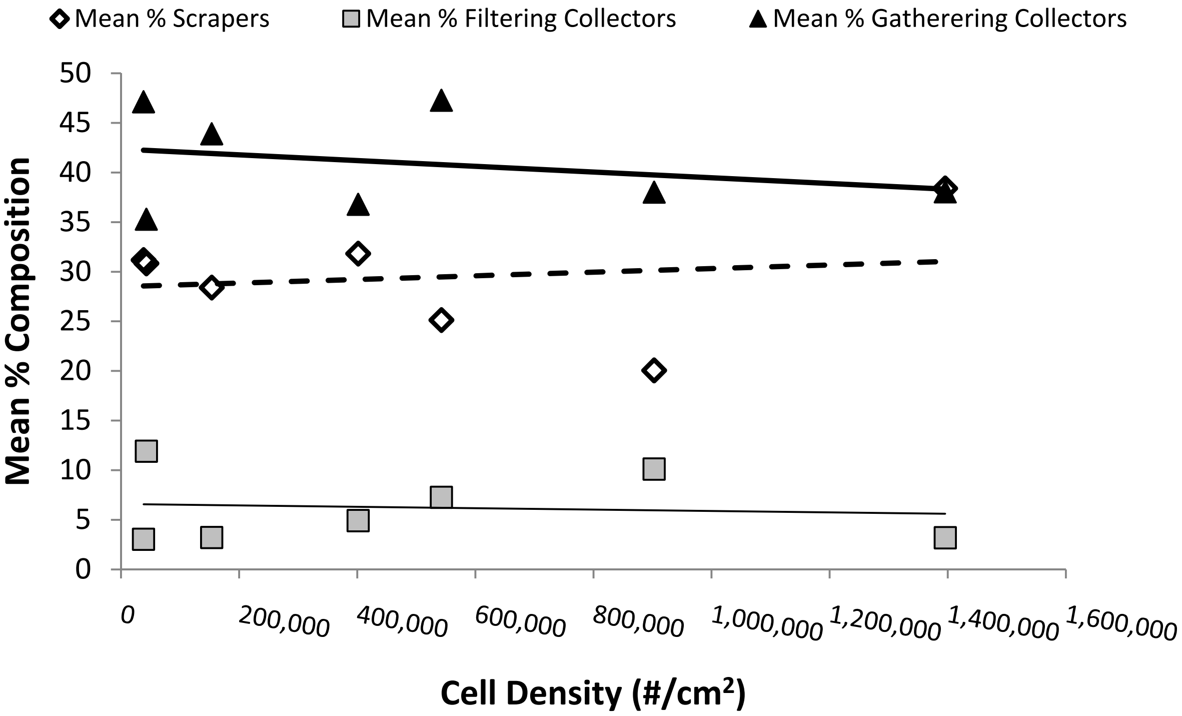


Figure 8. Mean % composition of invertebrate functional feeding groups versus algal biomass (ash-free dry weight) in the Wekiva River (Warren et al. 2000 and GreenWater Labs 2005)



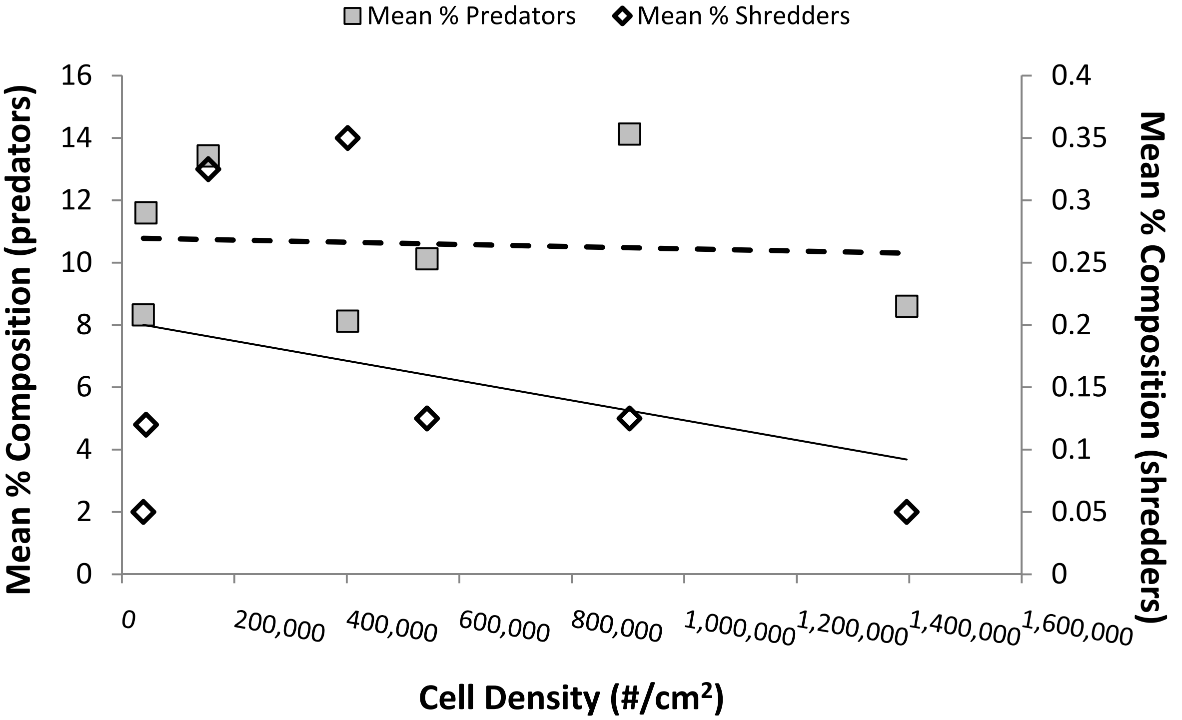
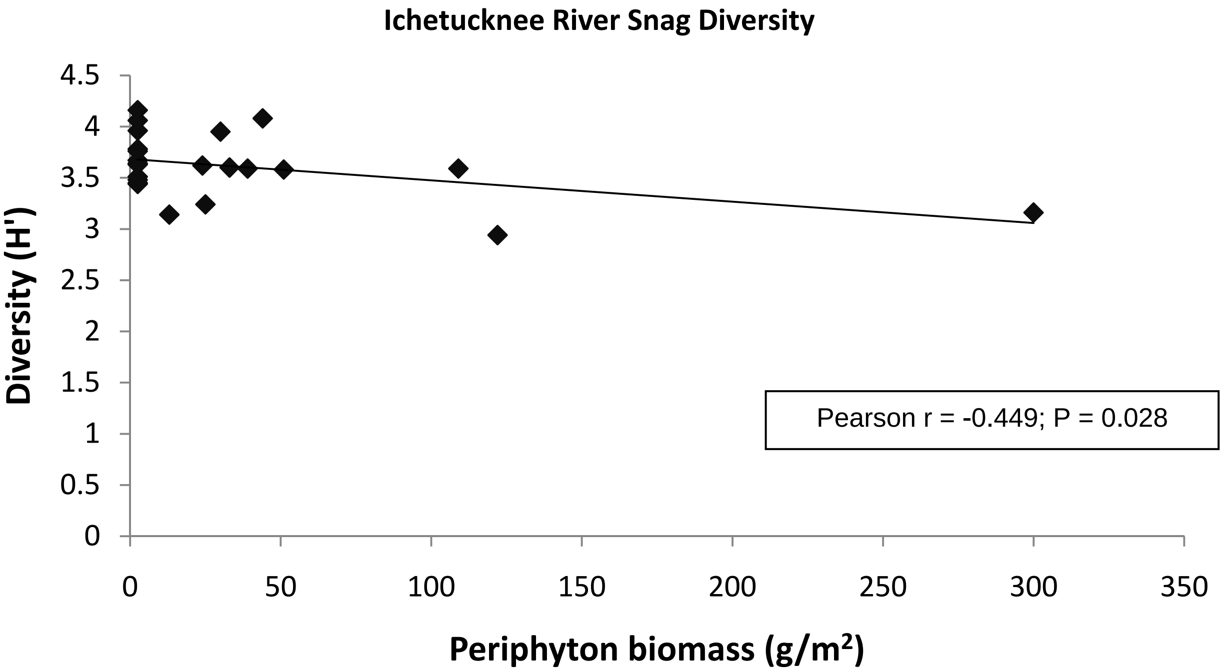


Figure 9. Mean % composition of invertebrate functional feeding groups versus algal cell density on the Wekiva River (Warren et al. 2000 and GreenWater Labs 2005)



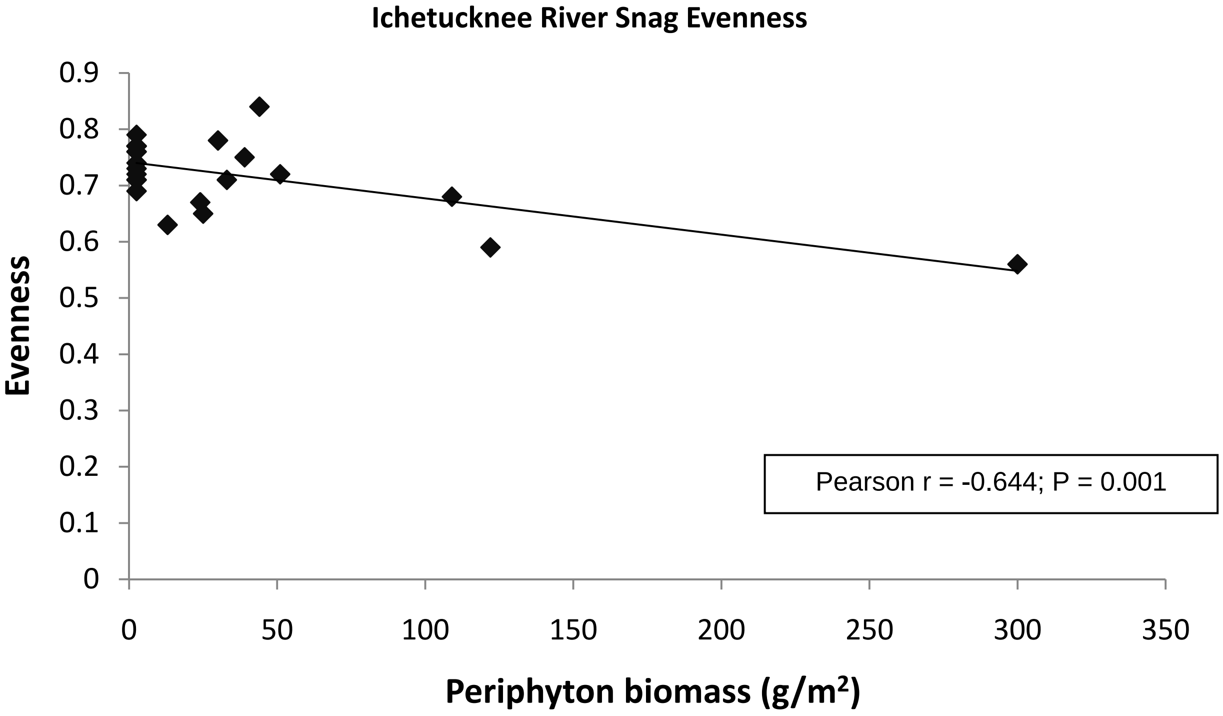


Figure 10. Macroinvertebrate community diversity (H') and evenness (E) versus periphyton biomass on snag habitat in the Ichetucknee River (Steigerwalt 2005)

Table 2. Summary of correlation analyses of functional feeding guild abundance in the Ichetucknee River versus periphyton abundance on snags (Steigerwalt 2005)

Functional Feeding Group	Sample size (n)	Pearson r	Probability
Scraper	3	0.874	0.323
Filtering collector	3	0.453	0.701
Gathering collector	3	–0.369	0.760
Shredder	3	0.356	0.768
Predator	3	0.911	0.271

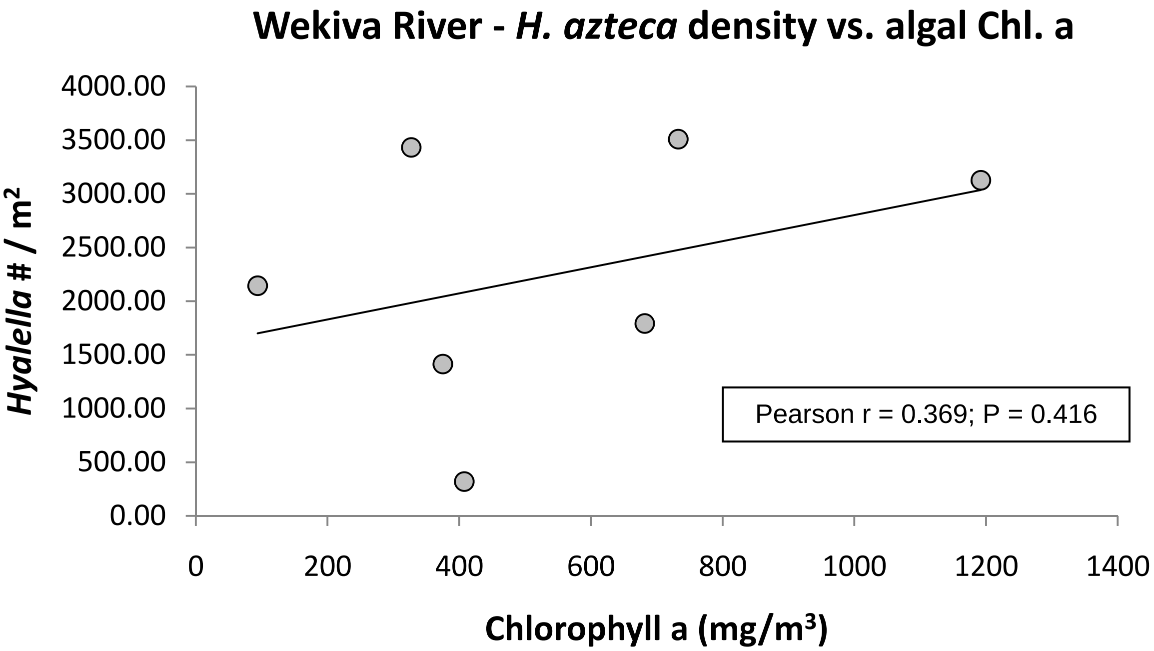
Table 3. Correlation coefficients (Pearson r) and associated probabilities comparing mean percent macroinvertebrate functional feeding groups (from Warren et al. 2000) with benthic algal abundance metrics (from Green Water Labs 2005)

Functional Feeding Group	Chlorophyll a (corrected) µg/mL	AFDW Biomass (g/m^2)	Cell Density ($\#/cm^2$)
% Scraper	r = 0.356; P = 0.433	r = -0.001; P = 0.998	r = 0.158; P = 0.735
% Filtering collector	r = -0.501; P = 0.253	r = -0.035; P = 0.941	r = -0.097; P = 0.836
% Gathering collector	r = 0.034; P = 0.943	r = -0.432; P = 0.333	r = -0.288; P = 0.531
% Shredder	r = 0.716; P = 0.071	r = 0.658; P = 0.108	r = -0.324; P = 0.478
% Predator	r = -0.486; P = 0.269	r = -0.271; P = 0.556	r = -0.071; P = 0.880

AFDW = ash-free dry weight
µg/mL = micrograms per milliliter
g/m^2 = grams per square meter
$\#/cm^2$ = pounds per square centimeter

evenness remained significant. Because her data indicate taxa richness increased with algal biomass, the decline in diversity is obviously due to the reduction in evenness. This indicates that increased algal biomass results in a less diverse benthic macroinvertebrate community due to increased dominance by a few invertebrate taxa better adapted to exploit the algae habitat. These could include the amphipod *Hyalella azteca* and baetid mayflies, both of which are observed in high abundance in mats of filamentous algae. Densities of *Hyalella* on the Wekiva River (Figure 11) exhibited a weak (statistically insignificant) positive correlation with algal abundance (chlorophyll a and AFWD biomass).

Preliminary studies of algae in the Wekiva River system (Mattson et al. 2006) and the stream literature in general indicate that increasing nutrient levels (particularly phosphorus, P) are associated with a shift in the benthic algal community, from one dominated by diatoms and other microalgae (forming thin “biofilms”) to an algal community dominated by filamentous Cyanobacteria (blue-green algae) and Chlorophyta (green algae), forming benthic and floating mats (Stelzer and Lamberti 2001; Chètelat et al. 1999; Stevenson 1997; Welch et al. 1988). The EPT Score is an index consisting of the sum of the mayfly, stonefly and caddisfly taxa present in a sample. Most taxa in these groups are more sensitive to water pollution and habitat alteration and are among the first to drop out of the invertebrate community with stream degradation. The EPT Score exhibited a significant negative relationship with increasing amounts of blue-green and green algae in the algal community (Figure 12: Pearson r = –0.202; P = 0.015). This suggests that the habitat and/or water quality changes resulting from shifts in algal community structure have a negative effect on benthic macroinvertebrate community diversity through loss of pollution-sensitive taxa such as mayflies, stoneflies, and caddisflies. This trend is related to the observations of Power (1990), who noted that mayflies and stoneflies were “uncommon” in filamentous



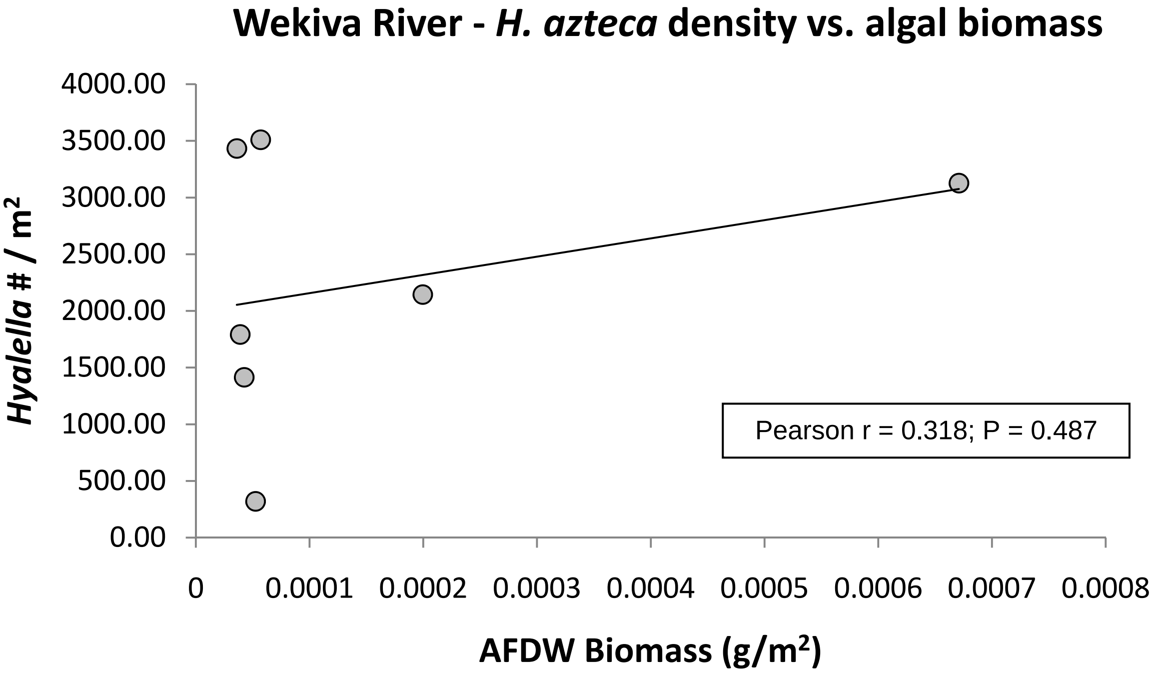


Figure 11. Density of the amphipod *Hyalella azteca* in relation to algal abundance (as chlorophyll a and ash-free dry weight [AFDW] biomass) on the Wekiva River (Warren et al. 2000 and GreenWater Labs 2005)

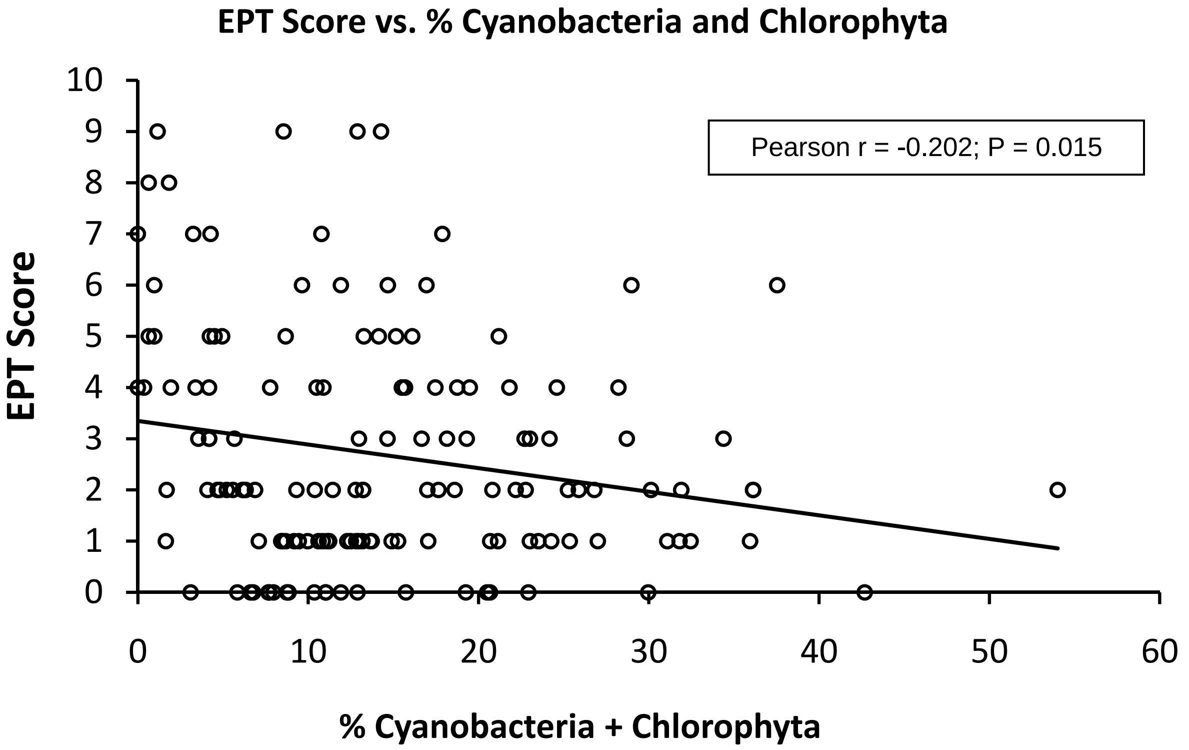


Figure 12. EPT Index (combined Ephemeroptera/Plecoptera/Trichoptera taxa richness) versus combined % Cyanobacteria (blue-green algae) and Chlorophyta (green algae) in the periphyton community for springs and spring-run streams statewide (FDEP bioassessment data)

algal mats and that chironomids seemed best adapted to exploit this habitat, possibly due to the widely varying water chemistry conditions (DO and pH) in the mats. This also is somewhat consistent with the data of Koksvik and Reinertsen (2008), who found increases in the relative abundance of EPT taxa with decreases in algal biomass.

In an opposite fashion, the EPT Score was significantly positively correlated with the % Bacillariophyceae (diatoms) in the periphyton community (Figure 13). Most of the algal-feeding scraper invertebrates in these groups in Florida appear to be adapted to feed mostly on microalgae (Merritt and Cummins 1996), and the correlation seen suggests an association between food resource quantity and quality and the relative abundance of EPT taxa, although the variance in the data indicates other factors are influencing the EPT Score.

The FDEP bioassessment data also indicated a significant positive relationship between % blue-green algae and green algae and the metric % dominance (Figure 14: r = 0.203; P = 0.015). This invertebrate metric indicates the relative abundance of the most dominant single taxon in the sample. It suggests that with increases in blue-green and green algae in the algal community, the invertebrate community is more dominated by a single taxon, able to best exploit that habitat and its resources. This is consistent with the decrease in evenness seen in the Ichetucknee snag data (Figure 10) and with the results of Koksvik and Reinertsen, who found greater relative abundance of chironomids with higher algal biomass, and the results of Maasri et al. (2008), who found significant changes in abundance of select chironomid taxa with changes in abundance of selected algal taxonomic groups.

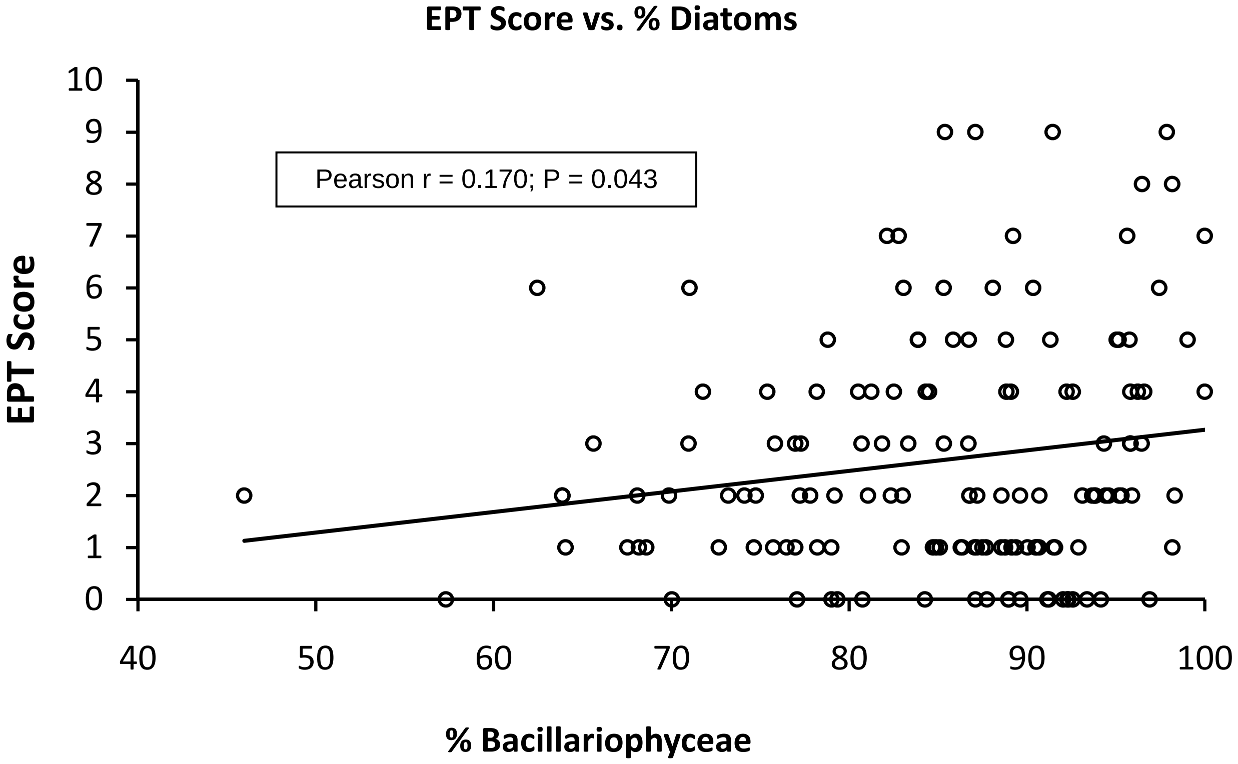


Figure 13. EPT Index (Ephemeroptera/Plecoptera/Trichoptera) versus % Bacillariophyceae (diatoms) in the periphyton community for springs and spring-run streams statewide (FDEP bioassessment data)

Macroinvertebrate taxa richness, EPT Index, and % dominance are components of a multi-metric invertebrate index in Florida called the Stream Condition Index (Barbour et al. 1996). There was a negative (but statistically nonsignificant) relationship between the SCI Score and % Cyanobacteria and Chlorophyta (Figure 15). Note that the SCI was recalibrated after 2004, so only data from 2004 and earlier were used for this analysis, as subsequent scores are not comparable. Given that some components of the score decrease (taxa richness, EPT Index) and some increase (% dominance), it may not be surprising that there is an overall weak relationship between algae and the SCI Score. It is notable that there may be a threshold effect; above about 30% Cyanobacteria (blue-green) and Chlorophyta (green), all of the high SCI values (>20, which indicates a “good” macroinvertebrate community condition) appear to drop out. To date, no study has evaluated possible algal thresholds from an ecological perspective. Welch et al. (1988) found that coverage of filamentous macroalgae above 20% appeared to constitute an aesthetic nuisance.

Canfield and Hoyer (1988) found that macroinvertebrate drift abundance (as density) and biomass exhibited weak positive correlations with epiphyte biomass in five spring-run streams in north-central and central Florida (Canfield and Hoyer 1988, Figure 16). Neither correlation was statistically significant (abundance —Pearson r = 0.297; P = 0.628: biomass — Pearson r = 0.640; P = 0.244). Macroinvertebrate drift has been implicated as a measure of invertebrate productivity (Allan 1995), suggesting that higher algal standing crop may be promoting higher benthic invertebrate productivity due to increased food resources. In contrast, recent work completed in the Silver River (Munch et al. 2007) suggests decreased

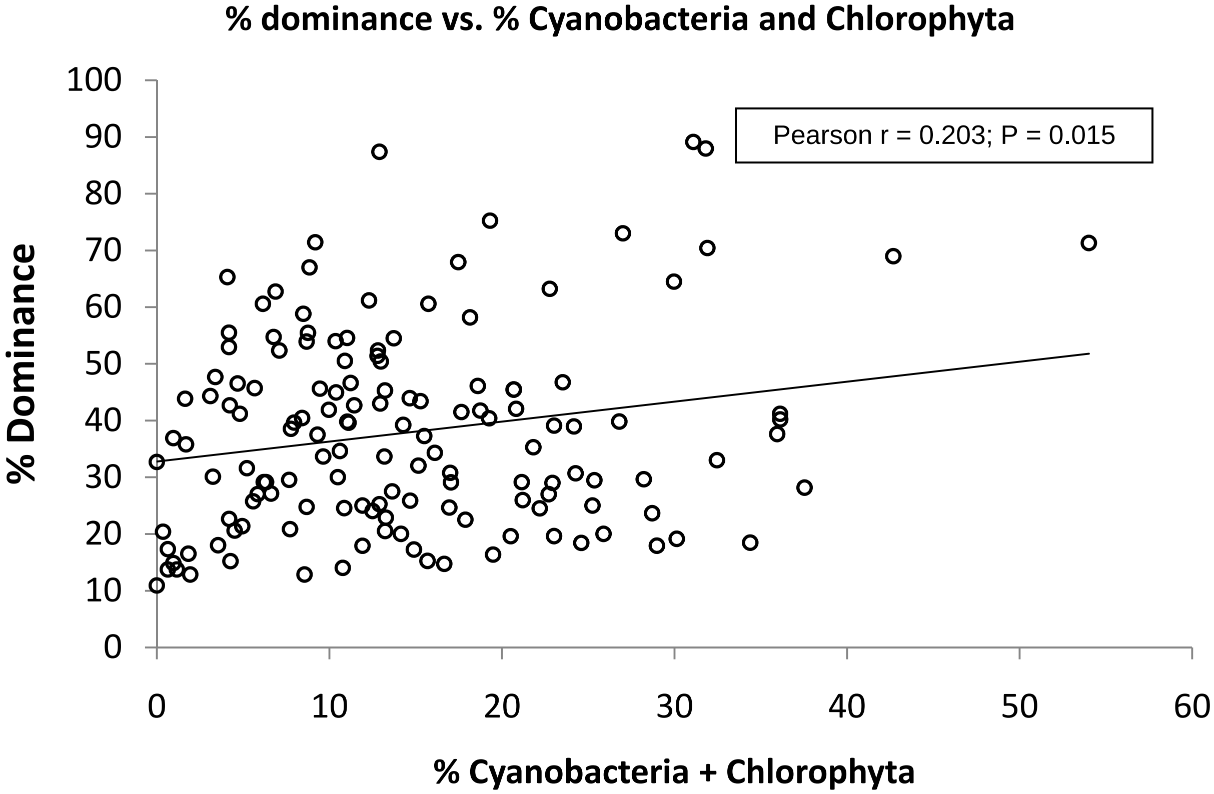


Figure 14. % dominance (relative abundance of single most dominant invertebrate taxon in the sample) versus combined % Cyanobacteria and Chlorophyta in the periphyton community for springs and spring-run streams statewide (FDEP bioassessment data)

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macroinvertebrate productivity (based on emergence rates) in association with increased nitrate levels and epiphyte biomass. Lobinske (1995) suggested that larval chironomid productivity appears to be reduced in Rock Springs Run (which has elevated nitrate levels) compared to Blackwater Creek in the Wekiva River system.

SUMMARY AND RECOMMENDATIONS

The analyses in this paper indicate a mix from “significant positive,” “significant negative,” and no statistically significant changes in benthic macroinvertebrate communities of springs and spring-run streams to increases in the abundance of algae and changes in algal community structure. These are summarized in Table 4, and a conceptual model of the interactions of algae with invertebrates is illustrated in Figure 17. The results of studies published in the stream literature indicated a similar mix of positive, negative, and null effects between benthic invertebrates and algae. Positive changes may be due to a combination of habitat effects (more algae providing additional structural habitat or attachment for invertebrates) and increased food resources for algal feeders. Negative changes may be due to habitat alterations (increased algae changing the physical nature of the habitat or altering near-bottom hydrology) or changes in water quality due to proliferation of algae. Overall, it appears more negative consequences than positive changes may result to macroinvertebrate communities from the proliferation of algae in springs and spring-run streams.

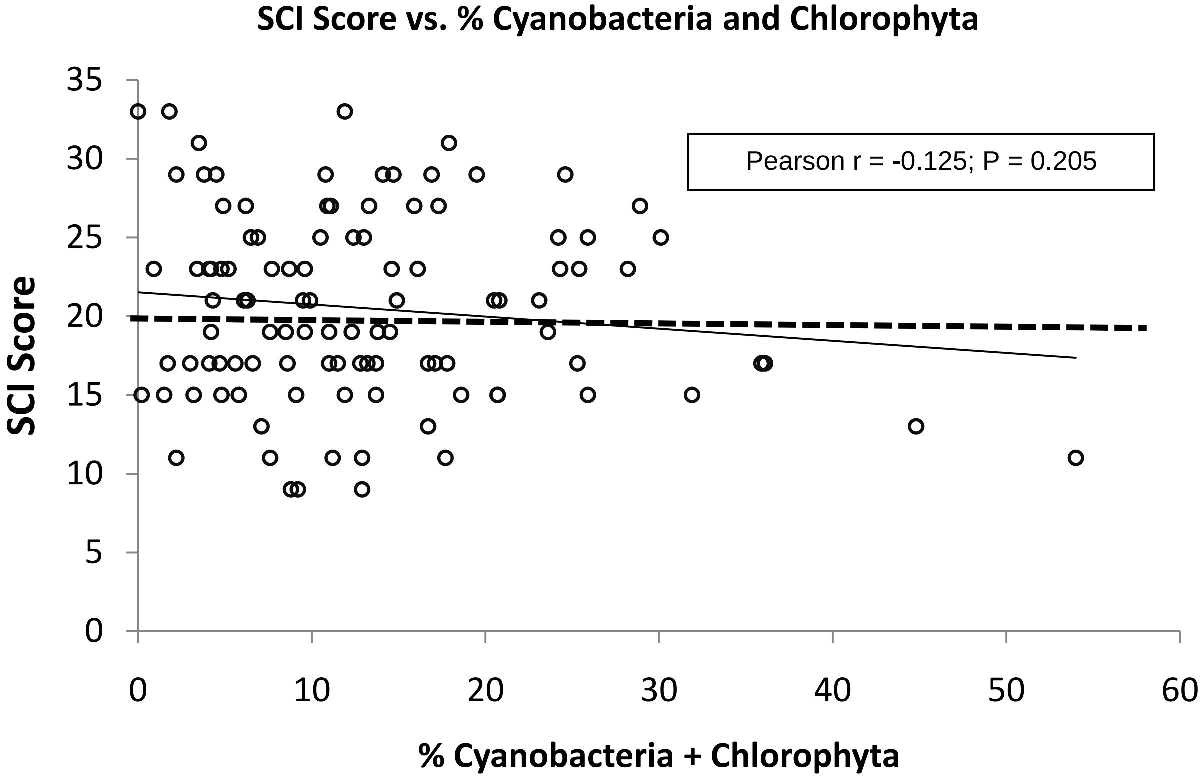

Figure 15. Stream Condition Index (SCI) Score versus combined % Cyanobacteria and Chlorophyta in the periphyton community (FDEP bioassessment data). The heavy dashed line is at 20, which indicates border between "good" and "poor" macroinvertebrate community condition.

Table 4. Summary of changes in benthic macroinvertebrate community measures with changes in benthic algal community characteristics

Change	Description
Positive	Increased macroinvertebrate taxa richness and abundance with increased algal standing crop/abundance
Negative	Decreased macroinvertebrate community evenness and diversity with increased algal standing crop/abundance
Negative	Decreases in EPT taxa, reduced total taxa richness and increased % dominance with increased relative abundance of Cyanobacteria and Chlorophyta in the benthic algal community
Null (?)	Possible alterations in macroinvertebrate functional feeding group relative abundance with increased algal abundance
Null (?)	Possibly increased macroinvertebrate drift abundance and biomass with increased epiphyte standing crop

Note:
EPT = Ephemeroptera/Plecoptera/Trichoptera

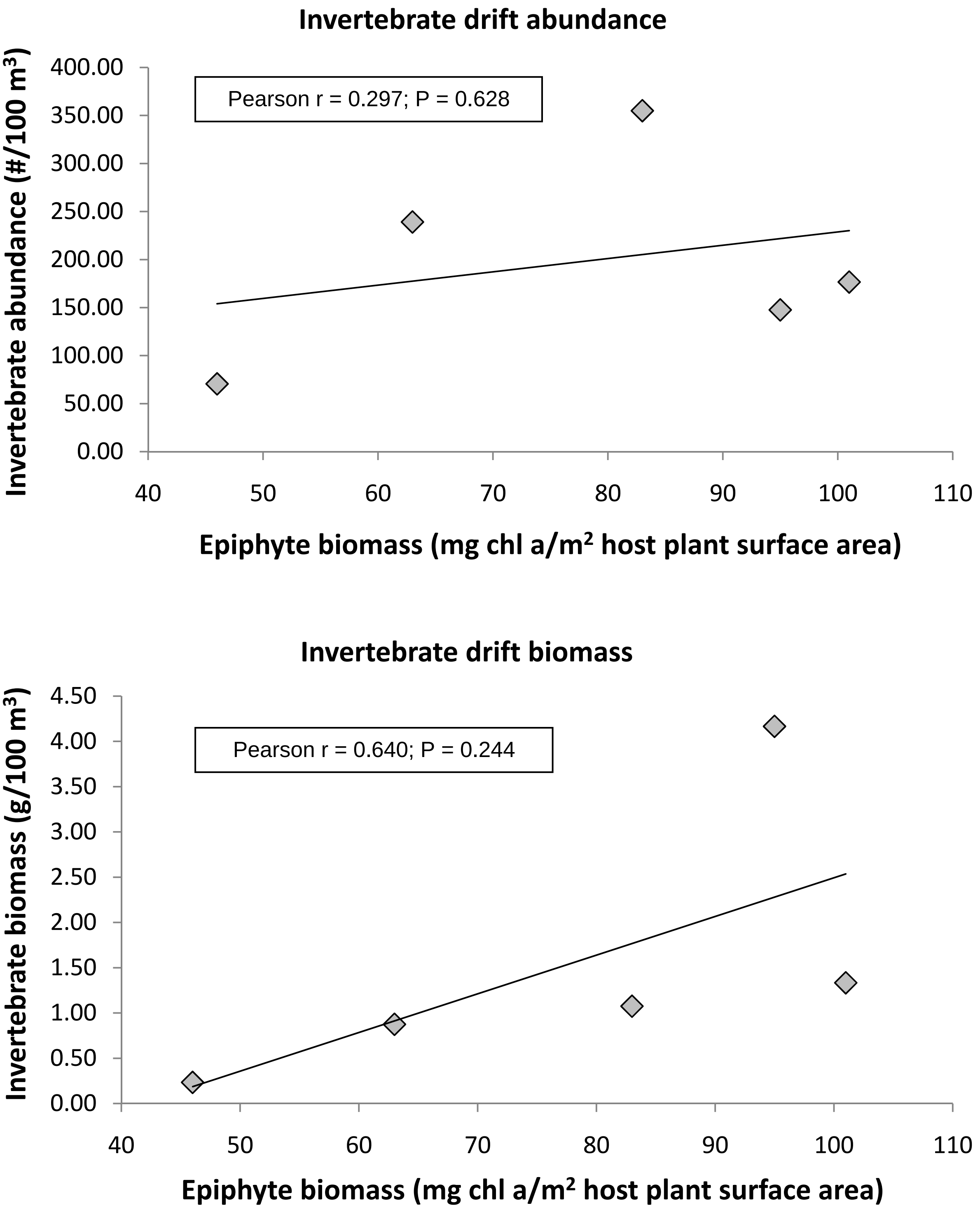

Figure 16. Benthic macroinvertebrate drift abundance and biomass versus epiphyte biomass in five spring-run streams in north and central Florida (from Canfield and Hoyer, 1988)

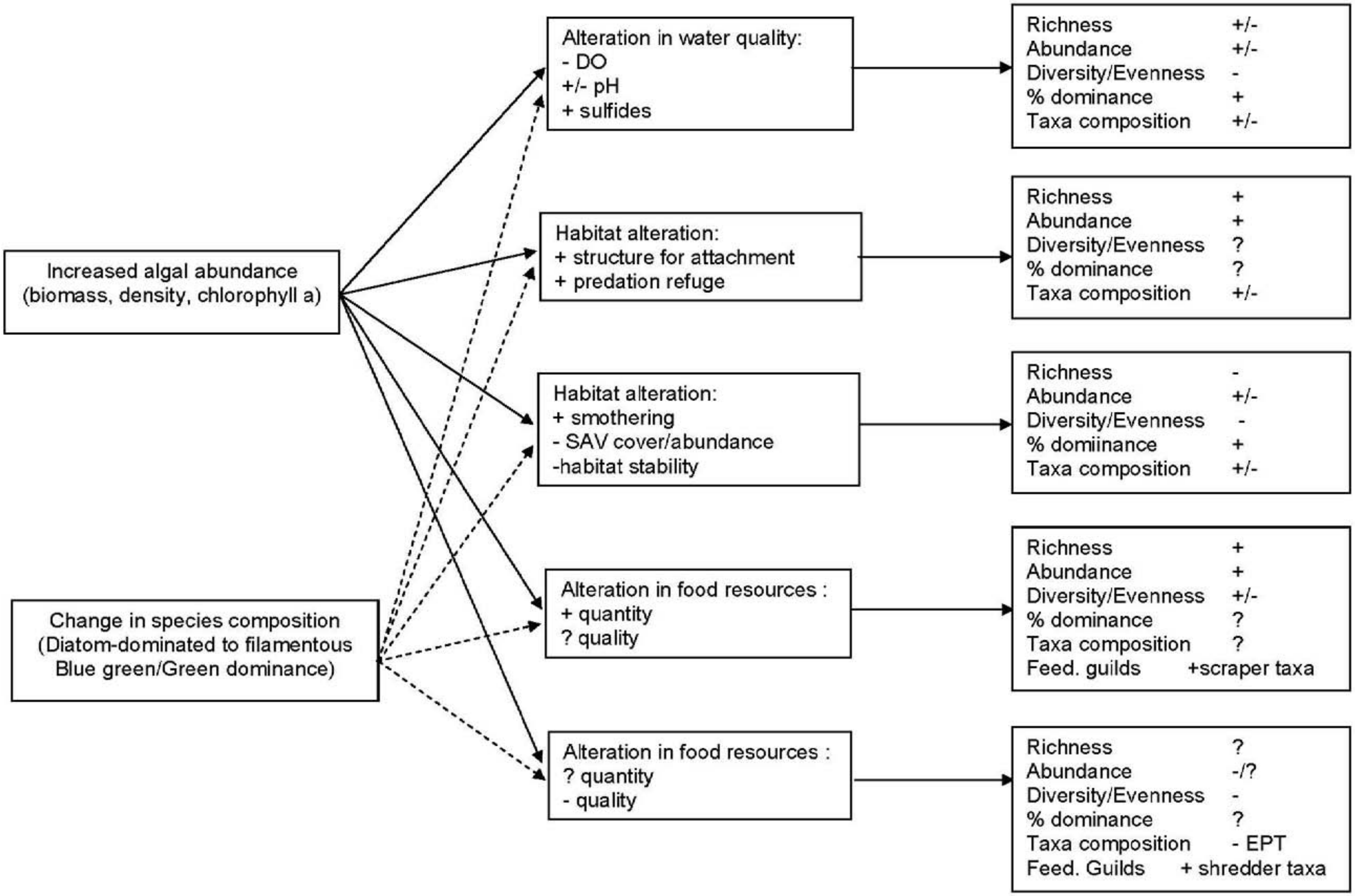

Figure 17. Conceptual model illustrating effects of benthic algal changes on benthic macroinvertebrates. + = increase; - = decrease; ? = no change or unknown.

Macroinvertebrate community taxa richness and abundance versus algae. There appears to be strong evidence of a positive relationship between algal abundance (as chlorophyll a, cell density, and/or biomass) and invertebrate taxa richness and abundance, as indicated by the results of this analysis and by Dudley et al. (1986), Koksvik and Reinertsen (2008) and Maasri et al. (2008). Most recently, Poirier (pers. comm., 2008) found that benthic macroinvertebrate density was positively correlated with biomass of Cyanobacteria (blue-green) and green algae in the St. Lawrence River (Canada). Steigerwalt (2005) used multivariate analysis (Canonical Correspondence Analysis) that indicated the "Quantity of epiphyton on snags was the strongest influence on taxa distributions and densities in the Ichetucknee River" (Steigerwalt 2005, page 23). Dudley et al. (1986) used experimental manipulations to show that some of these changes were due to provision of habitat and others due to increased food resources.

Macroinvertebrate community composition and algae. Results of this analysis indicate that changes in the abundance and/or taxonomic composition of the benthic algal community are associated with changes in the macroinvertebrate community. Results of this analysis indicated reduced invertebrate evenness and diversity with increased algal biomass (Ichetucknee River) and reduced taxa richness, increased % dominance and reduced richness of EPT taxa with increased proportion of Cyanobacteria (blue-green) and green algae in the algal community. Similar changes were seen in the literature. Power (1990), Maasri et al. (2008) and Koksvik and Reinertsen (2008) all suggest or indicate that chironomids are more prevalent in mats of macroalgae, while EPT taxa are less abundant. Brown (pers. comm., 2008) found that increased abundance of the invasive diatom *Didymosphenia geminata* was associated with reduced abundance of heptageniid mayflies, increased relative abundance of chironomids and a perlid stonefly, and no changes in baetid mayflies.

Macroinvertebrate functional feeding groups and algae. No statistically significant correlations were found between relative abundance of macroinvertebrate functional feeding groups and algal abundance, even though conceptual models suggest there should be some fairly strong relationships (Steinman 1996). Merritt et al. (1996) found shifts in feeding groups associated with environmental changes due to restoration of remnant oxbows in the Kissimmee River in south-central Florida, indicating that analysis of this attribute of the invertebrate community is promising. The algal and invertebrate data from the Ichetucknee River snag habitats were collected concurrently. The lack of statistical significance in these data (despite some fairly high correlation coefficients — see Table 2) is likely due to small sample size, as Steigerwalt (2005) lumped her individual sampling stations into three "reaches" to analyze feeding groups. Lack of statistical significance in the comparisons of the two Wekiva studies may be more expected, due to the fact they are nonconcurrent in time and did not sample at exactly the same stations. Environmental conditions during the FWCC invertebrate study were drought (low-flow) conditions, while the GreenWater study was conducted shortly following a period of very high river flows following a year dominated by hurricanes impacting central Florida. Low flows in the Wekiva River are associated with lower current velocity, lower water color, higher nitrate levels, and shallow depths. Higher flows (during the GreenWater sampling) are associated with higher current velocities and water color, greater depths, and lower nitrate levels.

Future Directions. A major limitation of this analysis was that the data used were not collected specifically to examine the relationships between benthic algae and macroinvertebrate communities; hence, these conclusions are preliminary. Specific studies examining this question are recommended. Studies should be designed and conducted with sample algae and invertebrates obtained concurrently from the same habitats, to compare the two. Field studies, even if conducted to specifically examine the interactions of algae with invertebrates, also will have limitations, since correlation does not indicate or imply causation. These field studies must be supplemented with manipulative, experimental studies conducted on standardized habitats in the field or in laboratory mesocosms to evaluate the specific mechanism by which algae may be affecting macroinvertebrate communities. Studies should also be conducted at the population level, looking at a variety of taxa (insects, mollusks, crustaceans, etc.), both common in spring systems and those which have some type of conservation status, such as endangered, threatened, or rare.

Questions that need to be addressed include:

What are the major algal herbivores in Florida spring-run streams?

What are the effects of changes in algal abundance on macroinvertebrate population and community characteristics, and what are the underlying mechanisms?

What are the effects of changes in algal community structure (including taxonomic composition) on macroinvertebrate population and community characteristics, and what are the underlying mechanisms?

How are nutrient effects on algal communities tied to effects on macroinvertebrate and fish populations in spring-run streams? What are the broader ecosystem impacts of nutrient enrichment in these aquatic ecosystems in addition to effects on algae?

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Helpful comments were received when this work was presented at the December 2007 meeting of the Florida Association of Benthologists and the May 2008 meeting of the North American Benthological Society. Gary Warren (FWCC) and Joy Jackson (FDEP) provided comments on this work, and Joy and Elizabeth Miller (FDEP) provided the FDEP Bioassessment Program data from spring-run streams. Alan Steinman and J. David Allan provided and gave permission to use their figure for Figure 5 of this report. Erich Marzolf, Larry Battoe, Chuck Jacoby, Ed Lowe, and Dean Dobberfuhl of SJRWMD provided helpful technical and editorial reviews of the manuscript.

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