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Description of Benthic Communities in Karst, Spring-Fed Streams of North Central Florida

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ABSTRACT: North-central Florida is dominated by a karst geology which gives rise to numerous springs and spring-influenced streams. These systems are fed by a regional aquifer system; the Floridan Aquifer. The periphyton communities of spring-influenced stream systems, such as the lower Suwannee and lower Santa Fe rivers, are characterized by an algal community typically dominated by diatoms (comprising 73% of the taxa list). Beds of submergent aquatic vegetation (SAV) are common in spring-influenced stream systems, dominated by macroalgae (primarily *Chara* spp.) and vascular plants (*Sagittaria kurziana, Vallisneria americana,* and others). Benthic invertebrate communities are dominated by chironomids, Ephemeroptera and Trichoptera on woody substrata (as suggested by data from Hester-Dendy samplers), with gastropod molluscs and crustaceans (primarily the amphipod *Hyalella azteca*) occasionally being relatively abundant. Sandy substrata are dominated by chironomids, gastropod and bivalve molluscs and oligochaetes. Our data indicate that a more species rich community is associated with hard substrata (such as wood and limestone shoals) than with soft-bottom communities. Epiphytic invertebrate communities on SAV are dominated by chironomids and ephemeropterans. Spring influence is a major structuring force in stream systems in north-central Florida. Increases in benthic invertebrate species richness and a higher proportion of diatoms in the periphyton community are associated with spring input. Two critical management issues regarding the springs and spring fed streams in the region are the allocation of groundwater from the Floridan Aquifer for human consumptive uses versus spring and stream ecosystem needs and prevention of groundwater contamination from overlying land uses.

The physiography of northern Florida is dominated by karst features (Stubbs, 1940). The underlying limestones giving rise to this karst topography form the container for the Floridan Aquifer, a regional aquifer system which covers a large portion of the southeastern U.S., from southern South Carolina, through portions of Georgia, all of Florida, and portions of southeastern Alabama (Rosenau et al., 1977; Ceryak et al., 1983). This aquifer exists under both confined (artesian) and unconfined (nonartesian) conditions. These geologic characteristics are responsible for the large number of springs found in Florida (Rosenau et al., 1977; Nordlie, 1990), most of which are associated with stream ecosystems, and most of which occur in the northern central part of the state, particularly in the Suwannee River drainage.

In this paper we provide a descriptive review of the flora and fauna of benthic communities of spring-fed and spring-influenced streams in north central Florida. Most of the data for this report came from unpublished reports and data from the stream monitoring programs of the Suwannee River Water Management District. Supplemental data were obtained from the files of other State of Florida agencies and from the grey and published literature. This summary will be valuable to researchers working in similar systems to enable comparisons to be made and additional questions developed.

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Table 1. Summary of watershed and hydrologic characteristics of stream systems of north-central Florida.

Stream	Watershed area (km^2)	Discharge (m^3/sec) Mean	Range
Suwannee River	25,771	299.9	83.8–2398.7
Alapaha River[a]	4766	45	0.88–532.4
Withlacoochee River[a]	5931	48.5	2.0–2248.6
Santa Fe River[a]	3585	45.5	17.2–481.44
Aucilla River	2279	16.5	0.45–211.3
Econfina River	780	4.1	0.07–71.9
Fenholloway River	1052	6.1	1.1–38.5
Steinhatchee River	1502	9.4	0.07–498.4
Waccasassa River	1373	8.5	[b]–345.5

[a] Tributaries of Suwannee River.
[b] Flow reverses due to tidal action.

Description of the Region

REGIONAL HYDROGRAPHY: The primary hydrologic feature of north-central Florida is the Suwannee River drainage. This river system begins in the Okeefenokee Swamp in southern Georgia and runs 378 km to the Gulf of Mexico. With a basin area of over 25,000 km^2, the Suwannee is the second largest river in Florida in terms of freshwater discharge. Mean daily streamflows range from 42 m^3/sec in the upper reaches to 300 m^3/sec near the mouth (USGS, 1992). Other drainages in the region (Table 1; Fig. 1) include the Aucilla River, the Coastal Rivers system, which includes three major streams (the Econfina, Fenholloway and Steinhatchee Rivers), and the Waccasassa River. All of these streams are low gradient systems with a channel morphology dominated by sand bottom with low riffle/pool development (after Brussock et al., 1985).

REGIONAL HYDROGEOLOGY AND STREAM PHYSICAL/CHEMICAL CHARACTERISTICS: All streams in this region are heavily influenced by groundwater inflow from the Floridan Aquifer when they lie downgradient of a topographic feature known as the Cody Scarp (Fig. 1). This feature is the boundary between two major geomorphologic districts: the Northern Highlands and the Gulf Coastal Lowlands (Fig. 1). In the Lowlands, streams intercept the potentiometric surface of the Floridan (which is generally unconfined in this region) and receive inflow from it via numerous springs and general baseflow through the channel. Many streams are captured by sinkholes where they cross the scarp (e.g., the Santa Fe and Alapaha Rivers), which may at times take the entire stream flow. They subsequently re-emerge as springs after flowing through an underground conduit (where they mix with the Floridan Aquifer). Smaller streams may be captured by sinks and not re-emerge, or several small sinking streams may form part of the recharge area for a spring or spring group downgradient of the stream sinks.

The influence of these geologic features on stream environments is represented by characteristics of the Suwannee River and its tributaries. The upper reaches of streams in this drainage exhibit variable, "flashy" streamflows, fed primarily by land runoff and seepage from shallow sand aquifers (Fig. 2). Once crossing the Cody Scarp, spring input from the Floridan Aquifer contributes to substantial

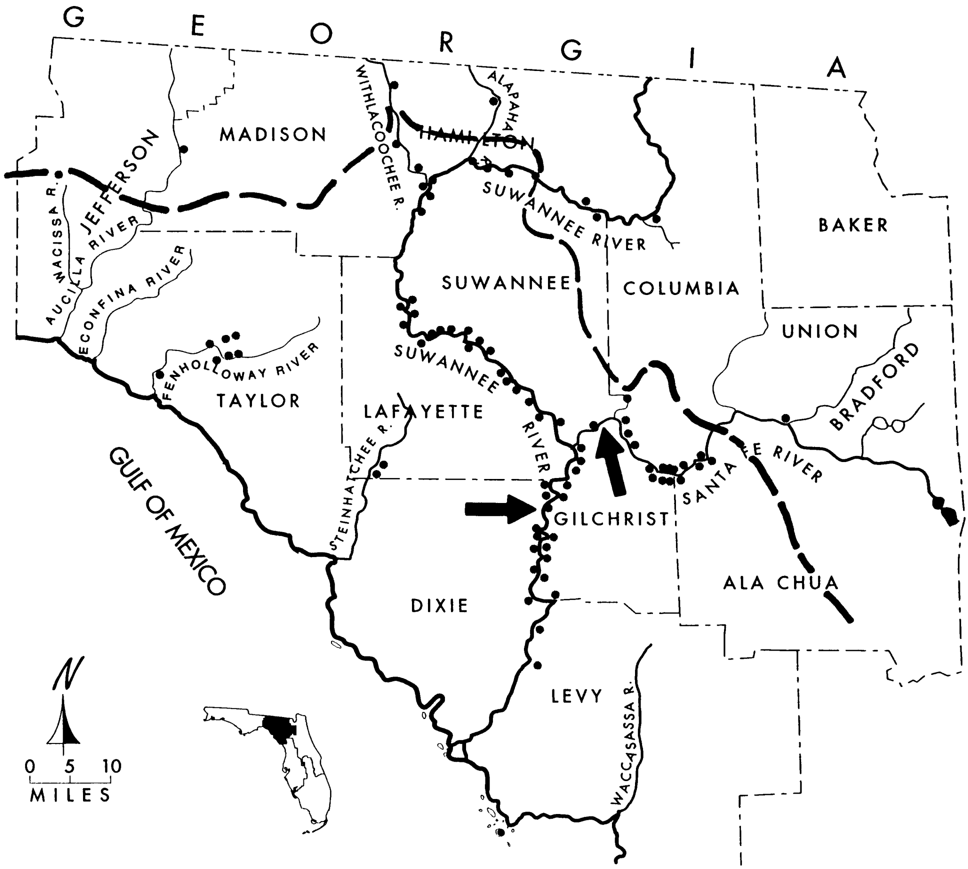


Fig. 1. Map of the region, showing major streams, springs (●), and the location of the Cody Scarp (– – –). Arrows indicate reaches where intensive sampling has been conducted for the data reported in this paper.

increases in flow and a more even, predictable flow regime (Fig. 2). Wharton et al. (1982) also noted the stable flow regime exhibited by spring-fed river systems in the southeastern U.S.

Water quality of the Floridan Aquifer in this region is characterized by high concentrations of calcium, magnesium and bicarbonates (Ceryak et al., 1983; Crane, 1986). The input of this hard, calcareous water dramatically changes the chemistry of streams when they intercept the aquifer and receive spring inflow. Most begin as acidic, poorly mineralized blackwater streams (particularly if originating in the Northern Highlands), but spring input alters stream water quality characteristics to those of alkaline, hardwater streams (Table 2), called calcareous streams in Beck's classification (Beck, 1965). Most of the major streams in this region (the Aucilla, Alapaha, lower Suwannee and Santa Fe) have been classified as calcareous streams (Nordlie, 1990), and others (the Withlacoochee and Waccasassa Rivers, and the streams of the Coastal Rivers drainage) are influenced heavily by spring input from the Floridan.

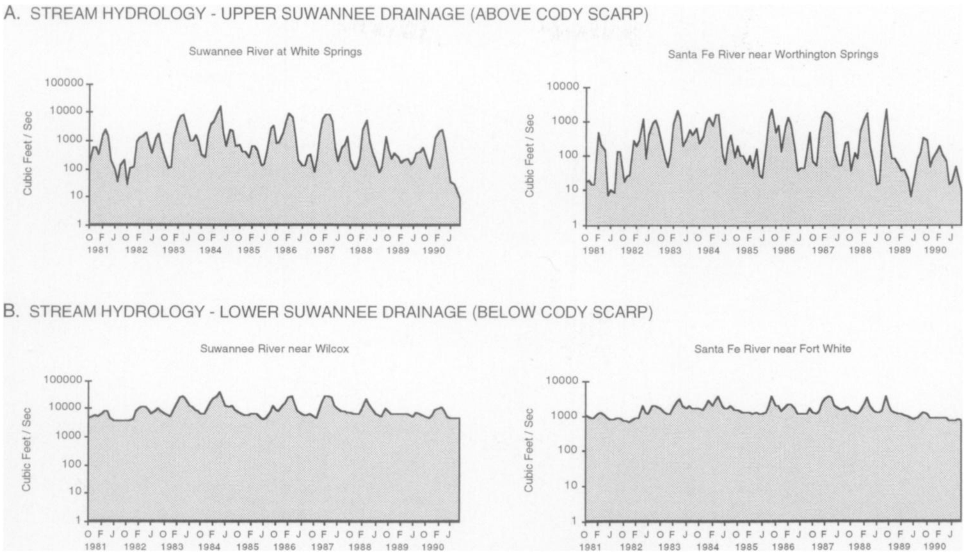


Fig. 2. Mean monthly stream flows for a ten-year period at four U.S. Geological Survey stream gauging sites on the upper (A) and lower (B) Suwannee and Santa Fe Rivers, reflecting stream hydrology in the upper and lower portions of the drainage.

SPRING PHYSICAL AND CHEMICAL CHARACTERISTICS: Rosenau et al. (1977) provide the most detailed summary to date of hydrologic and water quality characteristics of the springs of Florida. They employed the Meinzer Classification to describe spring hydrology, which rates springs based on mean daily discharge, ranging from first magnitude (>2.83 m^3/sec) to eighth magnitude (<0.00001 m^3/sec). Nine springs in the region are classified as first magnitude springs or spring groups. Based on limited data (Rosenau et al., 1977), most others are second (0.28–2.83 m^3/sec) or third (0.028–0.28 m^3/sec) magnitude.

Whitford (1956) classified Florida springs into six types based on water chemistry and associated algal communities. More recently, Woodruff (1993) recognized four types of spring water chemistries in Florida based on multivariate analysis of existing water quality data; calcium bicarbonate springs, salt springs, mixed springs and low ion springs. Most of the spring systems in the north-central Florida region are Whitford's hard, freshwater type or Woodruff's calcium bicarbonate type.

Periphyton and Submerged Macrophyte Communities

PERIPHYTON COMMUNITIES: The periphyton communities of Florida spring habitats were sampled by Whitford (1956). He characterized the algal communities of hard, freshwater springs and spring-fed streams (such as the Itchetucknee and lower Santa Fe Rivers) as a *Cocconeis-Stigeoclonium* type, dominated primarily by diatoms. Algae found by Whitford to be characteristic of hard freshwater springs and spring streams were diatoms of the genera *Synedra, Achnanthes, Cocconeis,* and *Gomphonema* and green algae of the genera *Stigeoclonium, Oedogonium* and *Cladophora.*

More recent data from the Suwannee and Santa Fe Rivers have been collected

Table 2. Ranges of water quality exhibited by stream reaches in different regions of the Suwannee River drainage in Florida. Data from SRWMD sampling conducted February 1989–January 1991.

Parameter	pH (units)	Alkalinity (mg/liter)	Conductivity (micromhos)	Color (Pt/Co units)	Total N (mg/liter)	Total P (mg/liter)
Upper Santa Fe River (Bradford County)	5.0–7.7	6.30–92.0	95.0–273.0	40.0–430.0	0.20–1.75	<0.05–0.37
Upper Suwannee River (Hamilton County)	3.2–7.4	0.50–23.0	50.0–122.0	200.0–600.0	0.33–2.62	<0.05–0.39
Withlacoochee River (at state line)	6.6–7.8	15.0–120.0	82.0–258.0	10.0–250.0	0.05–1.71	0.05–0.43
Lower Santa Fe River (at Hwy 129)	7.6–8.1	110.0–160.0	297.0–411.0	0.50–150.0	<0.05–1.35	<0.05–0.36
Lower Suwannee River (at Rock Bluff)	7.1–8.3	44.0–150.0	138.0–364.0	15.0–250.0	0.31–1.69	0.05–0.57

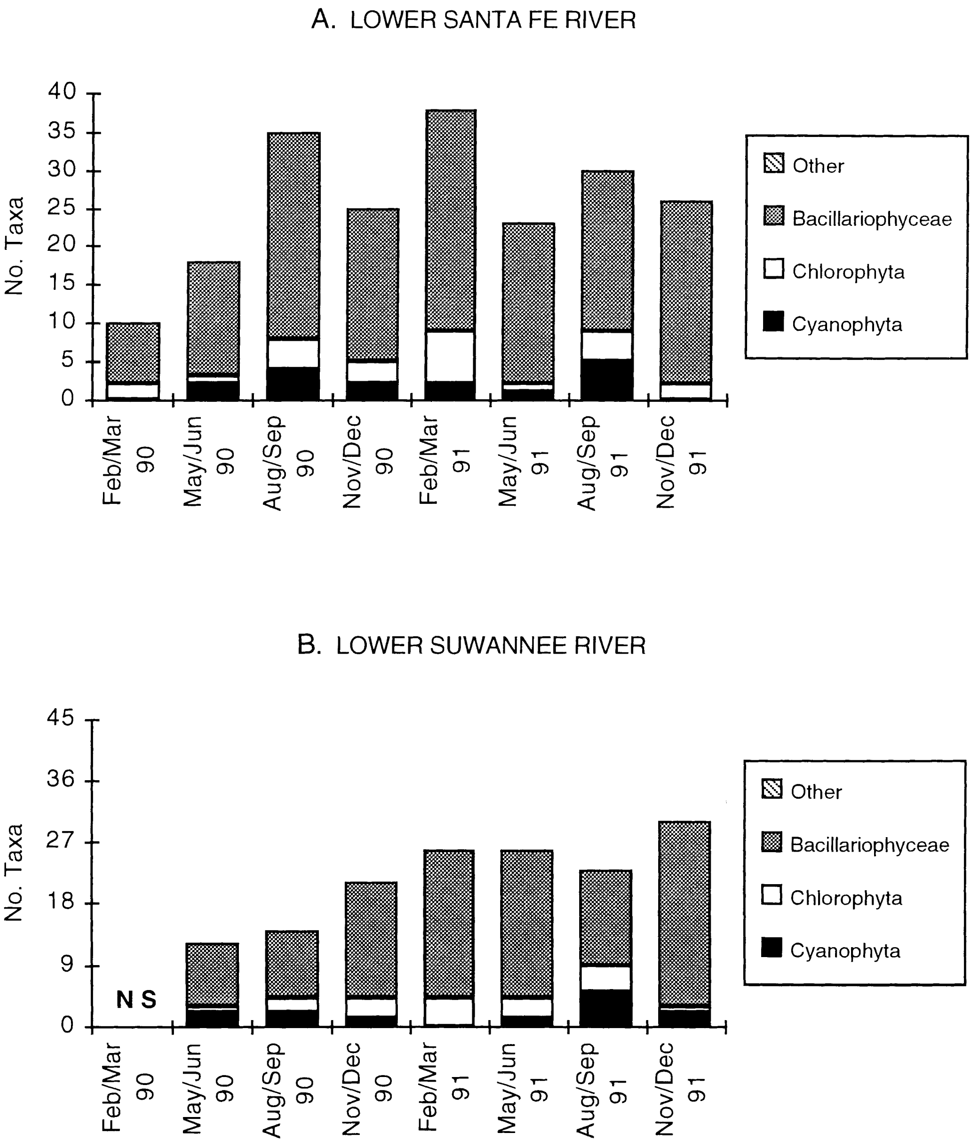
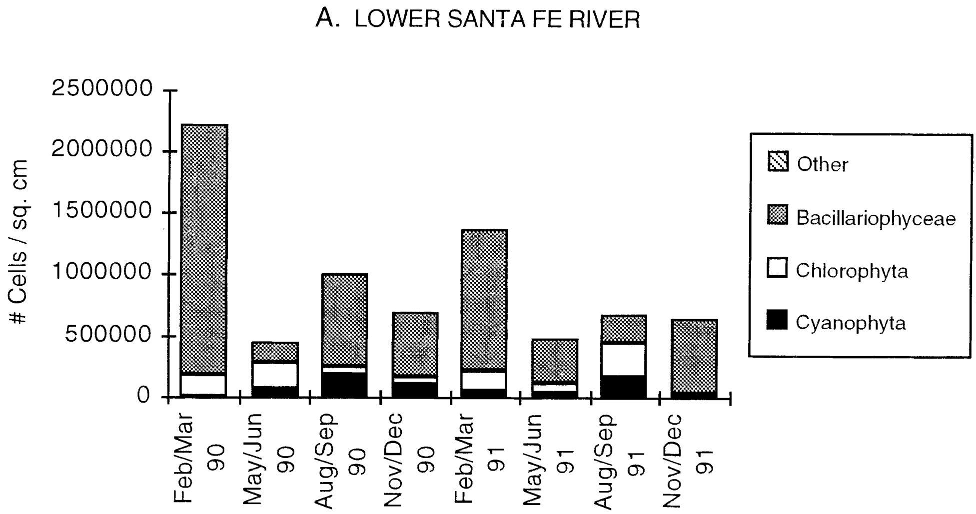


Fig. 3. Seasonal periphyton species richness on glass slide settling racks incubated in the (A) lower Santa Fe and (B) lower Suwannee Rivers.

quarterly using glass slide settling racks. A total of 168 species of algae have been collected from the spring-influenced portions of the Suwannee drainage (Appendix 1). Older taxonomic identifications were employed in order to make these data comparable with historically collected data. From these collections, a new species of *Anorthoneis* was described by Hein (1991) as *A. dulcis*; the first freshwater representative of this marine genus. In the Suwannee drainage, it appears to be confined to the spring-influenced portions (Hein, 1991).

These spring influenced portions of the lower Suwannee and Santa Fe Rivers support periphyton communities dominated by diatoms throughout the year, in



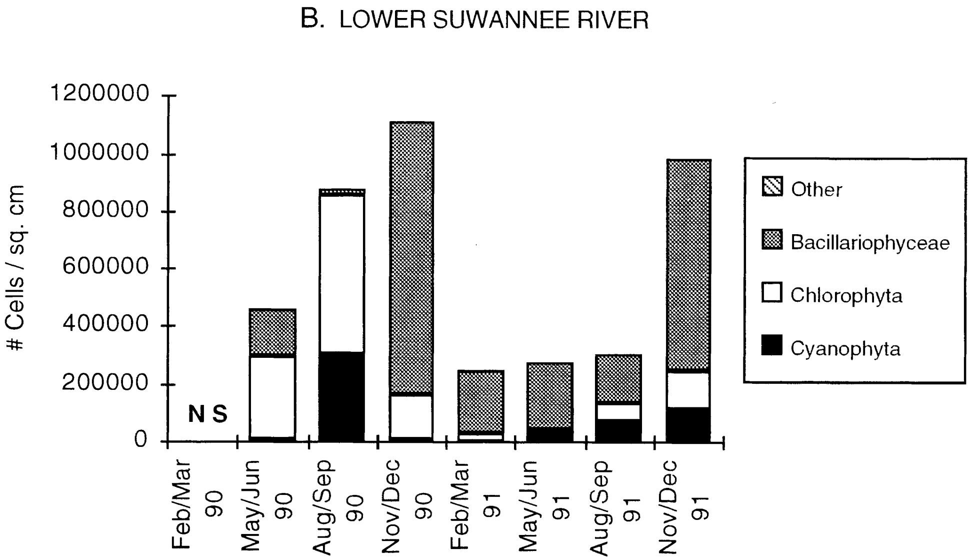


Fig. 4. Seasonal periphyton abundance on glass slide settling racks incubated in the (A) lower Santa Fe and (B) lower Suwannee Rivers.

terms of both species richness and abundance (Figs. 3, 4). Diatom genera most frequently collected included *Achnanthes, Cocconeis, Gomphonema, Melosira, Navicula, Nitzschia* and *Synedra.* Frequently collected green algae include *Protoderma viride, Scenedesmus acuminatus* and a *Stigeocolonium* sp. Higher algal taxa richness was seen in winter and summer on the Santa Fe (Fig. 3) and in spring on the Suwannee (Fig. 3). Peak algal densities were generally observed in the winter on the Santa Fe and in the summer-fall period on the Suwannee (Fig.

Table 3. List of common submerged macrophytes found in springs and spring-influenced streams in north-central Florida. Sources: Dutoit (1979), Canfield and Hoyer (1988) and Florida Department of Natural Resources unpublished data.

Chlorophyta	Bryophyta
Chara spp.	*Fontinalis* sp.
Various filamentous forms	
Tracheophyta	
Alismataceae	Najadaceae
Sagittaria kurziana	*Najas guadalupensis*
Sagittaria subulata	
	Nymphaeaceae
Ceratophyllaceae	*Cabomba caroliniana*
Ceratophyllum demersum	
	Onagraceae
Halogoraceae	*Ludwigia repens*
Myriophyllum heterophylum	
Myriophyllum laxum	Potamogetonaceae
Myriophyllum spicatum	*Potamogeton diversifolius*
	Potamogeton illinoensis
Hydrocharitaceae	*Potamogeton pectinatus*
Egeria densa	
Hydrilla verticillata	
Vallisneria americana	

4), with diatoms dominating relative abundance except during a very low flow event on the Suwannee in mid-1990, when green algae dominated algal relative abundance (Fig. 4).

Periphyton biomass ranged from <1 to 19 g/m^2 Ash-Free Dry Weight (AFDW) on the lower Suwannee and <1 to 17 g/m^2 AFDW on the lower Santa Fe. Periphyton biomass was generally highest throughout the year on the latter stream (R. A. Mattson, unpubl. report). Periphyton production rates appear to be highest in the spring-influenced portions of streams in this region, probably due to a combination of high water clarity, generally high nitrate concentrations, and constant flow and temperature conditions (R. A. Mattson, unpubl. report). More rigorous comparative studies of these spring and spring stream systems would be valuable for their management and protection. Since the older study of Whitford (1956) very few systematic or ecological studies of the algae of Florida springs and spring-influenced streams have been conducted.

SUBMERGED MACROPHYTE COMMUNITIES: The spring-fed streams of Florida are characterized by stands of submergent macrophytes (Clewell, 1991). The stonewort *Chara* sp. is the most common algal macrophyte and common vascular submergent plants include *Sagittaria kurziana, Vallisneria americana, Ceratophyllum demersum* and one or more species of *Myriophyllum* (Table 3). In the lower Santa Fe drainage, macrophyte coverage was dominated by *S. kurziana, V. americana, M. laxum* and *Chara* sp. (Dutoit, 1979; Florida Department of Natural Resources, unpubl. data). Exotic submergents such as *Hydrilla verticillata, Myriophyllum spicatum,* and *Egeria densa* are also present in many streams in the region and may dominate submerged macrophyte cover.

Species specific above-ground standing crops of submerged macrophytes on the

Itchetucknee River (a spring-run tributary of the lower Santa Fe River) ranged from 67.2 to 996.8 g dry weight/m^2 (Dutoit, 1979), with the highest standing crops being exhibited by *Chara.* Duarte and Canfield (1990) found submerged macrophyte standing crops ranging from 7.1 to 25.6 kg/m^2 wet weight in several spring runs in the region, and that standing crop was most influenced by the degree of canopy shading of the channel. They measured highest standing crops in the Wacissa River, probably because this stream is generally wider (less shaded by the riparian canopy), shallower and has slower current velocities than the other systems sampled (R. A. Mattson, pers. obs.).

Species specific leaf growth rates of macrophytes in the Itchetucknee River ranged from 0.46 to 13.25 g dry wt./m^2/day (Dutoit, 1979), with *Chara* exhibiting the highest growth rate. This alga exhibited highest growth rates in the spring (March–May), while vascular plants such as *Sagittaria* tended to exhibit higher growth rates in the summer (June–August) (Dutoit, 1979). Daily Maximum Primary Production rates (as g O_2/m^2/hour) in spring stream systems in the region ranged from 1.18 to 13.43 (Duarte and Canfield, 1990).

Benthic Macroinvertebrate Communities

Beck (1965) found benthic macroinvertebrate communities of calcareous streams in Florida were characterized by chironomids, ephemeropterans (primarily baetids and the heptageniid *Stenonema*), molluscs (particularly the snail *Elimia*), the trichopteran *Cheumatopsyche,* and crustaceans (the freshwater shrimp *Palaemonetes paludosus* and the amphipod *Hyalella azteca*). Thompson (1968) noted that a rich molluscan fauna is associated with the springs and spring-influenced streams of Florida, and that many snails in the family Hydrobiidae exhibit a high degree of endemism, being restricted to spring groups in a localized area or even to a single spring. Nordlie (1990) reported *Elimia* densities of up to 17,000/m^2 in the Itchetucknee River.

Recently collected semiquantitative data indicate that stream benthic macroinvertebrate communities are dominated by various aquatic insects (Appendix 2, Fig. 5). Collections in the lower Suwannee and Santa Fe Rivers, made quarterly using Hester-Dendy multiplate samplers, suggest that Diptera (primarily Chironomidae), Ephemeroptera (primarily Heptageniidae, Baetidae and Tricorythidae) and Trichoptera (primarily Hydropsychidae) dominate on woody substrata. Other groups characteristic of benthic communities on Hester-Dendy samplers deployed in the spring-influenced reaches of these rivers include molluscs (primarily gastropods of the genus *Elimia,* the family Hydrobiidae, and freshwater limpets in the family Ancylidae) and crustaceans (primarily *H. azteca*). A more species rich community of benthic invertebrates is associated with woody substrata (as suggested by data from Hester-Dendy samplers) compared with soft substrata (Fig. 6). This is similar to data collected from low gradient blackwater streams in the southeastern U.S. (Benke et al., 1984; Benke and Meyer, 1988).

Collections in the lower Santa Fe River with a petite ponar grab indicate that dominant taxa on sandy substrata (Fig. 7) include various infaunal chironomids, oligochaetes, and molluscs, including the gastropod *Campeloma* sp. and the exotic asian clam *Corbicula fluminea.* Native bivalves include sphaeriid (*Sphaerium, Musculium*) and unionid clams (primarily *Elliptio* and *Villosa* spp.). Heard (1979) lists 13 species of unionid clams in the Suwannee drainage. One, *Medionidus*

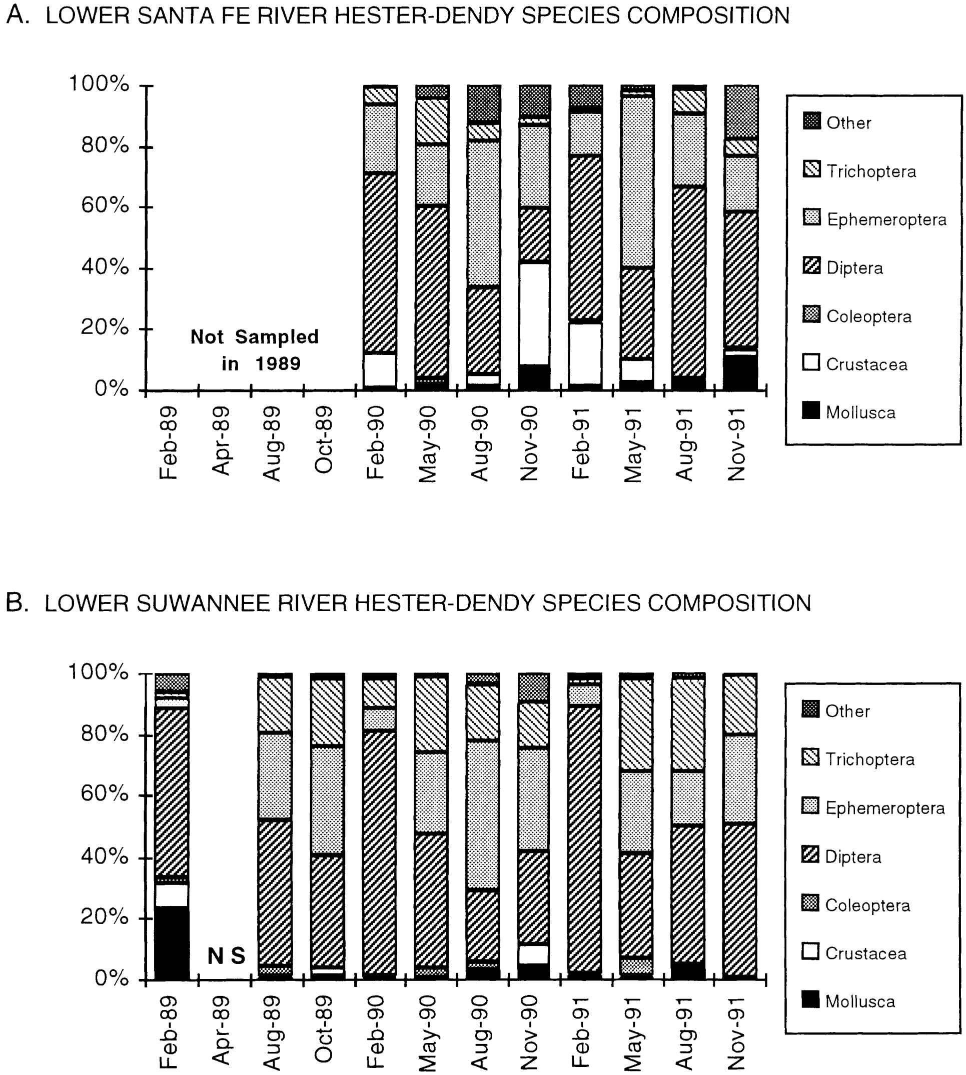


Fig. 5. Benthic macroinvertebrate species composition (as cumulative relative abundance from three replicate samples) on Hester-Dendy multiplate samplers incubated in the spring-influenced reaches of the (A) Santa Fe and (B) Suwannee Rivers.

walkeri, is an endemic, found primarily in areas influenced by calcareous groundwater input. Densities of *Corbicula* up to 6458/m^2 have been observed on the lower Suwannee (SRWMD, unpubl. data), and it is unknown how this exotic clam has affected native bivalve populations. Qualitative summaries of benthic invertebrate species composition on natural substrata in the spring-influenced reaches of other streams in the region indicate some of the same general trends (Fig. 8) (from Florida Department of Environmental Protection, unpubl. data). In terms of species richness, chironomids are a dominant feature of these communities; ephemeropterans, trichopterans, molluscs and crustaceans comprise most of the remainder of the species richness. Woodruff (1993) found a benthic community

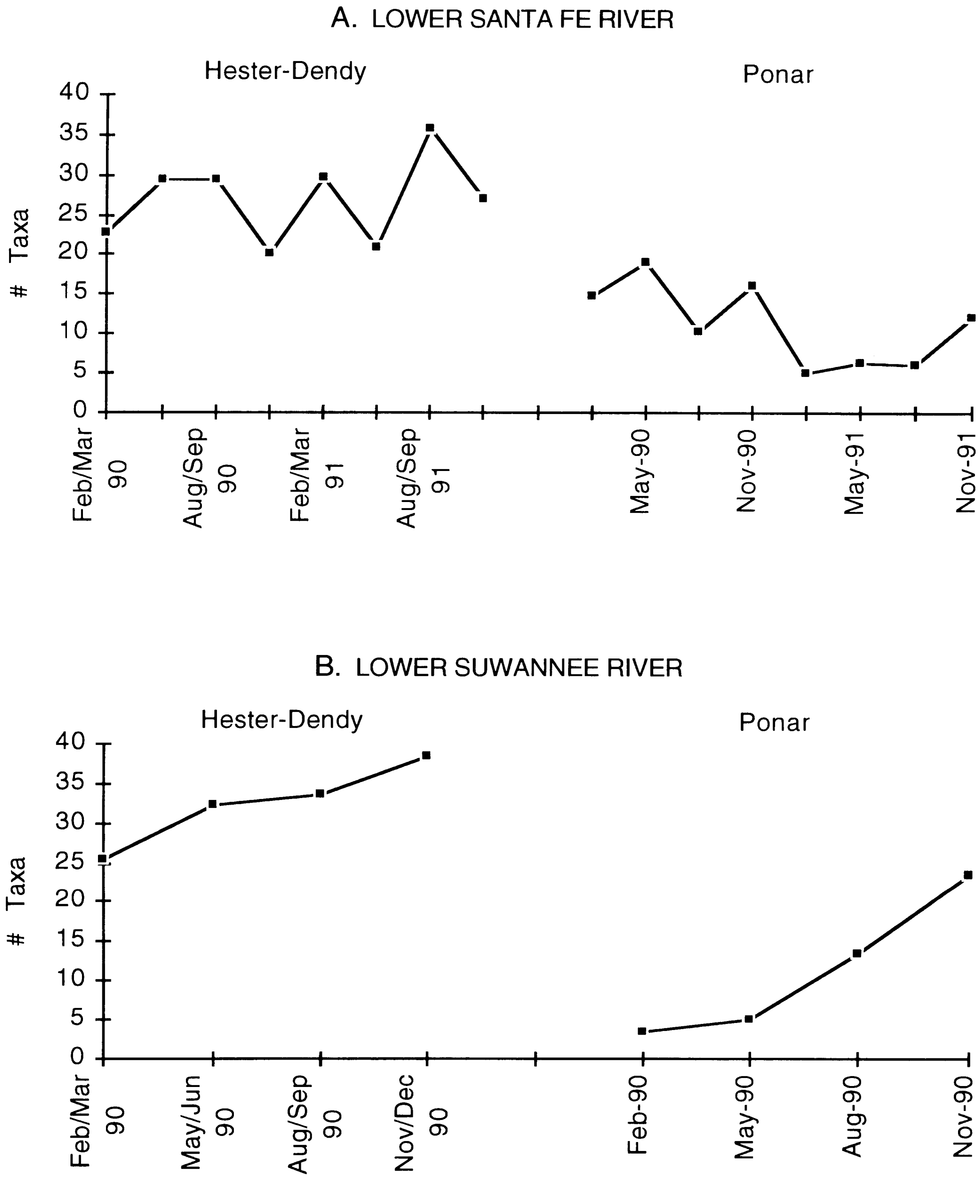


Fig. 6. Comparison of mean macroinvertebrate taxa richness (three replicate samples) from Hester-Dendy and petite ponar grab collections in 1990–1991 at one site on the lower Santa Fe River (A) and in 1990 at one site on the lower Suwannee River (B).

dominated by oligochaetes, amphipods, leeches and isopods on benthic sediment cores from Manatee Spring in the lower Suwannee.

Outcrops of limestone are another major type of hard substratum in many spring-fed rivers in this region and are frequently found in shoal and riffle areas of the river channels. Mason (1991) typically found highest Empirical Biotic Index values in rock basket collections (vs. ponar and dip net collections) in the lower

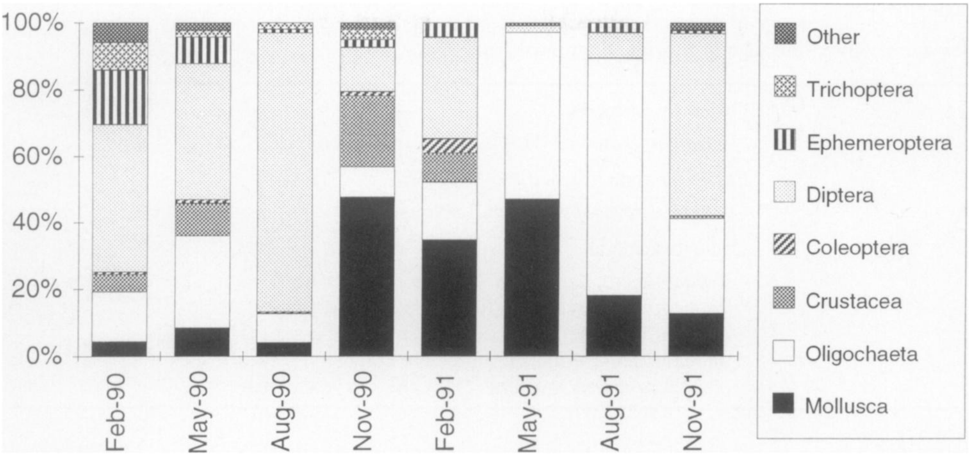


Fig. 7. Species composition of benthic macroinvertebrates (as cumulative relative abundance from three replicate samples) from petite ponar grab sampling in the lower, spring influenced portion of the Santa Fe River.

Suwannee (heavily influenced by spring inflow). Hydropsychid and psychomyiid caddisflies were "common inhabitants" in these basket collections (Mason, 1991). The Florida Game and Fresh Water Fish Commission (unpubl. report) found higher benthic invertebrate densities on limestone shoal areas (2109.6–4553.5/m^2) than on sand-bottom areas (230.6–421.6/m^2) in the lower Suwannee and lower Santa Fe Rivers.

Beds of submerged macrophytes are also a major invertebrate habitat in the springs and spring-influenced streams of the region. In the St. Marks River, Bartodziej (pers. comm.) found that epiphytic macroinvertebrate communities were dominated by chironomids (principally *Dicrotendipes* spp.), averaging 68% of the species composition on five species of macrophyte. He measured invertebrate

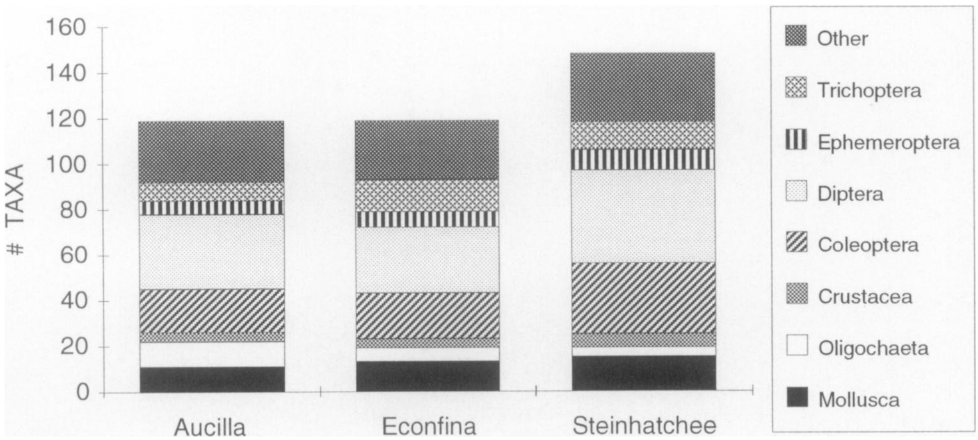


Fig. 8. Comparison of benthic macroinvertebrate species richness (as numbers of taxa in each major group) in the Aucilla, Econfina and Steinhatchee Rivers. Data from unpublished Florida Department of Environmental Protection study.

Table 4. Inventory of cave crustaceans collected from submerged cave and sink habitats in the Suwannee River drainage in Florida. Compiled from Franz, 1982.

Order Amphipoda
Crangonyx hobbsi (Hobbs' cave amphipod)
Order Isopoda
Caecidotea hobbsi (Hobbs' cave isopod)
Order Decapoda
Palaemonetes cummingi (Florida cave shrimp)?
Procambarus erythrops (Red-eyed cave crayfish)
Procambarus lucifugus (Light-fleeing cave crayfish)
Procambarus pallidus (Pallid cave crayfish)
Troglocambarus maclanei (McLane's cave crayfish)

densities of 500 to 3000 individuals/2000 cm^2 of plant surface area, with *Sagittaria kurziana* supporting significantly higher densities, primarily due to higher chironomid densities. Other taxa which form a large part of the epiphytic invertebrate communities are Ephemeroptera, primarily Baetidae (Bartodziej, pers. comm.) and *Tricorythodes albilineatus* and the amphipod *H. azteca* (R. A. Mattson, unpubl. data). Although not abundant, larvae of aquatic lepidoptera (the family Pyralidae) are commonly collected in submerged macrophyte beds.

An additional component of the benthic fauna of the region is the troglobytic fauna of the submerged cave habitats associated with the springs and spring-influenced streams (Hobbs, 1992). All are obligately associated with the cave habitats and exhibit characteristic adaptations such as blindless and lack of pigmentation. Most of these are crustaceans (Table 4), and many are designated by the State of Florida as endangered or threatened, primarily due to highly restricted distributions; some are endemic to a single submerged cave system (Franz, 1982).

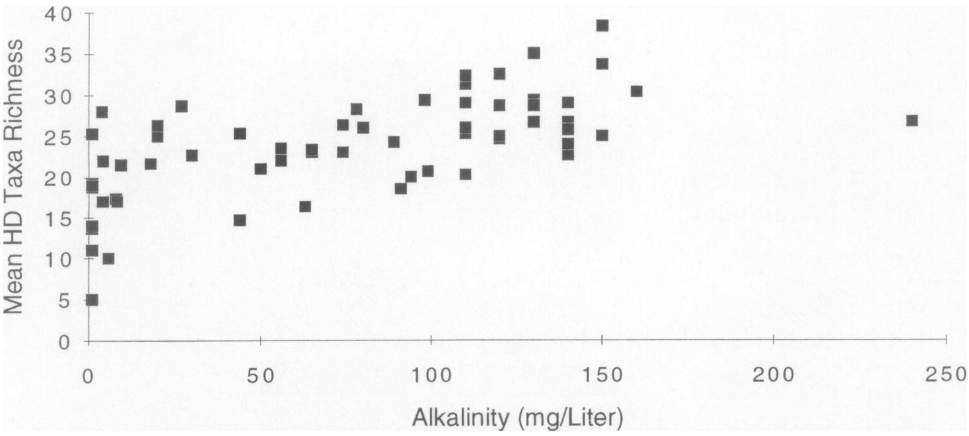


Fig. 9. Relationship between alkalinity and mean macroinvertebrate taxa richness on the Suwannee River mainstem. Data consist of mean taxa richness on three replicate Hester-Dendy samplers, collected quarterly 1989–1991 from five sites on the river mainstem, plotted against alkalinity measurement taken when samplers deployed. Data from SRWMD unpublished report.

Most appear to be omnivorous detritivores, surviving on organic material flushed into the caves through spring vents and sinkholes (Hobbs, 1992). Many may be found concentrated around organic inputs such as sinks or cave entrances (Franz, 1982; Hobbs, 1992). During river flooding in the Suwannee drainage, many springs "backflow" or take surface water when the river stage exceeds the potentiometric surface of the aquifer, which is probably one means of introducing particulate and dissolved carbon into the cave systems. Streever (1992) recently reported on large populations of *Corbicula* (up to 2820/m^2) in the submerged caves associated with selected spring systems in both the lower Suwannee and Santa Fe Rivers.

Biodiversity and Spring inflow

Data reported in this paper have come mainly from regional ambient stream monitoring programs. Most of the data have been collected from main stream reaches influenced by springs. Very little biological sampling has been conducted in the actual spring areas. Almost no experimental studies have been done to evaluate the relationships between spring input and stream community biodiversity. Studies of this type will have extremely important management implications for these lotic systems.

In north-central Florida, spring influence appears to be a major structuring force in stream communities. Increases in species richness in communities of benthic macronivertebrates are associated with input of quantities of hard, alkaline spring water in the Suwannee River mainstem (Fig. 9). Particular groups which show increases in species richness and/or relative abundance include ephemeropterans, molluscs and oligochaetes. Causative factors postulated for these trends include increased buffering, higher nutrient availability, higher primary production rates and more constant ("predictable") physical/chemical conditions. Stream periphyton communities undergo a shift in species composition with spring input; from communities dominated by green and blue-green algae to those dominated by diatoms (Mattson, unpubl. report). The spring-influenced streams of Florida are one of the few Florida stream habitats to support substantial coverages of submergent aquatic vegetation (Clewell, 1991).

In this region, the Floridan Aquifer, the primary water source for most of the springs and spring-influenced streams, is a primary source of water for human consumptive needs. It is likely that Florida will be the first eastern U.S. state to grapple with the same types of water allocation issues that have been characteristic of western U.S. states for many years. Water managers in Florida are now working to develop instream flow policies and criteria for the allocation of groundwater for human versus natural system needs. Maintenance of necessary quantities of groundwater input (how much is currently unknown at this time) will be critical to the preservation of biodiversity characteristics of springs and spring-influenced streams.

A second major threat to biodiversity is groundwater pollution with excessive nutrients and/or toxics due to land development. Many of the areas in the Coastal Lowlands are regions where the Floridan Aquifer is unconfined. These areas are moderately to highly prone to groundwater contamination (Suwannee River WMD, unpubl. data). Watersheds draining to sinking streams also represent a threat to groundwater quality. Submerged cave areas may thus be threatened by groundwater contamination or polluted groundwater may impact surface waters via spring discharge. Management efforts are currently focusing on better land use planning in areas prone to groundwater contamination (either high recharge areas or stream to sink watersheds) and development of best management practices to reduce nutrient and toxics loadings from existing land uses which appear to be threatening groundwater quality.

Acknowledgments

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Appendix 1

List of periphytic algae collected in the spring-influenced reaches of the Suwannee River drainage, 1990–1991, by the Suwannee River WMD.

DIVISION CYANOPHYTA

Anabaena sp.
Aphanocapsa delicatissima
Chamaesiphon sp.
Chroococcus dispersus v *minor*
Chroococcus limneticus
Chroococcus minutus
Fremyella sp.
Lyngbya nana
Lyngbya sp.
Oscillatoria angustissima
Oscillatoria geminata
Oscillatoria limnetica
Oscillatoria limosa
Oscillatoria sp.

DIVISION CHLOROPHYTA

Ankistrodesmus nannoselene
Bulbochaete sp.
Characium ambiguum
Characium pringsheimii
Chlamydomonas sp.
Closterium moniliferum
Closterium parvulum
Closterium sp.
Coelastrum sphaericum
Cosmarium sp.
Crucigenia tetrapedia
Dictyosphaerium pulchellum
Dispora crucigenioides
Eudorina elegans
Kirchneriella lunaris
Kirchneriella obesa
Oedogonium sp.
Pandorina morum
Protoderma viride
Scenedesmus abundans
Scenedesmus acuminatus
Scenedesmus armatus
Scenedesmus bijuga
Scenedesmus obliquus
Scenedesmus quadricauda
Schroederia setigera
Spirogyra sp.
Stigeoclonium sp.
Tetraedron minimum
Tetraedron trigonum

DIVISION CHRYSOPHYTA

Bacillariophyceae

Achnanthes clevei
Achnanthes curvirostrum
Achnanthes delicatula
Achnanthes exigua
Achnanthes exigua var. *constricta*
Achnanthes exigua var. *heterovalva*
Achnanthes hauckiana
Achnanthes hungarica
Achnanthes lanceolata
Achnanthes lanceolata var. *apiculata*

Achnanthes lanceolata var. *dubia*
Achnanthes lanceolata var. *haynaldii*
Achnanthes lanceolata var. *lanceolatoides*
Achnanthes linearis
Achnanthes minutissima
Achnanthes oestrupii
Achnanthes wellisiae
Achnanthes sp.
Amphipleura pellucida
Amphora libyca
Amphora ovalis var. *affinis*
Amphora perpusilla
Amphora veneta
Anorthoneis dulcis
Bacillaria paradoxa
Biddulphia laevis
Capartogramma crucicula
Cocconeis fluviatilis
Cocconeis pediculis
Cocconeis placentula
Cocconeis placentula var. *euglypta*
Cocconeis placentula var. *lineata*
Cyclotella atomus
Cyclotella comta
Cyclotella meneghiniana
Cymbella affinis
Cymbella minuta
Cymbella silesiaca
Cymbella tumida
Cymbella turgida
Cymbella turgidula
Cymbella sp.
Diploneis oblongella
Diploneis oculata
Epithemia adnata
Epithemia turgida
Eunotia arcus bidens
Eunotia curvata
Eunotia naegelii
Eunotia pectinalis
Eunotia pectinalis var. *minor*
Eunotia vanheurckii
Eunotia sp.
Fragilaria capucina var. *mesolepta*
Fragilaria construens
Fragilaria pinnata
Fragilaria sp.
Frustulia rhomboides
Gomphonema acuminatum
Gomphonema affine
Gomphonema angustatum
Gomphonema augur
Gomphonema clevei
Gomphonema gracile
Gomphonema grovei var. *lingulatum*
Gomphonema parvulum
Gomphonema subclavatum
Gomphonema tergestinum
Gomphonema sp.
Gyrosigma attenuatum
Gyrosigma eximium
Melosira ambigua
Melosira distans
Melosira roeseana
Melosira varians
Meridion circulare
Navicula angusta
Navicula capitata
Navicula cari
Navicula confervaceae
Navicula cryptocephala
Navicula exigua var. *capitata*
Navicula gastrum
Navicula graciloides
Navicula heufleri var. *leptocephala*
Navicula lanceolata
Navicula latens
Navicula lateropunctata
Navicula pupula
Navicula radiosa
Navicula radiosa var. *parva*
Navicula radiosa var. *tenella*
Navicula seminulum
Navicula viridula
Navicula viridula var. *linearis*
Navicula sp.
Neidium affine var. *longiceps*
Nitzschia acicularis
Nitzschia bacillum
Nitzschia constricta
Nitzschia fonticola
Nitzschia frustulum
Nitzschia gracilis
Nitzschia kuetzingiana
Nitzschia obtusa var. *scalpelliformis*

Nitzschia palea
Nitzshia paleacea
Nitzschia perminuta
Nitzschia romana
Nitzschia subtilis
Nitzschia tryblionella var. *victoriae*
Nitzschia sp.
Pinnularia abaujensis var. *subundulata*
Pinnularia viridula var. *linearis*
Stenopterobia delicatissima
Synedra rumpens
Synedra rumpens var. *familiaris*
Synedra socia
Synedra ulna
Synedra ulna var. *contracta*
Synedra ulna var. *oxyrhy. f. mediocontracta*
Terpsinoe musica

DIVISION EUGLENOPHYTA

Euglena sp.
Phacus orbicularis

Appendix 2

List of benthic macroinvertebrates collected in the spring-influenced reaches of the Suwannee River drainage, 1989–1991, by the Suwannee River WMD.

CNIDARIA

Hydrazoa

Hydra sp.

PLATYHELMINTHES

Dugesia sp.

NEMERTEA

Prostoma sp.

ASCHELMINTHES

Nematoda

Unidentified species

MOLLUSCA

Gastropoda

Amnicola sp.
Campeloma sp.
Elimia athearni
Elimia floridensis
Elimia sp.
Ferrissia sp.
Gyraulus parvus
Gyraulus sp.
Hebetancyclus excentricus
Unidentified Hydrobiidae
Laevapex sp.
Lioplax pilsbryi
Micromenetus dilatatus
Micromenetus floridensis
Micromenetus sp.
Neritina reclivata
Notogillia wetherbyi
Physella sp.
Planorbella scalaris
Planorbella trivolvis
Planorbella sp.
Pomacea paludosa
Pseudosuccinea columella
Pseudosuccinea sp.
Viviparus georgianus
Viviparus sp.

Bivalvia

Corbicula fluminea
Elliptio sp.
Musculium lacustre
Musculium sp.
Pisidium dubium
Pisidium sp.
Sphaerium sp.
Villosa villosa
Villosa sp.

ANNELIDA

Oligochaeta

Aelosoma sp.
Aulodrilus piqueti
Bratislavia unidentata
Chaetogaster sp.
Dero furcata

Dero trifida
Dero vaga
Dero sp.
Eclipidrilus sp.
Ilyodrilus templetoni
Isochaetides freyi
Limnodrilus hoffmeisteri
Nais behningi
Nais communis
Nais elinguis
Nais variabilis
Pristina leidyi
Pristina synclites
Pristina sp.
Pristinella osborni
Slavinia appendiculata
Spirosperma ferox
Stylaria lacustris
Haber cf. *speciosus*
Enchytraeidae sp.
Immature Tubificid w/o capelliform chaetae
Immature Tubificid w/capelliform chaetae

Hirudinea

Desserobdella phalera
Erpobdellidae spp.
Helobdella elongata
Helobdella fusca
Helobdella stagnalis
Helobdella triserialis
Helobdella sp.
Placobdella parasitica
Placobdella sp.
Unidentified species

ARTHROPODA

Chelicerata—Acarina

Atractides sp.
Arrenurus sp.
Eylais sp.
Geayia sp.
Hydrodroma sp.
Hygrobates sp.
Koenikea sp.
Krendowskia sp.
Lebertia sp.
Neumania sp.
Piona sp.
Sperchon sp.
Sperchonopsis sp.
Unionicola sp.

Chelicerata—Araneae

Dolomedes okefinokensis
Dolomedes triton

Crustacea—Amphipoda

Gammarus sp.
Hyalella azteca

Crustacea—Isopoda

Asellus sp.
Lirceus sp.

Crustacea—Decapoda

Procambarus fallax
Procambarus paeninsulanus
Procambarus sp.
Palaemonetes paludosus

Insecta—Collembola

Bourletiella sp.
Isotoma sp.
Podura aquatica
Willowsia sp.
Isotomidae unidentified sp.

Insecta—Coleoptera
Chrysomelidae

Agasicles hygrophila

Curculionidae

Lissorhoptrus sp.
Listronotus sp.
Onychylis nigrirostris complex
Stenopelmus rufinasus
Tanysphyrus lemnae

Dryopidae

Helichus lithophilus
Pelonomus obscurus

Dytiscidae

Agabus johannis
Bidessonotus longovalis
Celina sp.
Coptotomus interrogatus

Copelatus caelatipennis princeps
Cybister fimbriolatus
Hydroporus carolinus
Hydroporus lobatus ?
Hydroporus vittatipennis
Hydroporus undulatus ?
Hydroporus sp.
Hydrovatus pustulatus compressus
Laccophilus proximus
Laccophilus sp.
Liodessus affinis
Liodessus fuscatus
Matus ovatus
Thermonectus bassilaris

Elmidae

Ancyronyx variegatus
Dubiraphia vittata
Dubiraphia sp.
Macronychus glabratus
Microcylloepus pusillus
Stenelmis convexula
Stenelmis fuscata
Stenelmis hungerfordi
Stenelmis sinuata
Stenelmis sp.

Psephenidae

Ectopria sp.

Gyrinidae

Dineutus angustus
Dineutus carolinus
Dineutus ciliatus
Dineutus discolor
Gyrinus analis
Gyrinus elevatus
Gyrinus pachysomus
Gyrinus woodruffi

Haliplidae

Haliplus annulatus
Haliplus punctatus
Haliplus sp.
Peltodytes floridensis
Peltodytes lengi
Peltodytes oppositus
Peltodytes sexmaculatus

Hydrophilidae

Berosus exiguus
Berosus peregrinus
Derallus altus
Enochrus cinctus
Enochrus consors
Enochrus ochraceus
Enochrus pygmaeus nebulosus
Helobata striata
Helochares maculicollis
Hydrobiomorpha casta
Paracymus nanus
Sperchopsis tessellatus
Tropisternus blatchleyi
Tropisternus collaris striolatus

Noteridae

Hydrocanthus regius
Notomicrus nanulus
Suphisellus gibbulus
Suphisellus puncticollis

Scirtidae

Cyphon sp.
Prionocyphon sp.
Scirtes sp.

Insecta—Diptera
Ceratopogonidae

Alluaudomyia sp.
Atrichopogon sp.
Bezzia/Palpomyia group spp.
Culicoides sp.
Dasyhelea sp.
Forcipomyia sp.
Mallochohelea (?) sp.
Probezzia sp.
Sphaeromias sp.

Chironomidae—Tanypodinae

Ablabesmyia annulata
Ablabesmyia mallochi
Ablabesmyia ramphe group
Ablabesmyia sp.
Clinotanypus sp.
Coelotanypus scapularis
Conchapelopia sp.
Labrundinia johannseni

Labrundinia pilosella
Labrundinia sp.
Larsia sp.
Natarsia sp. A
Nilotanypus fimbriatus
Nilotanypus sp.
Pentaneura inconspicua
Procladius sp.
Rheopelopia sp. A
Tanypus carinatus
Thienemannimyia group spp.

Chironomidae—Orthocladiinae

Corynoneura sp.
Cricotopus/Orthocladius spp.
Cricotopus bicinctus
Cricotopus politus
Cricotopus sp.
Eukiefferiella claripennis group
Eukiefferiella sp.
Hydrobaenus sp.
Lopescladius sp.
Nanocladius crassicornus
Nanocladius sp.
Orthocladius annectens
Parakiefferiella sp.
Parametriocnemus sp.
Psectrocladius elatus
Psectrocladius sp.
Pseudosmittia sp.
Rheocricotopus robacki
Rheocricotopus sp.
Rheosmittia sp.
Stilocladius sp.
Synorthocladius sp.
Thienemanniella sp.
Tvetenia discoloripes group
Zalutschia sp. A

Chironomidae—Diamesinae

Potthastia longimana group

Chironomidae—Chironomini

Apedilum elachistus
Beardius truncatus
Chernovskiia sp.
Chironomus decorus group
Chironomus sp.
Cladopelma sp.
Cryptochironomus fulvus group
Cryptochironomus sp.
Cryptotendipes sp.
Demicryptochironomus sp.
Dicrotendipes lucifer
Dicrotendipes modestus
Dicrotendipes neomodestus
Dicrotendipes nervosus ?
Dicrotendipes simpsoni
Dicrotendipes tritomus ?
Dicrotendipes sp.
Endochironomus nigricans
Endotribelos hesperium
Goeldichironomus holoprasinus
Kiefferulus dux
Microtendipes pedellus group
Nilothauma sp.
Pagastiella sp.
Parachironomus carinatus
Paracladopelma sp.
Paralauterborniella nigrohalterale
Phaenopsectra punctipes group
Phaenopsectra sp.
Polypedilum aviceps
Polypedilum convictum
Polypedilum fallax
Polypedilum halterale group
Polypedilum illinoense
Polypedilum scalaenum group
Polypedilum tritum
Polypedilum sp.
Robackia claviger
Saetheria tylus
Stelechomyia perpulchra
Stenochironomus sp.
Stictochironomus caffrarius group
Stictochironomus sp.
Tribelos fuscicorne
Tribelos jucundum
Zavreliella marmorata

Chironomidae—Tanytarsini

Cladotanytarsus sp.
Paratanytarsus sp.
Rheotanytarsus exiguus group
Rheotanytarsus sp.
Stempellina sp.
Stempellinella sp.

Tanytarsus sp. A
Tanytarsus sp. C
Tanytarsus sp. D
Tanytarsus sp. E
Tanytarsus sp. G
Tanytarsus sp. I
Tanytarsus sp. K
Tanytarsus sp. L
Tanytarsus sp. M
Tanytarsus sp. O
Tanytarsus sp. P
Tanytarsus sp.

Chironomidae—Pseudochironomini

Pseudochironomus sp.

Diptera—Culicidae

Aedes vexans
Aedes sp.
Anopheles sp.

Diptera—Empididae

Hemerodromia sp.

Diptera—Muscidae

Limnophora sp.

Diptera—Simuliidae

Simulium sp.

Diptera—Stratiomyidae

Odontomyia sp.

Diptera—Tabanidae

Chrysops sp.
Tabanus sp.

Diptera—Tipulidae

Limonia sp.
Ormosia sp.
Prionocera sp.
Tipula sp.

Athericidae

Atherix sp.

Insecta—Ephemeroptera
Baetidae

Acerpenna pygmaea
Baetis alachua
Baetis armillatus
Baetis ephippiatus
Baetis frondalis
Baetis intercalaris
Baetis propinquus
Callibaetis floridanus
Procloeon hobbsi
Procloeon viridocularis

Baetiscidae

Baetisca obesa

Caenidae

Brachycercus maculatus
Brachycercus sp.
Caenis amica
Caenis diminuta
Caenis sp.
Cercobrachys etowah

Ephemerellidae

Eurylophella temporalis

Ephemeridae

Hexagenia bilineata
Hexagenia limbata
Hexagenia sp.

Heptageniidae

Stenacron floridense
Stenacron interpunctatum
Stenacron sp.
Stenonema exiguum
Stenonema smithae
Stenonema sp.

Leptophlebiidae

Choroterpes hubbelli
Leptophlebia bradleyi
Leptophlebia sp.
Paraleptophlebia volitans

Neophemeridae

Neoephemera compressa

Oligoneuriidae

Isonychia arida
Isonychia sp.

Tricorythidae

Leptohyphes dolani
Tricorythodes albilineatus

Insecta—Hemiptera

Belostoma lutarium
Belostoma testaceum
Belostoma sp.
Gerris conformis
Gerris nebularis
Hydrometra sp.
Limnoporus canaliculatus
Merragata sp.
Mesovelia mulsanti
Metrobates hesperius
Micracanthia sp.
Microvelia sp.
Neogerris hesione
Neoplea striola
Neoplea sp.
Notonecta irrorata
Notonecta sp.
Pelocoris femoratus
Ranatra australis
Ranatra buenoi
Ranatra fusca
Rhagovelia choreutes
Rhagovelia obesa
Rheumatobates tenuipes
Rheumatobates sp.
Saldula sp.
Sigara zimmermanni
Trichocorixa sexcincta
Trichocorixa sp.

Insecta—Lepidoptera

Parapoynx sp.

Insecta—Megaloptera

Chauliodes rastricornis
Corydalus cornutus
Sialis sp.

Insecta—Odonata
Zygoptera

Argia apicalis
Argia sp.
Calopteryx sp.
Enallagma sp.
Hetaerina titia
Hetaerina sp.
Ischnura sp.
Lestes sp.
Nehalennia sp.

Anisoptera

Anax sp.
Arigomphus pallidus
Arigomphus sp.
Boyeria vinosa
Didymops transversa
Dromogomphus armatus
Dromogomphus spinosus
Dromogomphus sp.
Epitheca princeps
Epitheca sp.
Erythemis simplicicollis
Erythrodiplax connata minuscula
Gomphus cavillaris
Gomphus dilatatus
Gomphus pallidus
Gomphus sp.
Hagenius brevistylus
Libellula sp.
Macromia sp.
Nasiaeschna pentacantha
Neurocordulia virginiensis
Neurocordulia sp.
Orthemis ferruginea
Pachydiplax longipennis
Progomphus obscurus
Progomphus sp.
Stylurus plagiatus
Stylurus sp.
Tramea sp.

Insecta—Orthoptera

Ellipes minutus
Neotridactylus apicalis

Insecta—Plecoptera

Acroneuria arenosa
Acroneuria sp.
Attaneuria ruralis
Hydroperla phormidia
Neoperla clymene
Neoperla sp.
Perlesta placida (complex)
Perlinella sp.
Paragnetina kansensis
Paragnetina sp.

Taeniopteryx lita
Taeniopteryx sp.

Insecta—Trichoptera
Helicopsychidae

Helicopsyche sp.

Hydropsychidae

Cheumatopsyche sp.
Hydropsyche simulans
Hydropsyche sp.
Macrostemum carolina

Hydroptilidae

Hydroptila sp.
Mayatrichia ayama
Neotrichia sp.
Ochrotrichia sp.
Orthotrichia sp.
Oxyethira sp.

Leptoceridae

Ceraclea sp.
Oecetis sp. 1
Oecetis sp. 2
Oecetis sp. 3
Oecetis sp. 4
Nectopsyche candida
Nectopsyche exquisita
Nectopsyche pavida
Nectopsyche sp.
Triaenodes sp.

Limnephilidae

Hydatophylax argus

Molannidae

Molanna tryphena

Philopotamidae

Chimarra florida
Chimarra moselyi
Chimarra sp.

Polycentropodidae

Cyrnellus fraternus
Neureclipsis sp.
Phylocentropus placidus
Phylocentropus sp.
Polycentropus sp.

Psychomyiidae

Lype diversa

Rhyacophillidae

Rhyacophila sp.

BRYOZOA

Pectinatella magnifica