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OFFICE OF SECRETARY
RULEMAKINGS AND
ADJUDICATIONS STAFF

I know you all are aware that building nuclear plants so close to the Gulf of Mexico, and on fragile coastal ecosystems, requires the utmost care in selecting sites and plans for construction. Any mistakes that result in damage to the Gulf Coast ecosystems will surely create an uproar on the scale of the BP oil spill. There are many of us here today who can comment on the science of that with more expertise than I have.

My mission today is to remind all of you that you have a responsibility not only to the folks who will live within the shadow of the new nuclear plants, but also to those who cannot speak for themselves, and who are perhaps not even recognized by most of us.

For this reason, I have given you copies of a paper written by Stephen J. Walsh of the US Geological Survey entitled Freshwater Macrofauna of Florida Karst Habitats.

The aim of the paper is to emphasize several very important points:

1. **You must understand that what affects salt water, as in the Gulf of Mexico, also affects freshwater habitats, as the water from the Gulf interacts significantly with the water of the Floridan Aquifer in the location you have chosen.**

2. **With the exception of those parts of Florida that have already used up freshwater resources in their area, and who have already turned to desalinization, the Floridan Aquifer is THE source of fresh water for all Floridians who live in the western half of the state.**

3. **Our freshwater quantity and quality in the western half of the state has suffered serious degradation as the state's population increases, requiring greater demands on the Floridan Aquifer, and greater opportunities for degradation of the aquifer thanks to mining, which exposes the water to airborne pollutants; large-**

scale farming with heavy use of fungicides, insecticides and fertilizer; and ever increasing development of land that used to serve to filter and cleanse the rainfall ~~is~~ as the water passes back into the aquifer.

3. **Within this USGS report are analyses that demonstrate how CRITICAL it is to maintain not only happy humans and fresh water, but also healthy waters in caves and springs to support <u>every</u> life form in Florida, from macrofauna right on up to humans.**

4. **The *reason* that *macrofauna are* so *important* is that they *are* the base of the chain of life. They are the bellwethers of the coastal habitats; they *are* the canaries in the coal mine.**

I urge you to think very carefully about not only ~~your company's~~ the challenges in the building of two more nuclear facilities in Florida's fragile coastal areas, but also of the absolute necessity of fiercely protecting the biodiversity that is critical to life for us now, and for the generations to come. Shrinking biodiversity and threatened macrofauna always means, inevitably, a less promising future for humans as well.

Susan Woods, President, Floridan Aquifer Legal Defense Organization

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Freshwater Macrofauna of Florida Karst Habitats

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INTRODUCTION

The caves, springs, and seeps that comprise karst habitats within the United States harbor unique and diverse faunal assemblages that are biologically important due to their high degree of endemicity. Culver and others (2000) summarized the described obligate cave fauna of the U.S. and determined that 594 (61%) of a total of 973 taxa are confined in distribution to one county; nearly a third of all taxa occur at single sites. The aquatic fauna is a major component of the karst biota and includes about one third of all known cave species. In fact, the distribution of the aquatic biota across karst habitats accounts for an estimated 4% of the total surface area of the contiguous U.S. (Culver and others, 2000). Karst systems of Florida contain among the most diverse aquatic faunas nationwide. Within Florida, the greatest karst biodiversity is found in the northern peninsula and east-central panhandle. Franz and others (1994) reviewed the cave faunas of Florida and southern Georgia and identified 267 biologically important caves serving as critical habitat for populations of 27 invertebrate and one vertebrate taxa, of which nearly all species (93%) are aquatic.

Compared to cave faunas, fewer synoptic studies are available for the myriad of spring habitats and species of the U.S. Williams and Smith (1990) provided an extensive international bibliography of spring habitats and their faunas. Few comprehensive surveys exist of the biota of Florida's extensive spring habitats. Woodruff (1993) summarized previous literature, conducted a limited survey of 13 selected Florida springs, and developed a classification system based on a cluster analysis of springs using water chemistry data provided by Rosenau and others (1977), the U.S. Geological Survey, Water Management Districts, and other sources. Mattson and others (1995) examined the biota of springs and spring-influenced streams of the Suwannee River drainage in northwest Florida and included a synopsis of the periphyton and benthic invertebrate communities.

The purpose of this paper is to summarize the relevant literature and information on the aquatic macrofauna of Florida karst habitats. The biota of submerged caves and springs are considered together because of the integral connection between subterranean and surface ground-water habitats in the state and the similar ecological conditions that exist for karst-adapted species. Major sources of information on organisms in Florida's karst environments are the synoptic works by Thompson (1968), Franz and Lee (1982), Woodruff (1993), Franz and others (1994), Deyrup and Franz (1994), Mattson and others (1995), and numerous original descriptions of both hypogean and epigean species.

STUDY AREA

Florida has expansive karst areas that include a combination of diverse and globally unrivaled large-magnitude springs, caverns, caves, sinks, disappearing streams and lakes, and complex subterranean aquifers (Rosenau and others 1977; Lane 1986; Miller 1997). Four principal aquifer systems are exposed at the surface or covered by a thin layer of confining soils and receive recharge primarily via precipitation (Figs.1, 2).

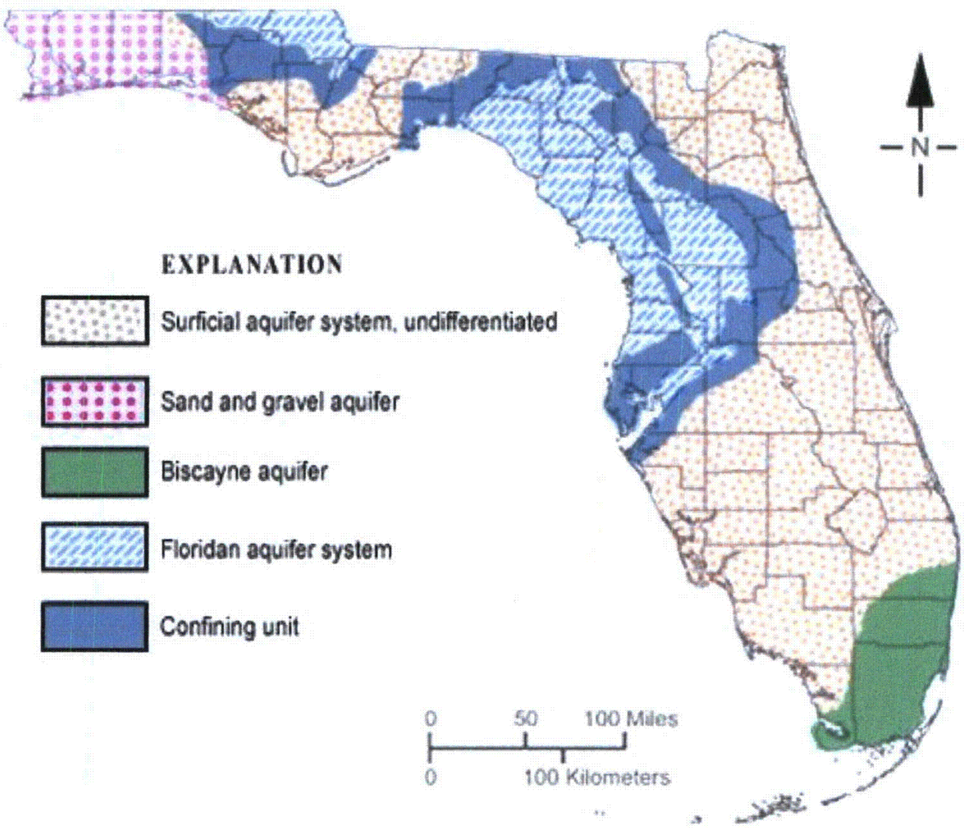

Figure 1. Principal aquifers of Florida exposed at or near the land surface (after Miller 1997).

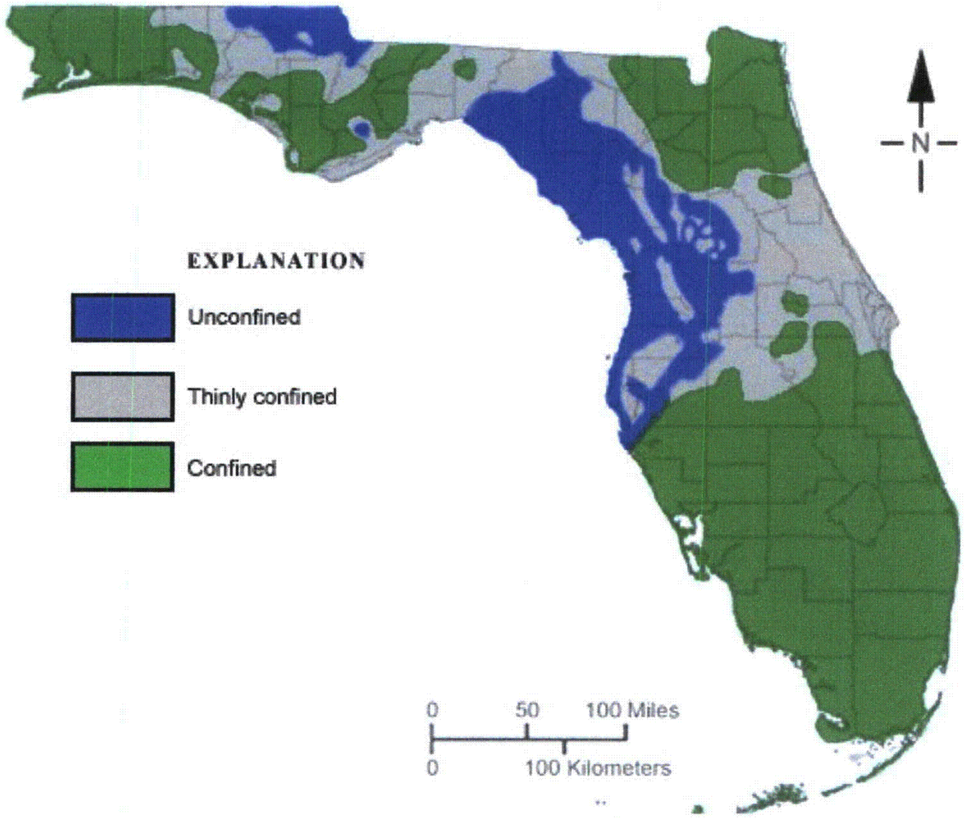

Figure 2. Extent of surficial contact with the Floridan Aquifer (from Miller 1997; unconfined = absent or thin; thinly confined <100 ft; confined >100 ft).

The largest system and major source of ground water, the Floridan aquifer, consists of a thick sequence of Tertiary carbonate rocks with a complex lithological profile defined by soil characteristics, permeability, geological depositions, and erosional history (Miller 1997). The smaller Biscayne aquifer, which serves as the primary source of ground water for largely urbanized areas of southeast Florida, is also comprised mainly of carbonate rocks. These two carbonate-rock aquifers are more mineralized than other Florida aquifers that are composed of siliclastic rocks. Because of their complex history, geomorphology, and ecological characteristics, the carbonate-rock aquifers provide important habitats for unique assemblages of spring- and cave-adapted organisms.

METHODS

Information on aquatic species in karst habitats of Florida was obtained from a variety of published sources. Emphasis is on macroscopic mollusk and crustacean invertebrates and one vertebrate that are obligately associated with ground-water environments. Synoptic taxonomic, distributional, and microhabitat data were obtained primarily from Hobbs (1942, 1989), Hobbs and others (1977), Thompson (1968, 1984), Franz and Franz (1990), Deyrup and Franz (1994),

and Franz and others (1994). Common names of decapod crustaceans and mollusks follow Williams and others (1989) and Turgeon and others (1998) except where species are unnamed, where other authors (e.g., Franz and others, 1994) propose alternative names, or names are suggested herein by inclusion within quotation marks. Conservation status was determined from Deyrup and Franz (1994), Taylor and others (1996), and the official list of state-protected taxa by the Florida Fish and Wildlife Conservation Commission. The following terminology, after Franz and others (1994), Culver and others (2000), and additional sources, applies to taxa associated with cave and ground-water habitats: troglobites are forms that are confined to caves and exhibit unique morphological specializations for subterranean life (e.g., depigmentation, reduction or loss of eyes, and development of accessory sensory structures); stygobites are aquatic troglobites; phreatobites are taxa that inhabit interstitial ground waters and may also occur regularly in some cave and spring habitats; troglophiles are taxa that may complete parts or all of their life history in caves as well as epigean habitats, but lack the extreme morphological specializations of troglobites; trogloxenes occur regularly in caves but do not complete their life cycles in them; accidentals are species that do not normally inhabit caves but are occasionally encountered in them; endemic taxa (= precinctive of Franz and others, 1994) are those that occur in highly localized habitats, often single caves, springs and spring-runs, and single aquifer systems. Occurrence of species by drainage or faunal region is based exclusively on published distributional information (Fig. 3, Table 1).

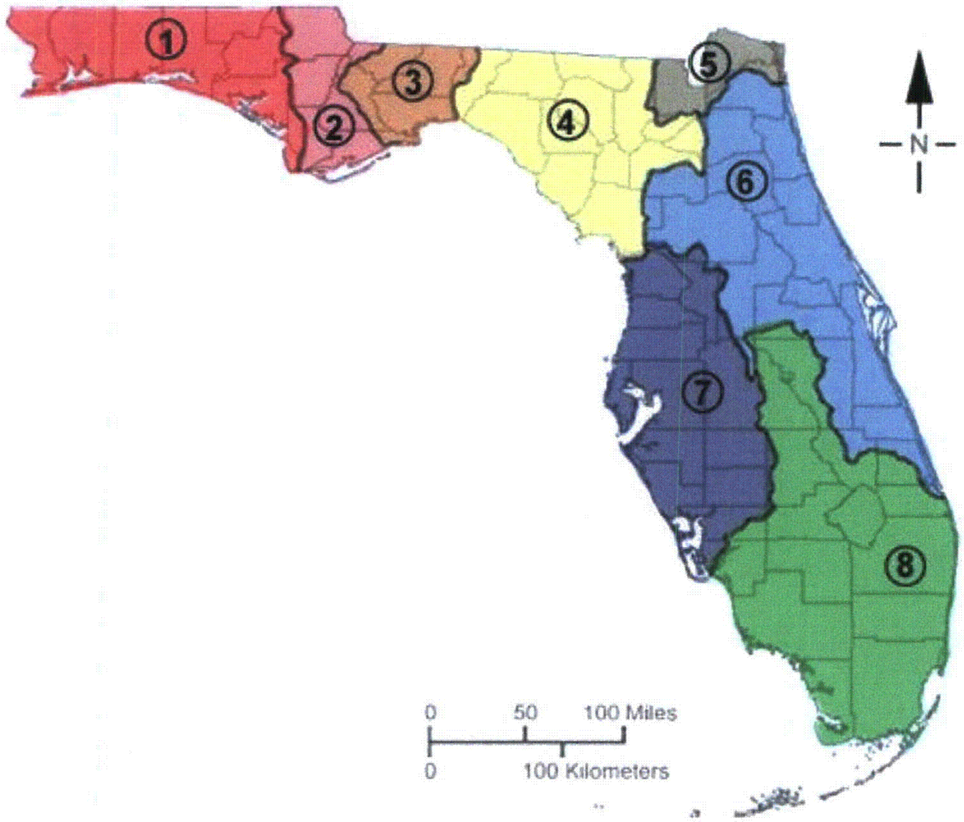

Figure 3. Surficial hydrologic subregions identified by Rosenau and others

(1977). Each subregion is an assemblage of smaller hydrologic units.

1 = Choctawhatchee-Yellow-Escambia
2 = Apalachicola-Chattahoochee-Flint
3 = Ochlockonee
4 = Aucilla-Suwannee
5 = Altamaha-St. Marys
6 = St. Johns
7 = west coastal area (Withlacoochee, Hillsborough, Peace, and others)
8 = southern Florida

Table 1. Obligate and predominate macrofaunal species of Florida karst habitats. Distributional occurrences (X) correspond with surficial hydrologic subregions of Rosenau and others (1977; see Figure 3; no obligate species are recorded in drainage 5). Conservation status categories are: E=Endangered, T=threatened, R=Rare, SSC=Species of Special Concern (FCREPA; Deyrup and Franz, 1994); E=Endangered, T=Threatened, SC=Special Concern (AFS; Taylor and others, 1996). Sites=number of cave or spring localities reported.

			Hydrologic Subregion							**Conservation Status**	
		sites	**1**	**2**	**3**	**4**	**6**	**7**	**8**	**FCREPA**	**AFS**
CAVES											
Gastropoda											
Hydrobiidae											
Dasyscias franzi	Shaggy Ghostsnail	1	X								
Amphipoda											
Crangonyctidae											
Crangonyx grandimanus	Florida Cave Amphipod	>20			X	X	X	X	X	SSC	
Crangonyx hobbsi	Hobbs' Cave Amphipod	>20			X	X	X	X	X	SSC	
Isopoda											
Asellidae											
Caecidotea hobbsi *	Florida Cave Isopod	10-11		X		X	X			SSC	
Caecidotea sp. 1 *	"Econfina Cave Isopod"	1	X								
Caecidotea sp. 2*	"Rock Springs Cave Isopod"	1					X				
Remasellus parvus *	Swimming Little Florida Cave Isopod	4			X	X				R	
Decapoda											
Cambaridae											
Cambarus cryptodytes	Apalachicola Cave Crayfish	20		X						R	T
Procambarus acherontis	Orlando Cave Crayfish	6					X			T	E
Procambarus attiguus	Silver Glen Springs Cave Crayfish	1					X			R	E
Procambarus delicatus	Big-Cheeked Cave Crayfish	1					X			R	E

Procambarus erythrops	Santa Fe Cave Crayfish	5			X				R	E
Procambarus franzi	Orange Lake Cave Crayfish	4				X			R	E
Procambarus horsti *	Big Blue Springs Cave Crayfish	3-4		X	X				R	E
Procambarus leitheuseri	Coastal Lowland Cave Crayfish	8					X		R	E
Procambarus lucifugus alachua	Alachua Light-Fleeing Cave Crayfish	13			X				R	T
Procambarus lucifugus lucifugus	Withlacoochee Light-Fleeing Cave Crayfish	2					X		R	E
P. l. lucifugus X *P. l .alachua*	[intergrade populations]	16			X	X				
Procambarus milleri	Miami Cave Crayfish	2						X	R	E
Procambarus morrisi	Putnam County Cave Crayfish	1				X			T	E
Procambarus orcinus	Woodville Karst Cave Crayfish	15		X					R	T
Procambarus pallidus	Pallid Cave Crayfish	>20			X				R	SC
Procambarus sp.	"Hawthorne Cave Crayfish"	1				X				
Troglocambarus maclanei	Northern Spider Cave Crayfish	16			X	X	X		R	SC
Troglocambarus sp. 1	Orlando Spider Cave Crayfish	1				X				
Palaemonidae										
Palaemonetes cummingi	Squirrel Chimney Cave Shrimp	1			X				E	
Caudata (Vertebrata)										
Plethodontidae										
Haideotriton wallacei	Georgia Blind Salamander	12	X						R	
SPRINGS										
Gastropoda										
Hydrobiidae										
Aphaostracon asthenes	Blue Spring Hydrobe	1				X			T	
Aphaostracon chalarogyrus	Freemouth Hydrobe	1				X			E	
Aphaostracon hypohyalinum	Suwannee Hydrobe	7			X					
Aphaostracon monas	Wekiwa Hydrobe	1				X			T	
Aphaostracon pycnum	Dense Hydrobe	1				X			SSC	
Aphaostracon theiocrenetum	Clifton Spring Hydrobe	1				X			T	
Aphaostracon xynoelictum	Fenney Spring Hydrobe	1					X		SSC	
Cincinnatia helicogyra	Crystal Siltsnail	1					X			
Cincinnatia mica	Ichetucknee Siltsnail	1			X				SSC	
Cincinnatia monroensis	Enterprise Siltsnail	1				X			E	
Cincinnatia parva	Pygmy Siltsnail	1				X				
Cincinnatia petrifons	Rock Springs Siltsnail	1				X				
Cincinnatia ponderosa	Ponderous Siltsnail	1				X				

Cincinnatia vanhyningi	Seminole Siltsnail	1					X		
Cincinnatia wekiwae	Wekiwa Siltsnail	1					X		
Spilochlamys conica **	Conical Siltsnail	>20			X	X			
Spilochlamys gravis **	Armored Siltsnail	>20					X		
Pleuroceridae									
Elimia vanhyningiana	Goblin Elimia	3					X		
SEEPS									
Odonata									
Cordulegastridae									
Cordulegaster obliqua fasciata	Arrowhead Spiketail	-	X	X	X	X			R
Cordulegaster sayi	Say's Spiketail	-	X	X		X	X		T
Corduliidae		-							
Somatochlora provocans	Treetop Emerald	-		X	X				T
Gomphidae		-							
Dromogomphus armatus	Southeastern Spinyleg	-	X	X	X	X	X	X	R
Progomphus bellei	Belle's Sanddragon	-	X	X	X				R
Petaluridae		-							
Tachopteryx thoreyi	Gray Petaltail	8	X	?	X	X			R

*occurs in caves and springs
**spring preference, not obligate

RESULTS AND DISCUSSION

Cave Habitats

Cave habitats in Florida with readily accessible entry points have historically generated considerable interest to speleologists and scientists. Franz and others (1994) provided a detailed history of biospeleological exploration of the state's cave habitats. This history includes notable contributions by various early explorers during the late 1800s, prolific crustacean studies of the late Horton H. Hobbs, Jr., and associates that culminated in a landmark monograph on Florida's crayfish fauna (Hobbs, 1942), and the important modern period (1970-1992), during which time Richard Franz (Florida Museum of Natural History) and colleagues continued a rich period of exploration, discovery, and description of new species, coupled with a synthesis of existing information and elucidation of distributional, phylogenetic, and ecological data.

Approximately 630 caves have been identified in Florida by the Florida Speleological Society, of which Franz and others (1994) reported at least 267 (42%) as having important macroscopic troglobitic faunas. Most of the species in these caves are aquatic, although these authors also included terrestrial taxa as well as those that are considered to be facultative in cave environments (i.e., troglophiles, trogloxenes, and accidentals). The most important cave habitats

are concentrated in the north-central peninsula and eastern panhandle, with over half of the biologically significant caves identified by Franz and colleagues located in four counties : Alachua (47 caves), Suwannee (43), Jackson (34), and Marion (27). Twenty additional counties in Florida and two in southern Georgia have caves, ranging in number from one to 15, that are important in the distribution of troglobites.

The known stygobites of Florida and southern Georgia include 18 crayfishes (including two subspecies and intergrade populations), three isopods, two amphipods, one shrimp, one snail, and one salamander (Franz and others, 1994; Table 1). Several of these taxa are undescribed due to a paucity of critical material with diagnostic morphological characters (e.g., reproductively mature male crayfishes). Greatest study has been devoted to the decapod crustaceans due in part to their remarkable radiation in Florida's cave habitats. In addition to the free-living species, there are at least four obligate commensals on stygobites in circum-Florida karst assemblages: *Cambarincola leoni* and other unidentified branciobdellid annelids reported from seven crayfish populations; and, three species of entocytherid ostracods (*Uncinocythere ambophora, U. equicurva*, and *U. lucifuga*), also recorded from several crayfish species. Several additional ostracods and copepods were retrieved either free swimming or from the gut of the stygobitic salamander, *Haideotriton wallacei*; however, the taxonomy, distribution, and ecology of these microcrustaceans are largely unstudied. Additionally, troglobitic and trogloxenic springtails (Insecta: Collembola) are often closely associated with subterranean aquatic habitats and may be important prey for stygobites. Franz and others (1994) provided a detailed, annotated list of other cave-associated species that includes 23 troglophiles, 47 trogloxenes, and 37 accidentals. The non-troglobitic organisms reported by these authors include a variety of terrestrial and aquatic non-arthropod invertebrates, arthropods (especially insects, epigean crustaceans, and arachnids), and vertebrates. The principally epigean vertebrate fauna consists of nine fishes, 16 amphibians, nine reptiles, two birds, and 13 mammals, including six bats.

Study of the zoogeography of Florida's troglobitic fauna has been refined through the years as new distributional data have become available and as geologic and hydrologic information has been incorporated. Early investigations such as those by Hobbs (1958), Caine (1974a), Relyea and others (1976), Hobbs and others (1977), and Franz and Lee (1982) were summarized and updated by Franz and others (1994) to include the most recent interpretations. The obligate cave faunas fall into six distinct regions, each characterized by a unique combination of hydrological, geological, and ecological characteristics: (1) Econfina Creek Fauna, with two endemic taxa (*Dasyscias franzi* and *Caecidotea* sp. 1), is known from a single cave associated with a limited karst area in Washington and Bay counties; (2) Apalachicola Fauna, with three endemic taxa (*Cambarus cryptodytes, Islandiana* sp., *Haideotriton wallacei*), in two segments (Marianna Lowlands, Jackson County, FL, and Dougherty Plain, lower Flint River, GA) with caves that are developed near the boundary of the Ocala Group, Suwannee, and Marianna limestones (all formations of the Floridan Aquifer); (3) Woodville Fauna, with two endemic taxa (*Procambarus horsti, P. orcinus*) associated with the Ocala Group limestones in eroded segments of the Tallahassee Hills and Woodville Karst Plain near and below the Cody Scarp (boundary between Northern Highlands and Gulf Coastal Lowlands), paralleling riverine karst areas of the Wakulla-St. Marks and Wacissa rivers; (4) Ocala Fauna, containing a rich stygobitic group that includes nine endemic taxa (*Palaemonetes cummingi, Procambarus erythrops, P. franzi, P. leitheuseri, P. lucifugus lucifugus, P. l. alachua, P. l. lucifugus* X *P. l. alachua, P. pallidus, Troglocambarus*

maclanei) in six geographically- and faunistically-distinct assemblages occurring in mature and riverine karst areas associated with the Ocala Group limestones from the Suwannee River drainage southward to Pasco County; (5) St. Johns River Fauna, containing seven endemics (*Caecidotea* sp. 2, *Procambarus acherontis*, *P. attiguus*, *P. delicatus*, *P. morrisi*, *P.* (*Lonnbergius*) sp., and *Troglocambarus* sp.) in two assemblages developed near contact zones of the Hawthorne Formation and underlying Ocala Group limestones, the Wekiva Assemblage in a small karst area along the Wekiva River, and the Lake George Assemblage, occurring along the western fringe of Lake George, Alexander Springs, and the lower Oklawaha River; and, (6) the Miami Fauna, a small assemblage containing one endemic species (*Procambarus milleri*) in solution holes and shallow wells associated with the Miami oolite formation of the Biscayne Aquifer. Several faunal regions include troglobitic taxa that also occur in at least one other region. Hobbs and others (1977), Franz and Lee (1982), and Franz and others (1994) provided detailed discussion of hypothesized zoogeographic relationships among the stygobitic crayfishes, including possible speciation and dispersal events.

Ecological data on stygobites of Florida are largely anecdotal. The most detailed invertebrate study to date was the comparison of hypogean and epigean crayfishes by Caine (1974b, 1978). Other studies documenting life-history and habitat information of cave crayfishes include Relyea and Sutton (1973a, b). Published taxonomic descriptions of some species include limited data on ecology, habitat, and associated species. Perhaps the most significant aspect of the ecology of Florida's stygobites, like troglobites elsewhere, are the limitations imposed by restricted energy input into the systems in which they occur. In many caves, allochthonous nutrients and detritus transported via ground water are the primary source of energy that supports troglobitic communities. However, some Florida caves have important bat colonies that produce large amounts of guano that sustains the subterranean fauna (Franz and others, 1994). Streever (1996) reported relatively low organic carbon influxes to Sim's Sink cave (Suwannee County) and speculated on possible energetic limitations to the endemic crayfish *Procambarus erythrops*. In a few systems, there may be flocculent mats of chemautotrophic bacteria that serve as a trophic base for stygobitic grazers (Hobbs and Franz, 1992; Franz and others, 1994).

Unlike the rich invertebrate radiation that has evolved in ground waters of the state, submerged Florida caves are unusual in their lack of vertebrate diversity. Other karst regions of North America (e.g., Edwards Aquifer, Interior Highlands) have prominent stygobitic fishes, but Florida has no true troglobitic fishes. Nevertheless, various cave systems in Florida are utilized by a small number of fish species. The Redeye Chub (*Notropis harperi*) exhibits the closest apparent association with Florida springs and caves (Marshall 1947) and has been observed deep in subterranean waters of the St. Johns River drainage. Relyea and Sutton (1973c) observed bullhead catfishes (*Ameiurus natalis*) in close association with Redeye Chub in isolated caves of the Suwannee River drainage, and speculated that both species may have been spawning in ground-water habitats. Diet analyses of the catfish revealed significant predation on troglobites, and fish exhibited fin abnormalities suggesting possible inbreeding from low population size. However, it remains unknown as to whether either of the above species is capable of completing its life history within caves. Other notable trogloxene and accidental fishes observed in Florida caves include the American Eel (*Anguilla rostrata*), Pirate Perch (*Aphredoderus sayanus*), Eastern Mosquitofish (*Gambusia holbrooki*), Striped Bass (*Morone saxatilis*), Brown Bullhead (*Ameiurus nebulosus*), Bluegill (*Lepomis macrochirus*), and Black Crappie (*Pomoxis*

nigromaculatus) (Franz and others, 1994). There have been few ecological studies of subterranean fish populations in Florida. Helfman (1986) observed daily movements of American Eel from food-limited cave interiors to shallow-habitat foraging areas.

Spring Habitats

Florida is renown for its extensive springs and spring-fed rivers. In their landmark monograph that continues to serve as a primary source of information, Rosenau and others (1977) surveyed the state's springs and provided detailed data on water chemistry and physical features. Springs are generally classified on the basis of geomorphology, flow, temperature, water chemistry, and other physical characteristics, excluding, for the most part, biological communities. There are 27 first-magnitude springs (those having a water discharge > 100 ft^3/sec) in the state, providing Florida with the largest number and discharge of major springs in any area of similar geographic size; these large springs account for about 80% of the total ground-water discharge for the state. Most of Florida's springs are artesian, formed as hydrostatic pressure of ground water in karst sediments rises to the surface and resurges through natural breaches in impermeable or thin confining layers (Fig. 1). There are also numerous water-table springs in the state, formed by percolation of surface water through permeable sediments and sheet flow along the gradient of an impermeable layer to an outcrop point where water issues forth as a seep or non-artesian spring. Many of the major springs in Florida are situated in the northern half of the peninsula and are associated with the high Tertiary stratum known as the Ocala Uplift. The elastic-sediment veneer of the uplift was deposited more thinly and eroded more quickly than other confining layers throughout the state, thus exposing the Floridan Aquifer at the surface. In addition, other spring concentrations are found in areas of surficial down-cutting, such as sinks and river valleys (e.g., the Suwannee River drainage). The Floridan Aquifer is not the sole source of water for the state's artesian springs; for example, many springs in the Central Highlands and eastern panhandle are supplied by intermediate aquifers (Woodruff, 1993). General descriptions of the geology and hydrology of Florida's ground-water resources is provided by Rosenau and others (1977), Lane (1986), and Miller (1997).

Woodruff (1993) proposed a revised classification of Florida's springs based on a detailed analysis of water chemistry data. Using cluster analysis of the six predominant ions, he recognized four basic groupings among 170 Florida springs: (1) low ionic springs; (2) calcium bicarbonate springs; (3) mixed springs; and, (4) salt springs. There is a gradient of increased ionic concentration across the groupings from low-ionic to salt springs, especially due to sodium and chloride. The most common spring type, calcium bicarbonate (76% of springs examined), are formed from dissolution of limestone and dolomite principally in the Floridan Aquifer and are typically associated with karst terrain subjected to river down-cutting extending from the panhandle southward through the peninsula. Woodruff (1993) recognized three subgroupings of calcium bicarbonate springs: a low-calcium bicarbonate subgroup distributed in the western panhandle and Central Highlands; an intermediate subgroup with a similar range but also including springs in the eastern panhandle, upper Suwannee, and St. Johns river drainages; and, a high-calcium bicarbonate subgroup largely confined to the Ocala Uplift region within the Suwannee River drainage. Salt springs (12% of those examined) and mixed springs (8%) occur primarily near coastal zones where salt deposits or saltwater intrusion influence ionic composition. Along the west coast, these spring types are found from the St. Marks River

drainage (Wakulla County) southward to Sarasota County, and on the east coast these spring types emerge inland within the St. Johns River drainage. Springs of the smallest group, the low-ion type (4%), are confined to the panhandle and northern peninsula where they resurge from surficial or intermediate aquifers. Woodruff's (1993) delineation differs slightly from that of Miller (1997; Fig. 6.4.1), but the distribution and physicochemical composition of each spring type corresponds well with regional geological and hydrological features of the aquifer system.

The extensive springs and spring-fed streams of Florida provide important habitats for rich biological communities (Nordlie 1990) that include a number of obligate spring taxa. Neverthelesss, relatively few detailed studies exist on the diversity, distribution, and ecology of the facultative and spring-dependent fauna and associated habitats in Florida springs. Woodruff (1993) found that the diverse chemical composition of Florida's springs has a strong influence on representative aquatic assemblages. Although the relatively stable physicochemical conditions of many springs contribute to extremely high productivity rates, other aspects of water chemistry (e.g., low dissolved oxygen levels) may be limiting for many species, especially near the vent (McKinsey and Chapman, 1998). Florida springs and spring runs support diverse, productive algal and macrophyte communities that serve as a trophic base for primary consumers while providing essential habitat for other species (Whitford 1956; Woodruff 1993; Mattson and others, 1995). The obligate spring-dwelling macrofauna of Florida is dominated by the diminutive hydrobiid gastropods, including many species that have highly restricted ranges often confined to single springs or reaches of spring runs (Table 1; in addition to those listed, there are at least four recently discovered new species of *Cincinnatia* confined to small springs in Seminole State Forest, Lake County; F.G. Thompson, pers. com.). Many other invertebrates and vertebrates utilize springs facultatively. Populations of some benthic invertebrates (e.g., gastropods, crustaceans) may reach extraordinary levels in spring habitats. These species are important primary consumers and a significant prey base for other organisms. Woodruff (1993) reported densities of amphipods exceeding 26,000 per m^2 in some springs. The survey by Mattson and others (1995) provides an example of the rich diversity of macroinvertebrates that populate Florida springs and spring-fed rivers (Table 2). Among the more visible groups of facultative species in springs are fishes; notable studies of Florida fishes in spring habitats and spring-fed streams include those of Hubbs and Allen (1943) and Hellier (1967). The ichthyofauna of Florida springs includes a large number of resident freshwater species, as well as many marine invaders that are able to persist due to the ionic composition of bicarbonate spring effluents. Many marine-derived species penetrate spring-fed systems far inland, have established breeding populations, and/or are diadromous, including the Striped Mullet (*Mugil cephalus*), Hogchoker (*Trinectes maculatus*), Atlantic Stingray (*Dasyatis sabina*), Gulf Pipefish (*Syngnathus scovelli*), Mountain Mullet (*Agonostomus monticola*), Gulf Sturgeon (*Acipenser oxyrinchus desotoi*), and many other species. One of the most familiar vertebrates in Florida springs is the West Indian Manatee (*Trichechus manatus latirostris*).

Table 2. Benthic macroinvertebrate diversity from spring-influenced reaches of the Suwannee River, Florida, reported by Mattson and others (1995). Some species represent taxonomic complexes, are undescribed, or were not identified below genus level. Unidentified species represent those unassigned below family level. Parenthetical numbers following select insect orders indicate numbers of families represented.

Phylum	Subphylum/Class/Subclass/Order	Genera	Species	Unident.
Cnidaria	Hydrozoa	1	1	
Platyhelminthes	-	1	1	
Nemertea	-	1	1	
Aschelminthes	Nematoda			1
Mollusca	Gastropoda	16	25	1
	Bivalvia	6	9	
Annelida	Oligochaeta	16	24	3
	Hirudinea	4	9	1
Arthropoda	Chelicerata-Acarina	14	14	
	Chelicerata-Araneae	1	2	
	Crustacea-Amphipoda	2	2	
	Crustacea-Isopoda	2	2	
	Crustacea-Decapoda	2	4	
	Insecta-Collembola	4	4	1
	Insecta-Coleoptera (11)	45	73	
	Insecta-Diptera (10)	89	133	
	Insecta-Ephemeroptera (10)	19	36	
	Insecta-Hemiptera	19	29	
	Insecta-Lepidoptera	1	1	
	Insecta-Megaloptera	3	3	
	Insecta-Odonata (suborder Zygoptera)	7	9	
	Insecta-Odonata (suborder Anisoptera)	19	29	
	Insecta-Orthoptera	2	2	
	Insecta-Plecoptera	8	12	
	Insecta-Trichoptera (10)	23	33	
Bryozoa	-	1	1	

Spring seeps are a small component of karst habitats in Florida, yet they often have unusual and highly localized biological communities. The majority of biologically important seep habitats occur in the northern portion of the peninsula and in the panhandle. Table 1 includes six species of dragonflies that have limited distributions near seep areas within Florida; some of these species have relatively widespread distributions in the southeastern U.S., but their habitat requirements appear to be confined to seepages. Other species may also be limited to or exhibit strong ecological affinities for seep habitats. Some burrowing crayfishes, especially in Coastal Plain drainages of the panhandle, are closely tied to seep areas (e.g., *Cambarus pyronotus*, *C. striatus*, *Procambarus rogersi*). *Procambarus geodytes* is a burrowing species that appears to be confined to sulfur and mineral seeps in the St. Johns River drainage (Hobbs, 1942).

CONSERVATION

The endemic fauna of Florida karst habitats includes many highly vulnerable species. Of the 27 stygobites listed in Table 1, nearly one third are known from only one cave system, and 67% of the taxa are reported from 10 sites or less. The most recorded endemic taxa are from the St. Johns River (8) and the Suwannee River (6) drainages, with the fewest known from the western panhandle and southern Florida regions. The Florida Committee on Rare and Endangered Plants

and Animals (FCREPA; Deyrup and Franz, 1994) recognized three species of special concern, 15 as rare, two as threatened, and one as endangered. In contrast, Taylor and others (1996) considered the crayfish fauna alone to include two species of concern, three as threatened, and nine as endangered. The Florida Fish and Wildlife Conservation Commission currently recognizes the following taxa on its official list of endangered (E), threatened (T), and species of special concern (SSC): Squirrel Chimney Cave Shrimp, *Palaemonetes cummingi* (T); Santa Fe Cave Crayfish, *Procambarus erythrops* (SSC); and, Georgia Blind Salamander, *Haideotriton wallacei* (SSC). Currently, *Palaemonetes cummingi* is the only stygobite of Florida karst that is afforded protection under the U.S. Endangered Species Act. The spring-obligate gastropod fauna includes species with highly restricted ranges, yet of those listed in Table 1, only two are considered endangered, three threatened, and three of special concern (Deyrup and Franz, 1994). Fourteen (78%) of the hydrobiid and pleurocerid snails are known from only single sites, and the majority of Florida's karst-limited gastropods occur in isolated springs of the St. Johns River drainage. At present, the endemic stygobitic and spring species of Florida's karst habitats may be inadequately protected insofar as listing by state or federal natural-resource agencies. All seep-associated dragonflies in Table 1 were considered imperiled by FCREPA, but none of them are currently pending or listed by the U.S. Fish and Wildlife Service.

Like many other geographic regions with prominent karst systems, the most significant threats to Florida's karst biota relate to human activities (Drew and Hötzl, 1999; Walsh, 2000). Spring and cave species are especially susceptible to habitat loss, ground-water contamination, aquifer withdrawals, saltwater intrusion, and competition or predation by nonindigenous species. Springs are frequently modified for consumptive or recreational purposes, with concomitant impacts on aquatic organisms. Many of Florida's karst species are threatened by habitat modifications due to their very localized distributions. For instance, the Enterprise Siltsnail (*Cincinnatia monroensis*) may have been eliminated by hydroelectric development at the single spring that it is confined to. Perhaps the most serious potential threat to Florida's hypogean and spring faunas is ground-water pollution and/or saltwater intrusion as land surface is developed and aquifer resources are increasingly tapped. Streever (1992, 1995) reported on a kill and post-kill recovery of the troglobitic Santa Fe Cave Crayfish (*Procambarus erythrops*) and three troglophiles that may have been due to physicochemical changes associated with flushing of contaminants and/or Suwannee River water during a flood event. In recent years, there have been notable increases in contaminants and nutrients within some Florida ground-water sources (e.g., Katz and others, 1999). Eutrophication in spring habitats may result in greater algal growth, increased turbidity, and physicochemical and biological changes that can be detrimental to native species. Although ecological effects of nonindigenous animals in Florida karst are largely undocumented, introduced Asiatic thiarid snails (Fawn Melania, *Melanoides turricula*; Quilted Melania, *Tarebia granifera*) have been found to displace native hydrobiid snails in several Florida springs (Thompson, 1984).

Florida has a rich and globally significant karst biota that has long interested biospeleologists. Consequently, considerable information is known about the taxonomy and zoogeography of this fauna. However, species remain to be discovered, systematic studies are incomplete, ecological data are largely lacking, and distributional and status information is dated. Thus, there is an urgent need to better document Florida's karst organisms in order to understand, protect, and effectively manage these assemblages.

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