The Ecological Role of the Karst Wetlands of Southern Florida in Relation to System Restoration

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INTRODUCTION

With the recent funding of the Comprehensive Everglades Restoration Plan (CERP), the largest ecosystem restoration program ever attempted, there is a pressing need to be able to detect changes in natural habitats as a result of restoration actions. Human activities, particularly the construction of canals and levees that can either drain or flood wetlands, have affected the natural variability of environmental conditions (Gunderson and Loftus 1993). CERP intends to restore natural hydropatterns to areas that have been damaged by water management. Baseline data on constituent aquatic communities and their ecology are needed before, during, and after the restoration activities commence.

Freshwater fishes and invertebrates are important ecosystem components in the Everglades/Big Cypress system. They operate at several trophic levels in the wetlands, from primary consumers of plant material and detritus to carnivores and scavengers. Factors that influence fish and invertebrate numbers, biomass, and composition therefore affect energy flow through the wetlands. The ecology and life histories of these animals are intimately tied to the hydrology of the wetlands, which is determined mainly by rainfall, but increasingly by water-management practices. Because of the hydrological changes wrought by drainage and impoundment, and the loss of spatial extent and functioning of former wetlands to development (Gunderson and Loftus 1993), there is little doubt that standing crops and overall numbers have declined. Changes to the original ecosystem have also altered the timing and the areas of prey availability to predators. Non-native fishes have colonized natural and disturbed habitats during the past three decades. Non-native fishes have affected native animals through predation, nest-site competition, and habitat disturbance (Loftus 1988) and may divert food-web energy into biomass unavailable to top-level predators.

Aquatic animals in southern Florida wetlands have a variety of ways to cope with environmental variability. These include movements to find refuge from drying habitats in winter and spring, and dispersal away from those refuges with the onset of the wet season (Kushlan 1974, Loftus and Kushlan 1987). This pattern of movements among habitats with fluctuating water depths is common to seasonal wetlands in the tropics (Lowe-McConnell 1987, Machado-Allison 1993). The major natural refuge habitat most-studied by scientists in southern Florida is the alligator hole (Craighead 1968, Kushlan 1974, Nelson and Loftus 1996). Canals and ditches offer a relatively recent but spatially extensive form of artificial refuge for aquatic animals on the landscape (Loftus and Kushlan 1987). In this study, we are studying the function of other types of aquatic refuges in the Everglades.

The Rocky Glades, or Rockland, habitat is a karstic wetland unique to Everglades National Park (ENP) in southern Florida (Figure 1), although similar habitats exist elsewhere in Yucatan, Cuba, and the Bahamas. Approximately half of the original area of this habitat occurs outside of ENP where agricultural and urban development has forever altered its geological structure and ecological function. This region is a high priority for restoration in CERP because it is the largest remnant, short-hydroperiod wetland in the eastern Everglades. That habitat has been disproportionately lost from the ecosystem. Unfortunately, the habitat remaining in ENP has been degraded by water management (Loftus et al. 1992).

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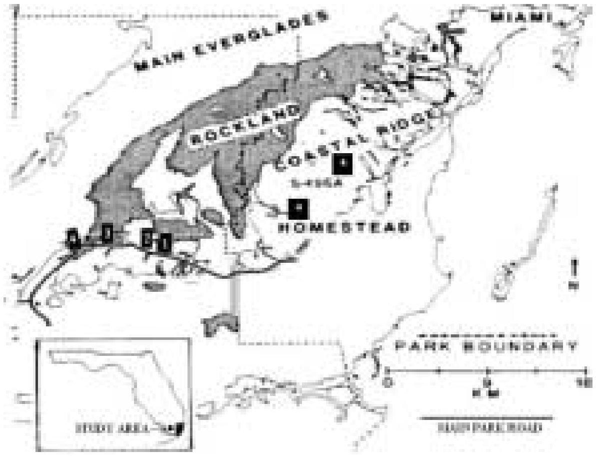


Figure 1. Locations of the study sites within the Rocky Glades and Atlantic Coastal Ridge in southern Florida. The numbers indicate the drift-fence arrays on the main park road, and the stars on the coastal ridge are the well sites with Miami cave crayfish.

The highly eroded karst structure of the Rocky Glades appears to be responsible for the persistence of aquatic-animal communities by offering dry-season refuge in thousands of solution holes of varying depths, (Loftus et al. 1992). Their work was the first to indicate a tight relationship among the biological, geological, and hydrologic components of this region. Loftus et al. (1992) also found evidence that aquatic animals disperse, feed, and reproduce on the wetland surface during the short flooding period, then retreat below ground for periods of months to years. They also reported that several introduced species, particularly the pike killifish (*Belonesox belizanus*), walking catfish (*Clarias batrachus*), Mayan cichlid (*Cichlasoma urophthalmus*), and black acara *(Cichlasoma bimaculatum*) were common in the Rocky Glades (Loftus et al. 1992). Unfortunately, their study was interrupted by Hurricane Andrew and not continued.

In this paper, we report the rationale and results of the first year of a new study in which the primary goal is to define the interactions of the aquatic-animal community with the geologic structure and hydrologic conditions of the Rocky Glades. We are addressing questions that have arisen from past work there. How do composition, size-structure, and recruitment of aquatic animals change during the flooding period? Are the dispersal patterns of animals related to water flow? Are the animals dispersing from the main sloughs to recolonize the Rocky Glades, or is the Rocky Glades a source of animal colonists for the sloughs? Do roadways act as barriers to movement? The objectives of this study segment are:

- Collect baseline ecological data on the epigean aquatic communities in the karst landscape of the Rocky Glades.

- Quantify the direction and degree of dispersal by fishes and invertebrates during the wet season.

- Document the seasonal changes in species composition, size structure, and reproductive patterns of animals on the wetland surface.

- Survey the topography of representative areas of the Rocky Glades, particularly around the sampling sites, to provide depth-distribution data for the simulation model of the region.

- Develop a visual survey method for sampling fish communities in open, rugged terrain to follow community dynamics in the Rocky Glades in the wet season.

- Identify the extent of near-surface voids.

The Atlantic Coastal Ridge is another area affected by urbanization and changing hydrologic management (Figure 1). Aquatic habitats, such as the transverse glades that cut through the Ridge, have been replaced by canals and will not be restored. Ground-water habitats and animal communities may have been less affected. As in karst areas elsewhere, deeper geological formations (>5 m) beneath the Rocky Glades and the Atlantic Coastal Ridge have voids of various dimensions known to house truly subterranean aquatic species (Radice and Loftus 1995, Bruno et al., this volume). These include the Miami Cave Crayfish *(Procambarus milleri)*, known only from a few wells in southern Florida (Hobbs 1971). The composition, distribution, and abundance of other hypogean animals are poorly known. Ground-water withdrawal and saltwater intrusion (Leach et al. 1972), limestone mining, and pollution may threaten these communities before they have been fully catalogued. Elsewhere in the world, such communities are known to be very sensitive to changes in their delicately balanced physical environment. The second goal of this project is to identify the composition, distribution by depth and space, and ecological relations of this subterranean fauna. The objectives of the second study element include:

- Develop effective traps to capture invertebrates and possibly fishes from subterranean habitats.

- Inventory hypogean communities and relate the composition and distribution to environmental factors.

- Collect life-history data for the Miami cave crayfish from a large captive population.

METHODS

This first project year has been a pilot study to test designs and methods. The study is divided into two elements with several components each.

Element 1 – In the Rocky Glades, we selected four sites along the ENP main road (Figure 1) to test the use of drift-fence arrays to describe directional animal dispersal and community successional patterns in the wet season. The four X-shaped arrays had 12-m wings made of black plastic ground cloth (Figure 2) to direct animals into one of 3 traps that faced east, north, and west, based on the direction that they were moving (Figure 2). The road shoulder formed a barrier to the south of each array. The 3-mm mesh minnow traps were fished overnight for 24 h to provide data on fish relative abundances, movements, and catch per unit effort (CPUE).

Figure 2. Top panel: Array 3 in the Rocky Glades; Bottom panel: three minnow traps facing west, north, and east at the center of the array.

When the wetlands reflooded in June, we collected samples daily for the first two weeks, then reduced the frequency to twice weekly for the next two weeks, and finally made collections once a week until the marshes dried. All animals were identified, weighed, and measured in the lab, and the numbers of animals in each trap on a particular day was compared to the water flow and depth to assess directional movement. We processed samples of fishes and crayfish for stable-isotope analysis as they appeared on the surface to compare with isotope signatures after several weeks and several months aboveground. These data may show whether trophic patterns change when animals begin to forage on the wetland surface. We also saved fishes for analysis of reproductive status to learn whether they are ready to spawn upon emergence onto the surface.

To complement data from the arrays, which are activity traps, we used visual sampling (Loftus et al. 1992; Frederick and Loftus 1993) to estimate fish composition and density on the surface of the Rocky Glades. We set up 24 survey plots, six at each array, that were scanned by binoculars each week in the wet season. Each 4-m^2 plot was scanned for 2 minutes, and all individuals seen were counted, and identified to species and size-class.

We began to survey the micro-scale topography of representative areas of the Rocky Glades. The physical characteristics of the sampling sites are required in the simulation model. The surface extent and depth dimensions of solution holes and surrounding marsh surface are measured by standard surveying techniques. Those physical characteristics will be correlated with biological measures of species composition, survival, and density. We have begun to use ground-penetrating radar (GPR) to try to estimate belowground extent of deep solution holes. We hypothesize that the survival of fishes reported by Loftus et al. (1992) in holes in which no standing water was visible, is related to the presence of hidden subterranean cavities connected to the holes.

Element 2: To inventory the hypogean fauna beneath Rocky Glades and the Atlantic Coastal Ridge, we selected a series of existing wells along four east-west transect lines from Miami to Homestead in which to sample routinely. Borehole videography is helping us to select the best wells and depths for sampling. We are using a combination of pumping and filtering ground water from wells to collect copepod crustaceans (Bruno et. al., this volume). We tested several designs for traps to collect larger invertebrates and possibly fishes in wells. We also used GPR to locate areas of high porosity in which hypogean animals might be likely to occur. Drilling of new wells to access subterranean cavities will begin in February 2001, in which a combination of videography and trapping will be used to capture and record animals for study. Any fishes or invertebrates collected will be identified, and then sent to specialists for confirmation.

We used YSI-6000 continuous recorders to measure water-quality in ground water to characterize the environment of hypogean organisms. We collect parameters such as dissolved oxygen, pH and temperature at the surface, middle and bottom of the wells. We will attempt to correlate the environmental variables with species distributions.

We are collating data on the distribution of the Miami Cave Crayfish from wells, and are trapping for it in existing and new wells. Because it is difficult to obtain enough wild-caught animals on which to base a life-history study, we have gained access to a captive population at a local fish farm where we perform monthly assessments of the proportion of males, females, gravid females, and juveniles in the population, their size distributions, size at maturity, fecundity, egg size, and other important life-history parameters.

RESULTS

The pilot study of the drift-fence arrays provided important inventory and baseline ecological data for the aquatic fauna. The method was successful in meeting the element's objectives. Arrays 3 & 4, west of the Pineland Trail in ENP, flooded in early June 2000. Array 3 had surface water until November, while Array 4 stayed wet until the end of December. Water flow at those arrays was generally east to west, towards Shark River Slough. Arrays 1 & 2, east of the Pineland Trail, did not flood until mid-July, 2000, and dried by November. Water flow was generally west to east at Arrays 1 & 2, towards Taylor Slough.

Animals appeared rapidly on the surface as the wetlands around the arrays reflooded. Fishes and crayfish reappeared in the traps on the same day that the wetlands reflooded, demonstrating the existence of local subterranean refuges. Large catches of several species occurred within a few days of reflooding (Figure 3). The fishes exhibited mass directional dispersal as the wetlands flooded. Although flow velocities were relatively slow in these shallow wetlands, the animals appeared to orient to the flow. Most individuals appeared to follow the flow of water, although a few species, particularly the Everglades crayfish (*Procambarus alleni*) moved mainly against the flow. Subsequent sampling provided data on community-succession patterns as new species appeared in the traps and relative abundances changed. The majority of species appeared at each array within one week of flooding (Figure 4). Non-native and larger-bodied native fishes were slower to appear at the arrays, indicating dispersal from distant refuges.

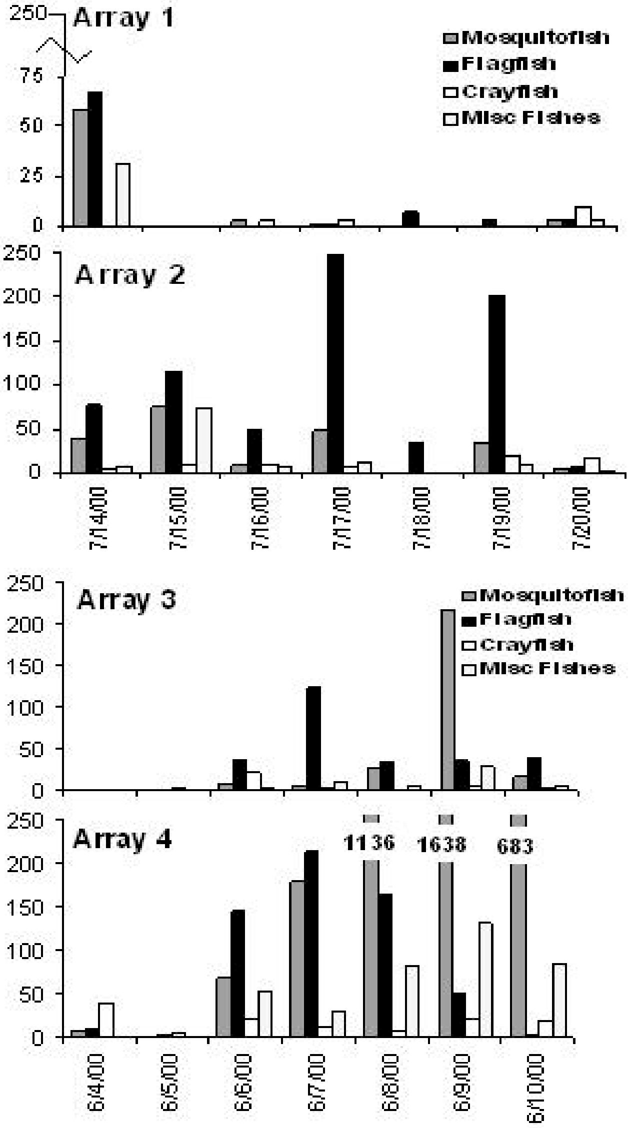


Figure 3. Appearance of fish and crayfish at the arrays shortly following marsh flooding.

We documented the onset of recruitment using the size-structure data and the visual-sampling data. All fishes emerging onto the surface were adults that began reproducing with one or two weeks. Small juveniles appeared in the wetlands within a month of reflooding (Figure 5). In the visual plots, mosquitofish (*Gambusia* *holbrooki*) were most visible, probably because they are in constant motion. Sedentary, cryptic species were more difficult to observe.

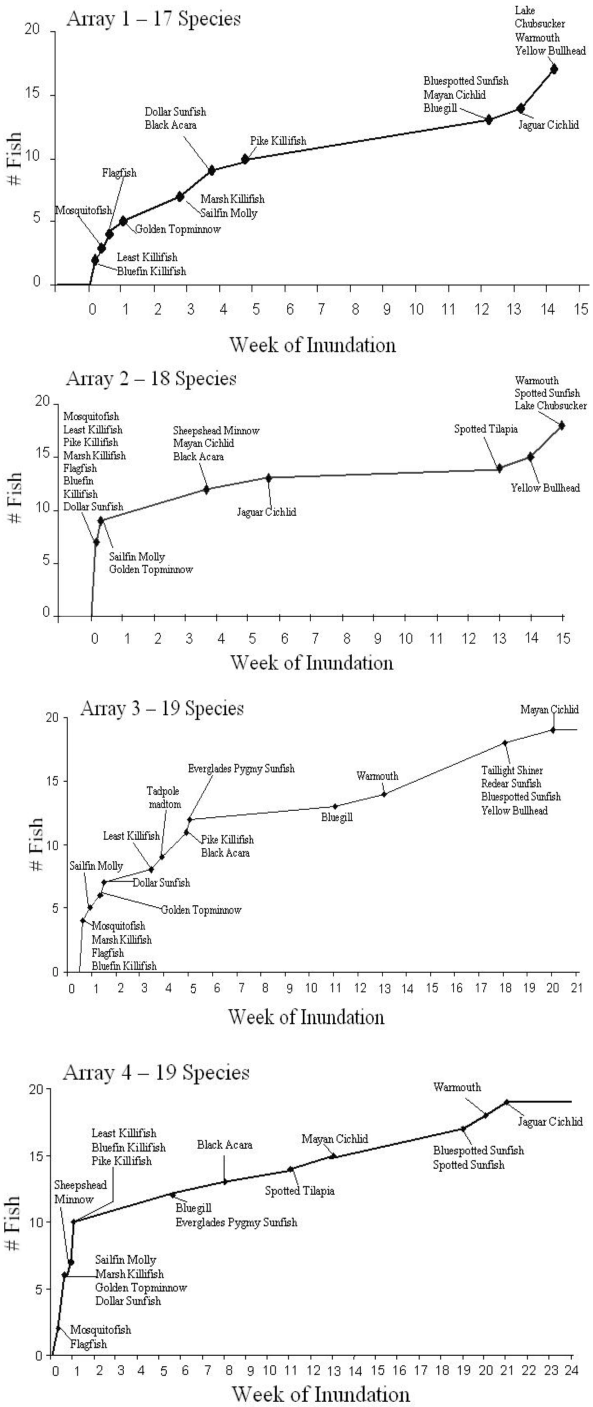


Figure 4: Succession of fish species at the arrays. Cichlids, tilapia, and pike killifish are non-native species.

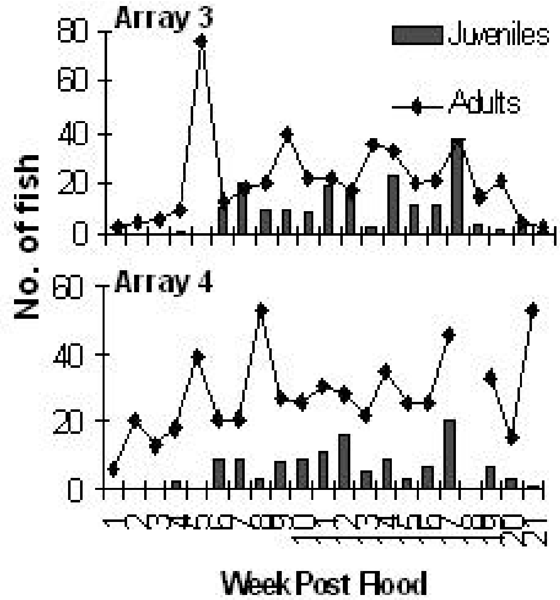
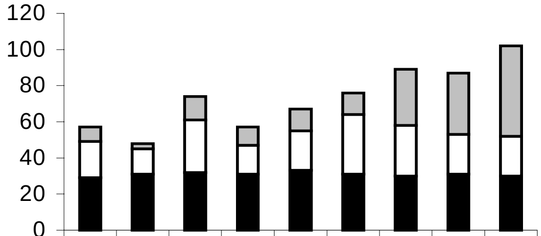


Figure 5: Visual-sample data from arrays 3 & 4 showing the pattern of juvenile recruitment.

In the second element of the pilot study, we have tested the most effective trap designs for capturing animals from groundwater in wells. We selected a 0.5-L plastic bottle trap with an inverted funnel to capture large animals, and a 3.8-cm diameter, 30-cm long perforated PVC tube with a removable core of plastic filter material to serve as an artificial substrate for smaller-bodied animals. These are our standard sampling units for the wells.

Preliminary sampling of wells by pumping and filtering in ENP resulted in more than 10 species of copepods (Bruno et al., this volume) and other crustaceans. Samples from wells on the coastal ridge near Homestead and Miami have produced records from several new locations for the Miami Cave Crayfish (Radice and Loftus 1995), as well as an amphipod that may be new to science. We continue to receive anecdotal reports from local residents of blind white shrimp and fish in wells, but have been unable to confirm those reports.

We have collected nine months of data on the size-structure, sex ratios, sexual status, fecundity, and size of maturity for the Miami Cave Crayfish from the captive population. The proportion of juveniles increased in late spring and again in late autumn because of recruitment in earlier months (Figure 6). The mean size of males and females in this species did not differ, unlike many other crayfish species that exhibit strong sexual dimorphism.



	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
▨ JUVENILE	8	3	13	10	12	12	31	34	50
☐ MALE	20	14	29	16	22	33	28	22	22
■ FEMALE	29	31	32	31	33	31	30	31	30

Figure 6: Proportion of the captive Miami Cave Crayfish population comprised by juveniles, females and males. N of ~30 for females is the sample size sought during each month's random sample, after which that month's sampling ceases.

As might be expected for a species that lives in a fairly constant environment, the data indicate that this crayfish is capable of year-round breeding (Figure 7). We are examining data on the number of eggs produced by variously sized female, the length of time until she releases them into the environment, and their growth in constant temperature in captivity. Those data are being compared to species of surface-dwelling crayfishes in southern Florida.

Figure 7: Gravid female Miami Cave Crayfish with newly extruded egg mass.

The ground-water environment is somewhat variable, as seen in this five-day plot during the dry season of 2000 (Figure 8). Water temperature changed on a diel basis, as did pH, and to a lesser extent, dissolved oxygen. The peak in specific conductance and corresponding rise in pH resulted from a rain event that probably washed soil into the well. Note that the % saturation of dissolved oxygen was very low so any animal in this environment must be adapted to low oxygen tensions.

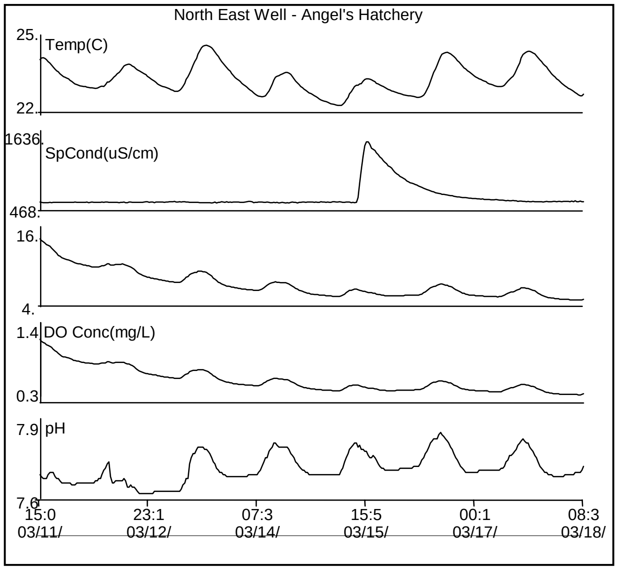


Figure 8: Five-day springtime plot from a well on the Atlantic Coastal Ridge north of Homestead of water temperature (^{o} C), specific conductance (μS/cm^3), % O_2 saturation, dissolved oxygen level (mg/L) and pH.

RESEARCH NEEDS / APPLICATIONS

The use of drift-fence arrays and visual sampling are new sampling techniques for shallow-water marshes with open, rugged terrain, where other methods fare poorly. We will expand our testing of the sampling characteristics of these methods, and continue to follow animal-community patterns by visual survey and by trapping. Based on the results of further testing, these methods are likely to be accepted by other scientists studying aquatic animals in shallow wetlands. We are now evaluating the results of the pilot project to design and implement a more spatially expansive study for this next year.

The project elements combine to answer questions about the ecological interrelations of surface and subterranean habitats to address how management has adversely affected this region and describe the benefits that restoration will produce. The Rocky Glades and other short-hydroperiod wetlands have been implicated in the decline of nesting wading birds in the Everglades (Fleming et al. 1994). The loss of naturally short-hydroperiod wetlands may have affected the availability of important late wet season/early dry season feeding habitat for wading birds and other predators when wet prairie and slough habitats were too deep for feeding. This project also addresses questions important to understanding the ecology of freshwater communities in southern Florida, and the data will provide more confidence in tools like the ATLSS fish-simulation model to be used in CERP assessments. Data from the present study will provide the information needed to predict the responses of aquatic communities to restored hydrological patterns and to an increase in the spatial extent of the system. The data, and the models that incorporate them, should also help define the reasons behind wading-bird decline as relates to prey availability and abundance.

In addition to the application of these data to modeling, the data collected during these companion studies represent new information about the composition and adaptations of the surface-water and ground-water communities. The baseline data from this study will be essential to future monitoring of the effects of the restoration effort. Preliminary collections from the wells have produced several first records for species for the United States, and potentially new species for science. The data are under review by USFWS, which is considering one species for candidacy for listing under the Endangered Species Act. The interactions of groundwater and surface-water habitats demonstrate the critical and delicate ecosystem linkages that occur on this karstic landscape. The relationships we describe, and the information we collect may help managers of other karstic wetlands, as in Mexico, Belize, and the Bahamas, better protect their resources.

There are several areas for collaboration with other USGS researchers. The occurrence of holes on the Rocky Glades landscape appears to vary spatially, and the availability of holes for refuge is an important factor to include in the spatially explicit ATLSS fish model. We hope to work with experts from the USGS Cartography Division to examine whether remote sensing will allow the estimation of the frequency and distribution of solution holes. We will continue our collaboration with geologists from USGS to further explore the relationship of karst structure to aquatic animal ecology.

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