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Front Cover: Rice Bay Formation, looking southwest along Grotto Beach. Photograph by Sandy Voegeli.

Back Cover: Dr. John Milliman, The College of William and Mary. Keynote Speaker for the 13th Symposium. Photograph by Sandy Voegeli.

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DISCOVERY OF "THREE ROSES CAVERN," A SUBMERGED HORIZONTAL CAVE SYSTEM ON SAN SALVADOR ISLAND, BAHAMAS

Eric S. Cole, John Campion, Chris Hallgren, and Daniel White
Biology Department
Saint Olaf College
Northfield, MN 55057
colee@stolaf.edu

Sandy Voegeli and Vincent Voegeli
Gerace Research Centre
San Salvador Island, Bahamas

ABSTRACT

A new, underwater cavern system was discovered in a little-known pond on San Salvador Island. The pond was given the name "Merman" Pond because of its proximity to Mermaid Pond. The cavern was named "Three Roses Cavern." This study was undertaken to describe general geologic and biotic characteristics of Three Roses Cavern. In summary, Three Roses may be unique on San Salvador because it harbors fish species that typically inhabit shallow back-reef environments, suggesting that the conduit opens either into neighboring Pigeon Creek, or the more physically remote back-reef environment off the southeastern shore of San Salvador Island.

INTRODUCTION

Merman Pond is an interior pond located on the Montreal Settlement at the southeastern end of San Salvador Island, Bahamas (Figure 1). Landsat infrared images suggest that this pond is "cool" (1985 Landsat Thematic Mapper, Infrared Satellite Image of San Salvador, from the former Gerace Research Center Website). During January, 2006, we cleared a trail to this pond and performed casual snorkel and SCUBA reconnaissance. We returned in March, 2006, and again in January and June, 2007. The pond is generally shallow, less than a meter in most places, deepening to about 1.5 meters towards the center (depending on the tide). Despite being separated from Pigeon Creek by a carbonate dune, and lying 1.4 km from the ocean, Mermaid Pond is clearly tidal, exposing 20-30 meters of carbonate shoreline at low tide.

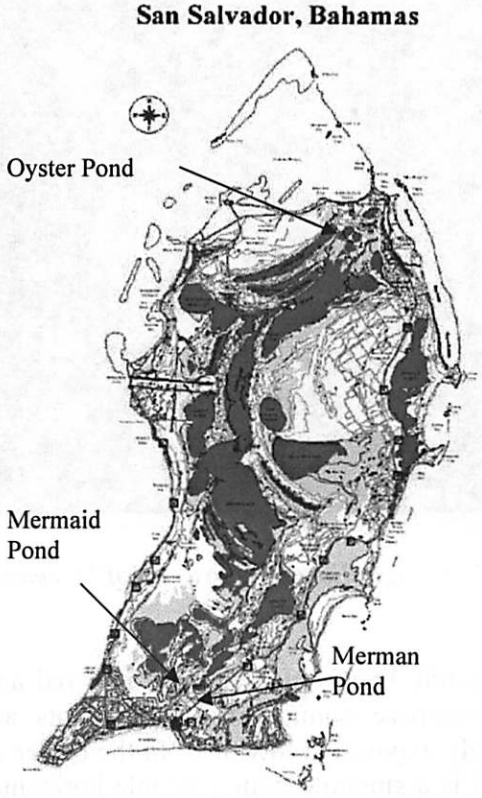


Figure 1. Map of San Salvador Island showing location of Merman Pond. From: Robinson and Davis, 1999, San Salvador Island GIS Database. University of New Haven and Gerace Research Centre.

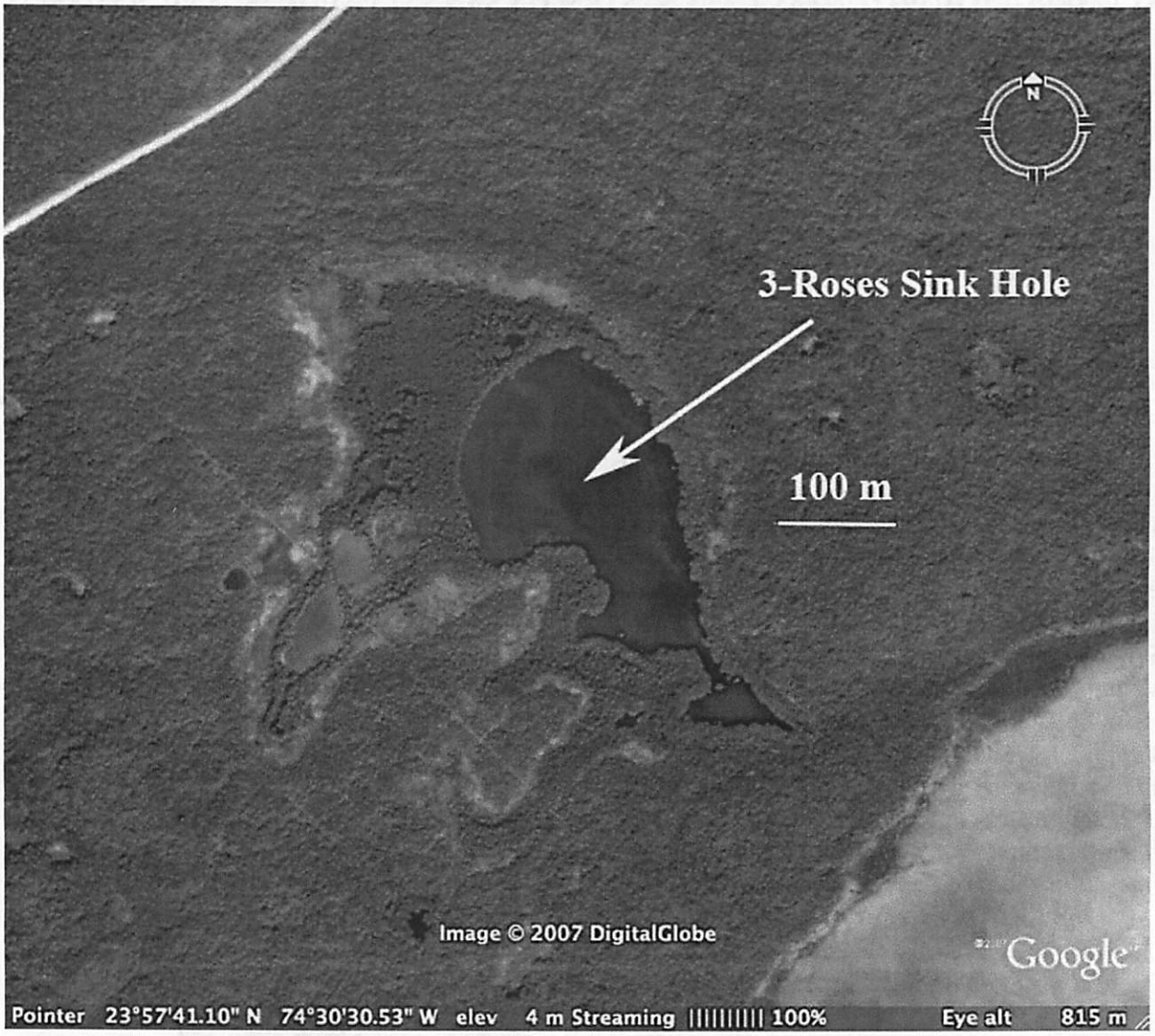


Figure 2. Google Earth™ close-up of Merman Pond showing location of sinkhole.

The high-tide line is marked by a rich red and black mangrove community whose roots are completely exposed at low tide. In the center of the pond is a sinkhole with a sizable horizontal cave entrance in its eastern wall. The "sink-hole" appears to be the result of a collapse in the carbonate pond bottom (Figure 2). This hole is approximately 30-40 meters across, and exhibits a sloping floor, high in the west, and sloping to a depth of 4.5 meters in the east. Here, the "ramp" encounters a vertical wall; it is at the base of this wall that Three Roses Cavern opens. What is remarkable about this system is that the cavern and the adjoining sink-hole appear to be serving as a refuge for schools of fish that are more typical of a back- reef or tidal creek environment. We explored the cave (within the limits of our non-technical expertise), and the surrounding land and waters to try and account for the source of these reef-fish

within an otherwise shallow, marine-pond environment.

METHODS

To survey the biodiversity within the cavern opening, we employed both snorkel and SCUBA. We also used a Nikonos 35 mm underwater camera, and a Hydrolab Quanta™ water chemistry probe. We deliberately entered the cavern at times between low and high tide (there was very little tidal lag between this pond and the coast) so that the current was pushing against us as we swam into the opening, rather than drawing us into the cavern. This also allowed the tide to flush debris from the cavern, resulting in heightened visibility. Inside the cavern, we used underwater photography and videography techniques supplemented with visual identification to confirm the presence of various species of fish. We also collected a sample of one of three sponge species covering the cavern walls, and a resident goby for identification using a "slurp gun". We measured the dimensions of the first two cavern chambers using a 30 m tape measure. To survey the depth of the drop-off at the back of the second chamber, we lowered the tape measure down until it hit bottom and recorded the distance. We also used an underwater compass to determine the orientation of the cavern. Back at the Gerace Research Centre, we used hydrochloric acid and a light microscope to examine the tissues of living sponge sample.

RESULTS

Physical Characteristics

Merman Pond is probably protected from hurricane events by its small size (wave propagation is minimal), a dense, contiguous mangrove shoreline, and a shallow carbonate ridge separating it from the southern backwaters of Pigeon Creek, 115 meters to the east. The pond is tidal, rising and falling 1-2 meters. Salinity typically ranges from 34.6-35.1 g/Liter (TDS) although following an unusually heavy spring rain in 2007, salinity plunged to 14.1 g/L suggesting that it serves as a rainwater catchment for a large surrounding area, and rainfall can over whelm its tidal turnover. Other physical characteristics (Table 1) suggest that Merman is typical of inland ponds on San Salvador that are served by open conduits to the sea. In short, the water resembles seawater. The pond is located at latitude 23° 57.686' north by, longitude 74°30.560' west. The center of the pond features a large sinkhole that contains the entrance to Three Roses Cavern.

Table 1. Physical Characteristics of Several Inland Ponds on San Salvador Island. Data from Quanta Probe Measurements, January 07.

	Merman	Mermaid	Oyster
TDS (g/L)	35.1	34.5	34.8
Temp (C)	26.9	25.7	25.5
pH	7.9	7.73	7.49
ORP (mV)	283	283	324
dO (%)	98.6	86.1	67.2

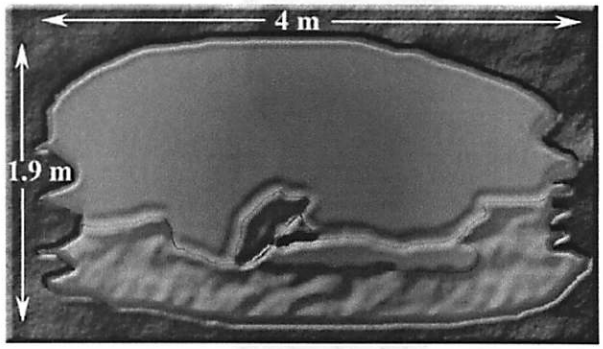


Figure 3. A diagrammatic sketch of the entrance to Three Roses Cavern.

As Figures 3-5 indicate, the sinkhole is approximately 4.3 m deep at its deepest. The sinkhole appears to have formed from a collapsed carbonate platform that slopes gently from west to east. At the eastern end, the sloping floor of the sinkhole intersects a vertical cliff face. At the bottom of the cliff face lies the cavern opening, 4 m wide and 1.9 m tall that faces 230 degrees west by southwest. The first

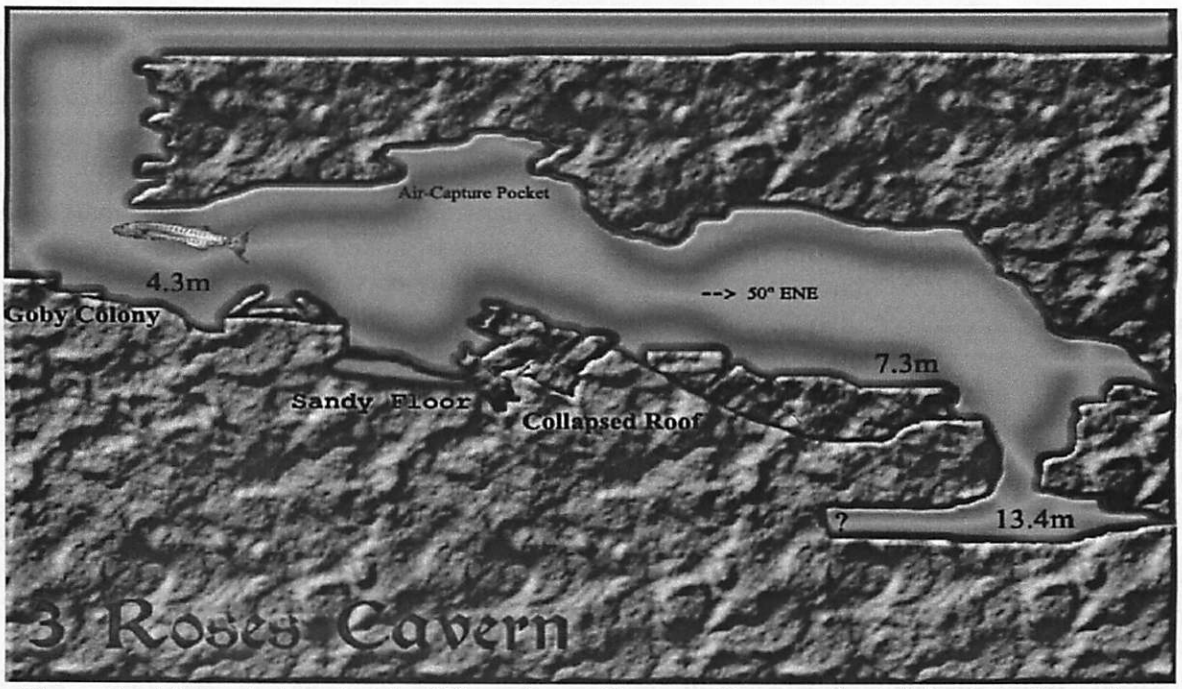


Figure 4. A lateral view sketch of Three Roses Cavern. (Barracuda sighting is indicated).

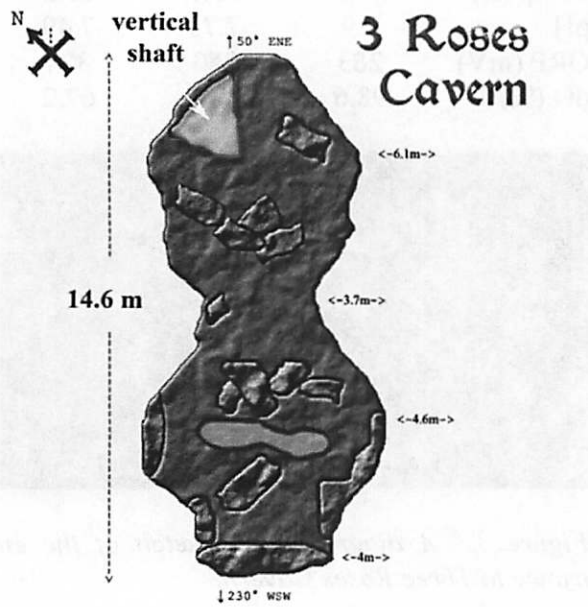


Figure 5. A top-down view of the explored area of Three Roses Cavern.

chamber widens to 4.6 m and features a hard carbonate floor littered with collapsed roof slabs further inside.

We noticed no conspicuous speleothems, although this could be due to the fact that much of the cavern roof has collapsed in sheets, obscuring both original floor features and ceiling features. The cavern narrows to 3.7 m briefly, then opens up to the 6.1 m wide second chamber that descends to a depth of 7.3 m. At the back of the second chamber, a narrow passage drops vertically to 13.4 m and possibly curves back under the main chamber into an unexplored area. The tide was monitored and a slack tide seemed to occur in synchrony with the coastal change in tide.

Biotic Characteristics of Merman Pond

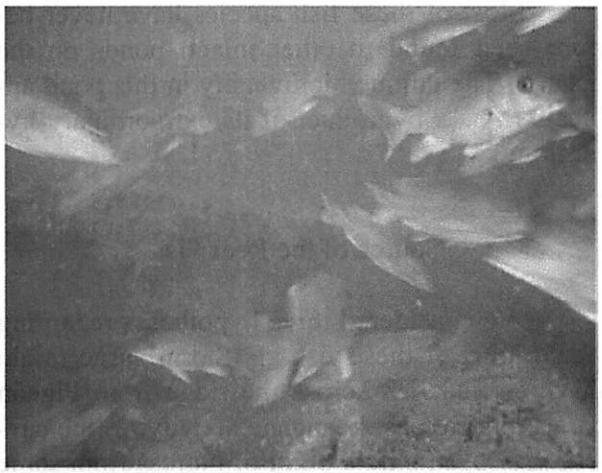
The shoreline of Merman Pond is a rich (though narrow) mangrove composed of both red and black mangroves (*Rhizophora mangle* and *Avicennia germinans*). The *Rhizophora* prop-roots are unusually devoid of epizooitic life. This makes sense when observed at low tide when the prop-roots are completely exposed along with 20-30 meters of carbonate pond bottom.

The pond bottom is a smooth carbonate loosely covered with a mixture of shallow flocculent sediment, and molluscan shell hash. The most common living invertebrates include gastropods (*Battilaria minima* and *Cerithium lutosum*), bivalves (*Tellina*, *Polymesoda maritima*, and *Anomalocardia auberiana*) and occasional lugworms (*Arenicola*) among other polychaete annelids. These organisms are also common to both Oyster Pond, and Mermaid Pond.

In the shallows, the most common vertebrates include two small pond fish the Sheepshead Minnow (*Cyprinodon variegatus*) and the Bahamian Mosquitofish (*Gambusia manni*) species that are commonly found in other inland ponds on the island as well (Godfrey et al., 1994). Near the northeastern end of the pond, the bottom changes to shell hash and an unidentified species of halfbeak (*Hemiremphidae*) may be found swimming in the shallows. Juvenile halfbeaks, less than a centimeter in length, were also sighted in March, 2006, suggesting that these typically coastal fish are breeding in Merman Pond. Halfbeaks have never before been reported in the inland ponds of Sand Salvador Island.

Biotic Characteristics of 3-Roses Cavern

We identified five species of reef fish living in the sinkhole and cavern opening, the Grey Snapper (*Lutjanus griseus*) (a single individual), and schools of Schoolmaster Snappers (*Lutjanus apodus*) and Yellowfin Mojarra (*Gerres cinnereus*) (Figure 6). A colony of Crested Gobies (*Lophobogius cyprinoides*) exist just outside the cavern entrance, making homes in the gravely bottom, and a single Great Barracuda (*Sphyraena barracuda*) was sighted hovering just outside the cavern entrance. Crested Gobies have never before been reported on San Salvador. Within the cave itself, sponge specimens were abundant on floor and ceiling. We observed through a light microscope that our sponge sample contained both proteinaceous spongin and silicaceous spicules (resistant to HCl treatment) suggesting species of the Class Demospongiae.



a.

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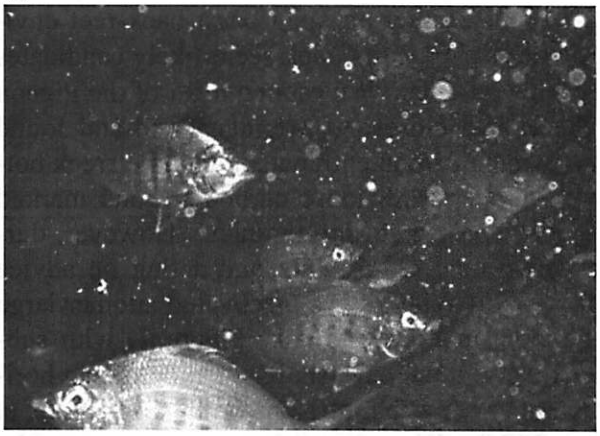

c.

Figure 6. Reef fish found in 3-Roses Cavern. a) Schoolmaster snappers and b) a gray snapper (center) at the mouth of 3 Roses cavern. c) a school of Yellowfin Mojarra just inside 3 Roses Cavern. These rarely came out into the well of the sinkhole.

Most of these fish species have never before been found in other inland ponds on the island. The unique biodiversity in this pond appears to be a byproduct of its extraordinary hydrology.

Source of the Reef Fish

We considered three hypotheses regarding the origins of these fish--1) Storm surge might have carried fish across the ridge from Pigeon Creek during past hurricane activity, 2) the cavern may open onto a point of ingress from some location on Pigeon Creek, or 3) the cavern may open onto the back-reef environment of the outer coast. To test these hypotheses we cleared a trail from the eastern most point on Merman Pond into Pigeon Creek (a distance of 115 meters). We were able to trace storm debris up the east-facing slope of the ridge that separates the two water bodies, but found that debris stopped well short of the ridge top. By no means definitive, this does suggest that, at least recently, storm-surge probably did not populate our pond with fish.

This leaves the cavern as the most likely source of fish migration into Merman Pond. Given the shallow water habits of the cavern's occupants, either an open coast back-reef environment or Pigeon Creek seem likely candidates for the entrance. We canoed most of the Pigeon Creek area closest to Merman Pond and found no evidence of an entrance, in fact the creek bottom is deep with loose carbonate sand marked by callianassid shrimp mounds. However, during our June, 2007 visit, and acting on advice from John Winters, we discovered another large sinkhole in Pigeon Creek (Figure 7) with submerged vertical cave shafts opening onto a horizontal cave system at 12 m depth (See White, et al., 2006). We are still left to contemplate the open coastline (1.4 km away) as a possible outlet for both cavern systems (Figure 7). The Pigeon Creek conduit had been noted earlier by Kenny Buchan, former director of the GRC, in his PhD dissertation (2005).

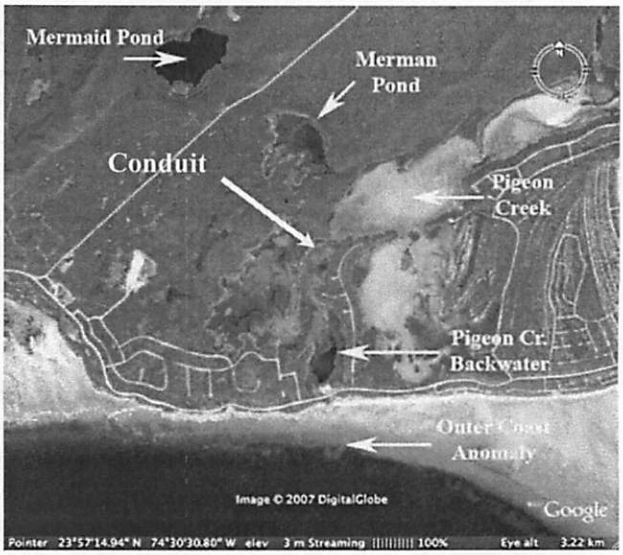

Figure 7. GoogleEarth™ image of Merman Pond, 3-Roses Cave, and adjacent Pigeon Creek with its conduit indicated.

DISCUSSION

Since Merman Pond is tidal and fully marine, and no other openings have been found, the cavern system acts as the sole conduit, exchanging water with the ocean tide. The absence of any notable tidal lag and sizable populations of reef fish (including a well grown barracuda) suggest an unusually large cave passageway. There are several possibilities as to where this cavern opens, either on the oceanic cliff structure known as "the wall," in the back-reef environment, or in the shallow, tidal mangrove habitat of Pigeon Creek. Since manual exploration of the cave is dangerous and impractical, we turned to the fish species sighted inside the cavern (and their habits) to shed light upon the location of the opening.

Since the Bahamian *Gambusia* and *Cyprinodon* are commonly found in marine ponds throughout the Bahamas (Bohlke and Chaplin 1968), they are likely the result of dispersal processes common to all the inland ponds, and unrelated to the cavern.

The Crested Goby, never before sighted on San Salvador, is fairly hardy and inhabits a

range of environments, from tidal creeks and patches of eroded limestone to brackish inland lakes and ponds or mangrove swamps (Bohlke and Chaplin, 1968). In a later reconnaissance of the Pigeon Creek conduit, crested gobies were also found in the surrounding shallows.

The Yellowfin Mojarra and Gray Snapper reveal slightly more. The Gray Snapper, although not generally found in ponds, frequents rocky areas, coral reefs, dock structures (Randall, 1968) and tidal creeks bordered by mangroves (Bohlke and Chaplin, 1968). The Yellowfin Mojarra on the other hand occurs in tidal creeks, rocky surf zones (Bohlke and Chaplin, 1968) and nearby coral reefs (Humann, 1989). The Yellowfin Mojarra prefers depths of 1-12 m (Humann, 1989) while the Gray Snapper frequents depths of 1-18 m (Humann, 1989). This indicates that the conduit entrance is likely within a tidal creek, coral back-reef, or rocky shallow habitats between 1-12 m deep.

The presence of the Great Barracuda inside the cavern does little to tighten this depth range, or indicate a particular habitat, since Barracuda inhabit a wide range of marine environments and are found anywhere between 0-18 m deep (Humann, 1989). However, the presence of the Barracuda does serve as a striking reminder that the cavern must lead to a remarkably different environment, since Barracuda are quite out of place in a shallow inland pond.

The presence of the Schoolmaster and Halfbeaks provide us with our final clues. Schoolmasters frequent coral reefs (Randall, 1968) but are also commonly found in tidal creeks lined with mangroves (Bohlke and Chaplin, 1968) and generally prefer depths between 3 and 24 m (Humann, 1989). Half-beaks on the other hand, are generally inshore surface dwellers, not often found far out to sea (Bohlke and Chaplin, 1968). This narrows the likely depth of the cavern exit to 3-6 m, deep enough for the Schoolmasters, but shallow enough for the Halfbeaks.

Further, the conduit exit must be located near a shoreline with easy access to deeper waters, and may likely be a tidal creek or a back-reef environment, since many of the fish we identified are common in that habitat. This leads us to believe that the conduit leads either to nearby Pigeon Creek, a large, thriving tidal creek environment with nearby coral reefs or a shallow backreef environment on the outer coast. Anecdotal accounts report sightings of most of these fish in Pigeon Creek. Our most recent visit also uncovered a likely candidate for an outlet to Three Roses Cavern, within neighboring Pigeon Creek (White, et al., 2006). It remains possible that fish have entered Merman Pond through multiple paths, both through the conduit and overland from Pigeon Creek during unusually harsh Hurricane storm surges.

The structure of Three Roses Cavern, (and the neighboring Pigeon Creek Conduit) are similar, and invite comparison. Each appears to have been breached by a collapsed carbonate roof, creating a sink-hole exposing what once must have been a broad cave chamber with a floor 4-7 meters below current sea level. In both cases, vertical shafts connect this upper horizontal cave system with a deeper horizontal chamber 12-13 meters below current sea level. Tidal currents at the mouth of each cave suggest that both systems must still open out to the sea (unpublished observations).

Cave morphology has been much studied on San Salvador Island, and two models have been proposed to account for their formation: the "flank margin" model in which carbonate dissolution occurs most aggressively at the edges of freshwater haloclines due predominantly to chemical processes (Pace, et al., 1992; Mylroie, et al., 2004; Roth et al., 2006), and a "bioerosion" model in which haloclines serve to trap organic matter, and microbial respiration acidifies the water increasing its dissolution capacity at this carbon-rich interface (Schwabe et al., this volume). If carbonate dissolution at a halocline was involved, then both Three Roses Cavern and her sister, the Pigeon Creek Conduit, must have been formed during multiple periods of lower interglacial sea-level. It is to be hoped that further study will reveal more of the dynamics of these submarine cave systems, and the geologic history of their formation.

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