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Cover photograph –Barn Owl (*Tyto alba*) at Owl's Hole Pit Cave courtesy of Elyse Vogeli

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CHARACTERIZATION OF THREE ROSES CAVERN AND ITS ACCOMPANYING CONDUIT SYSTEM ON SAN SALVADOR ISLAND, BAHAMAS: AN INLAND REFUGE FOR COASTAL FISH.

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ABSTRACT

We explored potential colonization routes for coastal fishes that have come to populate Merman Pond, a small anchialine pond in the southeastern corner of San Salvador Island. The pond itself is shallow, tidal, and circumscribed by a mangle community. Low tide fully exposes the surrounding mangrove prop-roots, accounting for their low epiphyte load, and a 5 meter beach appears, consisting of smooth carbonate covered in shallow shell hash and sediment. In the center of the pond, approximately 1 meter deep, the smooth carbonate floor has collapsed, producing a depression nearly four meters deep, and revealing the entrance to a submarine cavern: Three Roses Cavern (See Cole et al., 2006). From our exploration of Merman Pond, it appears that this conduit, Three Roses Cavern, is solely responsible for the lake's tidal flux. What is remarkable about this conduit, aside from its size, is that it harbors a host of ocean fish typically found in tidal creeks and back-reef environments, species never before documented for the inland ponds of San Salvador Island. We explored two possible avenues by which fish may have come to inhabit Merman Pond. The first is an overland route described by the "hurricane hypothesis", in which tidal surges may have washed founding fish populations over the narrow isthmus separating Merman Pond from neighboring Pigeon Creek. The second is a subterranean route (the "cavern hypothesis") in which fish may have immigrated through a series of flooded marine caverns from either Pigeon Creek or the outer coast. Using Google Earth™ satellite imagery, field reconnaissance, and species comparisons, our work supports the "cavern hypothesis". Furthermore, we identify a potential access to the Three Roses cave system opening into neighboring Pigeon Creek. We have named this conduit "Winters' Hole." Here we describe newly discovered aspects of this cave system, and the vertebrate species that it harbors.

INTRODUCTION

Merman Pond is an interior pond on the southeastern end of San Salvador Island, Bahamas (Figure 1). At first glance, the pond resembles other inland ponds on the island. The bottom

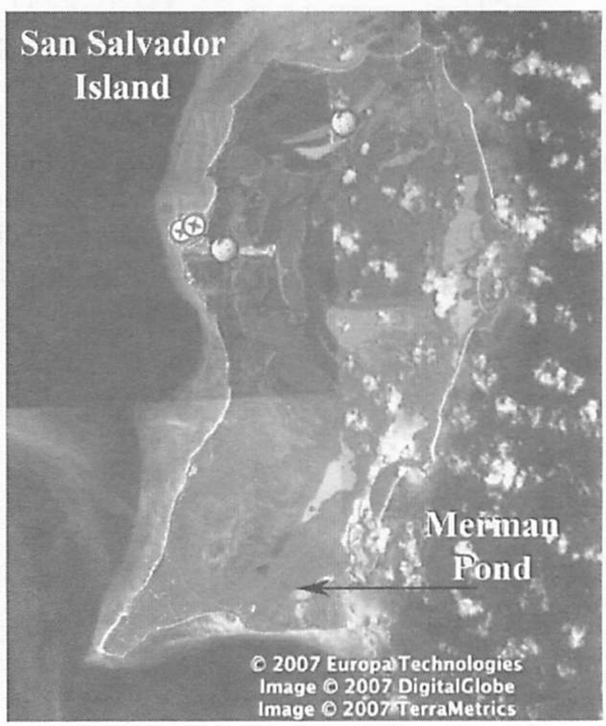


Figure 1. Location of Merman Pond.

sediment is typical, consisting of a loose flocculent layer covering a hard carbonate floor. The shoreline, like many of the other inland ponds, is lined with a thick mangrove forest containing both red *(Rhizophora mangle)* and black mangroves *(Avicennia germinans)*. The gastropods (*Battilaria minima* and *Cerithium lutosum*), bivalves (*Tellina, Polymesoda maritima,* and *Anomalocardia auberiana*), and the two small pond fish (*Cyprinodon variegatus* and *Gambusia*) found in the pond are all commonly found in the other inland ponds on the island as well (Godfrey et al., 1994).

Figure 2. Merman Pond at low tide.

Merman pond has tidal movements that fluctuate nearly 1 meter (Figure 2) between high and low tides, lagging very little, if at all, with the ocean indicating the presence of a formidable conduit. Merman Pond also hosts species of large fish more typical of tidal creeks and coastal back-reef environments. None of these have been reported in other inland ponds on San Salvador Island. These larger, coastal fish could have been swept over into Merman Pond from neighboring Pigeon Creek by an exceptionally large storm surge accompanying a hurricane. It has been demonstrated that hurricane tidal surges can dramatically alter fish habitats (Kaufman, 1983; Scoffin, 1993). It is also possible that the conduit located in Three Roses Cavern could connect to either Pigeon Creek or to a back-reef environment, and provide passage for the fish we observed. We report on our ongoing search for possible cavern outlets in neighboring Pigeon Creek and our investigation of the isthmus between Pigeon Creek and Merman pond (Figure 3) in an attempt to assess if a storm surge could have pushed a large volume of water (along with founding fish) across it.

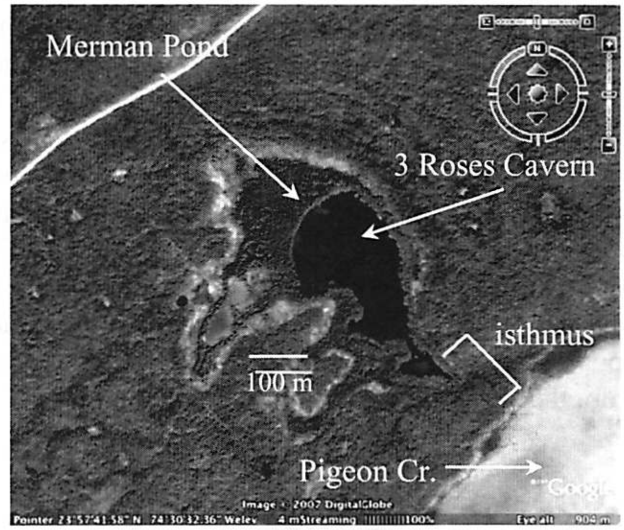


Figure 3. 3-Roses Cavern, in relation to Merman Pond and Pigeon Creek. (GoogleEarth™)

RESULTS

Exploring Three Roses

In 2006, we explored, mapped, and characterized the first two chambers of Three Roses Cavern (Cole, et al., 2006). Several species of coastal fish were documented that had never been seen in the inland ponds of San Salvador Island (see Table 1).

Table 1.Fish species identified in Three Roses Cavern.

Common Name	Scientific Name
Crested Goby	*Lophogobius cyprinoides*
Yellowfin Mojarra	*Gerres cinnereus*
Gray Snapper	*Lutjanus griseus*
Great Barracuda	*Sphyraena barracuda*
Schoolmaster	*Lutjanus apodus*
Half-beaks	*Hemiremphidae*

Only the first two rooms of the cavern (Figure 4) were explored because the second room ended in an abrupt drop down a vertical shaft, that was deemed unsafe for exploration. The outer chambers were occupied by Yellow-Fin Mojarra, and Schoolmasters. Just outside the opening was a thriving population of Crested Goby, that had taken up residence in the rocky rubble. Merman pond's salinity is usually fully marine (34.6 g/L in January 2006, 35.1 g/L, TDS) in January 2007, becoming significantly fresher by July (14.1 g/L), following an intense period of rain when the pond appeared flooded with freshwater carrying tannins from the surrounding terrain.

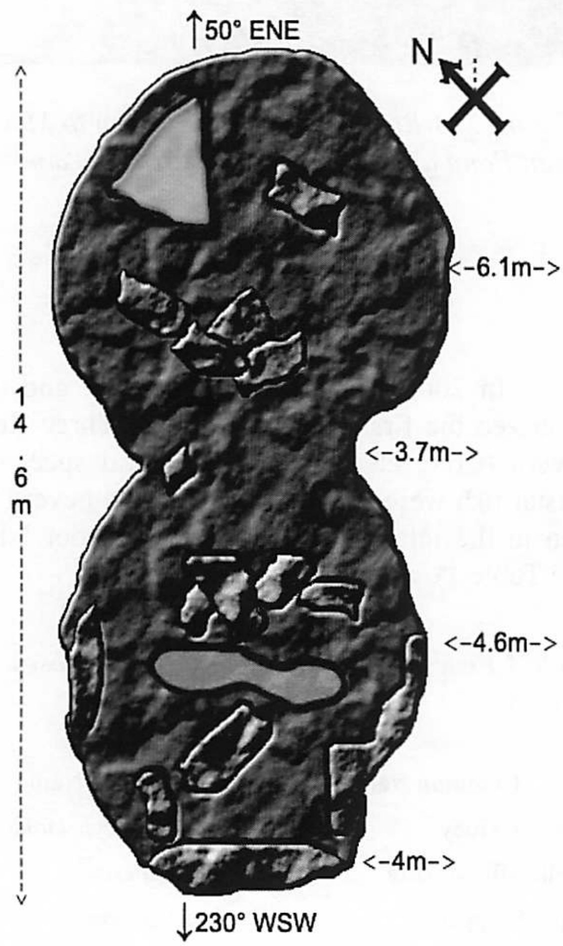


Figure 4. Top-down view of Three Roses Cavern. Artist's impression. Not to scale. Reprinted from Cole, et al., 2006. Used with permission.

Avenues of Fish Immigration

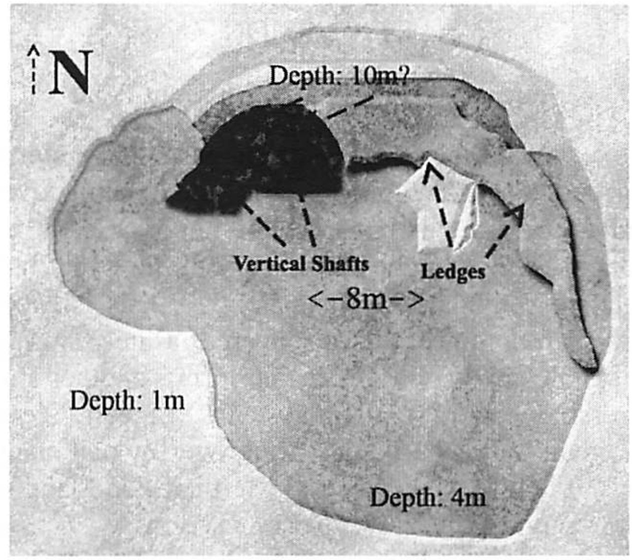
Finding coastal reef fish living in a shallow inland pond stimulated interest in determining their mode of colonization. Two possible avenues presented themselves. First, and perhaps most obviously, these fish could have gained access to Merman Pond through the Three Roses Cavern system. Second, Merman Pond is located less than two hundred meters from Pigeon Creek that opens onto the sea. Hurricane storm surges could conceivably have lifted fish over the intervening isthmus and populated Merman Pond in that way. We explored both of these hypotheses.

Hurricane Hypothesis. The trail between Pigeon Creek and Merman Pond was 320 m long and consisted of mangrove habitat surrounding the waterways and scrub-brush in between. The trail began at the south end of Merman Pond (23° 57.35 N, 74° 30.371W) and ended near the south end of Pigeon Creek (23° 57.683 N, 74° 30.512 W). Elevation changes along the trail between Pigeon Creek and Merman Pond were minimal, (rough estimate, 5-6 m), and elevation changes alone between the two water sources are unlikely to be a major impediment to storm surges carrying water, debris, and possibly fish to Merman Pond. Debris along the trail however was found to penetrate only 42 m in from the shore of Pigeon Creek, with the majority of debris lying within 24 m from the creek. Debris found included pieces of green plastic, bottles, a shoe, rope, net and various small pieces of flotsam and jetsam. All in all, it seemed unlikely that storm surge (at least in recent history) was responsible for the rich community of reef-fish found in the sink-hole of Merman Pond.

Cavern Hypothesis. If the fish were not brought over by a storm surge, then most likely they entered the pond through Three Roses Cavern and a conduit system communicating with the sea. The fish we identified are typically found in either back-reef or tidal creek environments rather than deep water. Pigeon Creek was surveyed by canoe from the ocean-access southward to the large reservoir adjacent to Merman Pond. (The asterisk in Figure 5 marks this "reservoir"). We also searched from the southern-most backwater north to the same reservoir (See Figure 6).

*Figure 5. Merman Pond, Pigeon Creek. Conduit and Outer Coast Anomaly. (Courtesy of Google Earth.) * indicates a "reservoir" in Pigeon Cr. separated from Merman Pond by a small lithified dune.*

Most of Pigeon Creek is extremely shallow (less than 1 meter deep) with the exception of the channel running through the center that appeared to be around 5-6 meters deep. The substrate is loose sand, heaved into conical mounds by Calianassid shrimp, and sparsely populated by sea grass. At the south end of the "reservoir" (asterisk in Figure 5), the creek narrows, and we discovered a 8 meter wide sink hole with two vertical shafts leading to a submarine cavern system. John Winters suggested we search there based on memories of upwellings he encountered years before (personal communication). This sink hole houses a pair of vertical shaft conduits that conduct water synchronously with the tide. Fish identified in this sink-hole included mojarra,



schoolmasters, and the crested goby we had seen in Three Roses. We also found Gray Angelfish, and several species of grunts and snapper.

Discovery of the Pigeon Creek Conduit. The Pigeon Creek Conduit (and sink-hole) lie near a narrows in Pigeon Creek, between a mangrove island and the east shore, GPS coordinates: {23° 57.285' N, 74° 30.467 W}. The sinkhole is rough-

Figure 6. Bird's eye view of the Pigeon Creek Conduit, artist's impression. Not to scale.

ly 8 m in diameter, with a sandy bottom, and an overhanging (southwest facing), smooth carbonate cliff (Figure 6). Although the creek-bed surrounding it is less than 1m deep, the sinkhole drops to 4 meters. Twin vertical shafts in the northwest corner of the sinkhole plunge to approximately 10 meters, where they open onto a large horizontal cave system running towards the Northwest (and coincidentally, towards Merman Pond and Three Roses Cavern). Water issues forcefully from these twin shafts when the tide is rising, and they draw water alarmingly with an out-going tide. Many reef fish congregate near the conduit opening, likely feeding on invertebrates attracted by the increased nutrient levels, as observed near other conduits on San Salvador (Whitelaw, 2000). The presence of entangled monofilament lines, and a trail leading to this site from a nearby road access, suggest that local fishermen are acquainted with this location.

DISCUSSION

Sources of Reef Fish in Merman Pond

Field reconnaissance suggests that a storm surge riding up Pigeon Creek and spilling over into Merman Pond, while not impossible, is no longer the most appealing theory for how reef fish came to populate Merman Pond. This is especially true since we discovered a neighboring sinkhole in Pigeon Creek harboring another impressive conduit-cavern system, "Pigeon Creek Conduit". It is particularly note-worthy that many of the fish species found in Merman Pond, and at the entrance to Three Roses Cavern, were also abundant at the mouth of the Pigeon Creek Conduit. Most notably, the Crested Goby was found at the mouth of both cavern systems though it is uncommon elsewhere and unreported in any other inland pond on the island.

Three Roses Cavern and the Pigeon Creek Conduit: a Tentative Geology

Since neither of these conduits appear to have a consistent vertical profile or a uniform lateral morphology, it is unlikely that they were formed by bioerosion (Mylroie and Carew, 1991). The Three Roses region actually consists of two valleys in between three fossilized dunes. One dune lies in between Merman and Mermaid pond, another between Merman Pond and Pigeon Creek and the third between Pigeon Creek and the ocean (Hearty et al., 1992). Beneath each of these dunes likely lies a small freshwater lens (Gentry and Davis, 2004). "Flank Margin Caves" have been reported to form where the vadose/phreatic boundary converges with the halocline (Pace et al., 1992). This frequently occurs at the lens margin (Mylroie et al., 2002) which often occurs at the edge of inland ponds on San Salvador (Davis and Johnson 1988). The Merman Pond and adjoining southern Pigeon Creek seem excellent for flank margin cave development, because the three nearby dune ridges likely have freshwater lenses underneath. Also, since as flank margin caves expand, they create small passageways that lead into the dune (Davis and Johnson 1988), it is not unreasonable to suggest that one of these passageways may have breached another flank margin cave nearby. Further, the structure of the Three Roses Cavern entrance in Merman Pond, that of two large chambers with a thin wall separating them at the edges is typical of flank margin cave expansion (Roth et al., 2004). Thus, it is both likely and plausible that both Three Roses Cavern and the Pigeon Creek Conduit match the description of a flank margin cave system. Confirmation of their connection awaits the use of fluorescent dye tracing or other such methods. It is no doubt significant that both caverns open up onto horizontal passageways at depths 10-13 meters below present day sea level.

A Third Cavern Outlet?

When the ocean tide is rising, water issues out of the twin vertical shafts that form the Pigeon Creek Conduit. As the tide changes, and begins to flow out of Pigeon Creek, water is drawn into the conduits with no detectable tide lag. These observations argue that, whether or not this conduit communicates with Three Roses Cavern, it must be connected to the outer coast. Satellite imagery detects an interesting pattern or "anomaly" on the wall closest to the Pigeon Creek cave opening (See Figure 6). A SCUBA expedition with surface support will be required to survey the wall in this area, to see if there are promising cavern openings at similar depths.

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