Effects of Hurricane Joaquin on the Sediment, Biota and Water Chemistry of Interior Ponds of San Salvador, Bahamas

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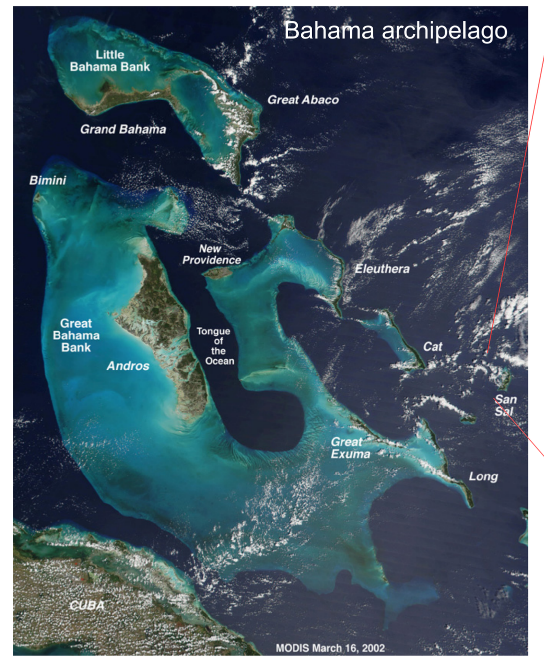
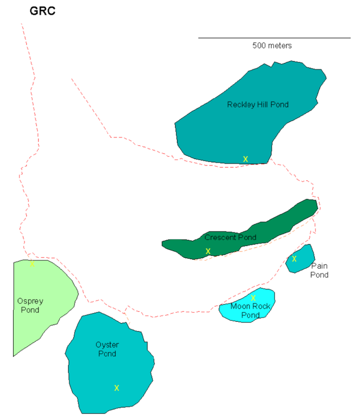
ABSTRACT

Research conducted in March 2016 evaluated Hurricane Joaquin's impact on marine and hypersaline interior ponds of San Salvador, Bahamas. Sediment cores and water samples were collected from six ponds (Osprey, Oyster, Moon Rock, Pain, Crescent and Reckley Hill) for analysis of water chemistry, sediment sizes and types, and mollusk distributions. While tempestites were predicted, none were identified in the sediment cores from the ponds, attributed to distance and physical barriers to the ocean. Alternatively, autochthonous shell-hash layers identified in almost every pond are attributed to the high energy generated during Joaquin. Sixteen species of gastropods and bivalves and two species of algae were encountered in the cores from ponds. Compared to previously published data for pH, salinity, and nutrients, our data show little change in water chemistry 6 months after the hurricane. In Oyster Pond, with several conduits to the ocean, abundances of macroalgae and invertebrates on red mangrove (*Rhizophora mangle*) prop roots and pond outcroppings indicate that the dominant invertebrate species on prop roots is the black mangrove oyster *(Isognomon alatus*), while previous studies report burnt mussels (*Brachidontes exustus*) as dominant. Dominant macroalgae on prop roots include *Batophora oerstedii* and *Acetabularia crenulata* and *A. calyculus*, while previous studies reported a greater variety of macroalgae more evenly distributed on prop roots. This study provides evidence that the red mangrove prop-root biota is recovering, and is currently less diverse and less abundant than pre-hurricane conditions. On pond outcroppings, many of the same invertebrate and oyster species cited in pre-hurricane studies were noted, but in different quantities. Macroalgae populations shifted after the hurricane due to the absence of previously observed red algae *Dasya crovaniana*, *Polysiphonia subtilissima*, and green algae *Anadyomene stellata* and *Pedobesia lamourouxii*. Overall, this study documented thick shell-hash layers in most ponds, and a decrease in algal species richness in Oyster Pond, as well as an alteration of dominant mussel species as compared to pre-hurricane conditions.



San Salvador, Bahamas above: satellite image. Island is ~21 km x 8 km **left**: San Salvador is an outer island in the Bahamian carbonate platform (shown left; MODIS).



Field Station Trail Map main trail shown as red dotted line, ancillary trails (orange dotted line), ponds along the trail, with yellow Xs marking sediment core localities (after Godfrey et al., 1994, Map 2).

INTRODUCTION

Hurricane Joaquin stalled over the Bahamas for 3 days during October 2016, dropping nearly 20 inches of rain and sustained winds of over 120 mph. This wind energy and influx of freshwater had a profound effect on San Salvador's population, infrastructure and vegetation. Two UTC faculty led a group of 9 Honors program undergraduates (mostly non-science majors) to the Gerace Research Centre (GRC) to answer the research question - *Can hurricane effects be documented in interior ponds?*

Historical Research

San Salvador's interior and coastal ponds have been the focus of research for biological, sedimentological and climatological research for decades. (Edwards et al., 1990; Hagey, 1991; Godfrey et al.,1994; Carew and Mylroie, 1995; Teeter, 1995, and several others). More recent research on interior and coastal ponds includes work published by Whitelaw, 2001; Freile et al., 2006; Park et al., 2008; Sipahioglu et al., 2010.

Research for comparisons incorporated into our study include water-chemistry research (Rothfus, 2012) that documented variations in salinity in most interior ponds accessible on foot from the GRC and some coastal ponds as well as a baseline for biota and conditions in Reckley Hill, Crescent and Oyster ponds the year before hurricane Joaquin hit (Ford and Abernathy, 2014). Biotic communities cited in Godfrey et al. (1994) are used for comparisons in this research as well. Extensive research over 20 years by Eric Cole and coauthors (e.g., Cole et al., 2007) on scaly pearl oysters affected by hurricanes in San Salvador's inland ponds, many of which have been used for comparisons in this research. Crescent and Moon Rock ponds have been the focus of impacts of conduits on biota in Crescent Pond (Whitelaw, 2001) and XRD and AAS analyses on inorganic carbonate mud in Moon Rock Pond (Freile et al., 2006).

Tempestites on San Salvador Island have been documented in cores taken from coastal ponds (e.g., Billingsley & Niemi, 2016; Mattheus & Fowler, 2015; Dalman & Park, 2012; Sipahioglu et al., 2010; Park et al., 2008; McCabe & Niemi, 2008 and others), but we have found no reference to tempestites identified in interior pond sediments.

METHODS

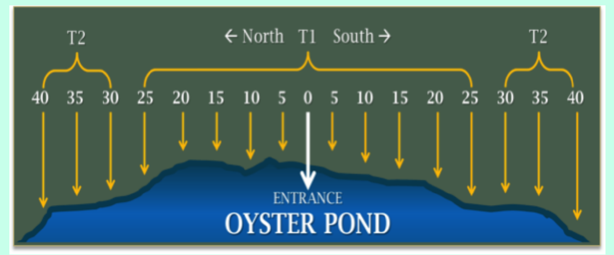
Three groups formed around 4 questions - 1) did the interior pond sediments contain tempestites from Joaquin; 2) did the mangrove prop-root communities change (Ford and Abernathy, 2014); 3) did clusters of communities populating the bottom of the ponds alter; 4) did the water chemistry values change in comparison to earlier results (Rothfus, 2012). Each group formed an hypothesis and developed a research strategy to test hypotheses.

The **Sediment group** sampled 6 inland ponds. Each pond was sampled by a different person to prevent cross-contamination. Each pond was sampled with at least 1 sediment core using a clear 30" long polycarbonate tube with a removable plastic sealing cap. Students made on-site observations and measurements, sketched and photographed the core samples in field notebooks. In the lab, they examined sediment and biological samples using hand lenses and microscopes, identifying biota encountered in the cores.

The **Benthic Outcropping Communities group** and the **Prop Root Communities group** focused their efforts in Oyster Pond, which is a normal salinity pond with at least two conduits connecting it to the ocean.

The Outcroppings group used the line intercept method to sample pond outcroppings. Three 15-meter transects were laid 10 meters apart with a 230° compass heading in order to cover as much of the pond as possible. Members swam the transect lines, recording initial observations on a dive slate, took digital photos for further study. They sampled outcroppings of any species of algae not immediately identified. In the lab, they identified the unknown biota and calculated species percent coverage using digital photographs. They also collected water samples in zip-top bags for lab analysis.

Using measuring tape, Ziploc bags, a 0.25m^2 quadrat, orange flagging tape, and a GoPro, **the Prop-Root group** selected shore-parallel transects to survey the red mangrove prop-root biota. Along the mangrove rim along the edge of the pond, this group sampled every 5 meters for 40 meters from each side of the entrance, taking a visual survey of the species present on the roots, photographs for reference, samples of the visible algae for later identification. They visually estimated percent coverage of each species (algae and invertebrates).

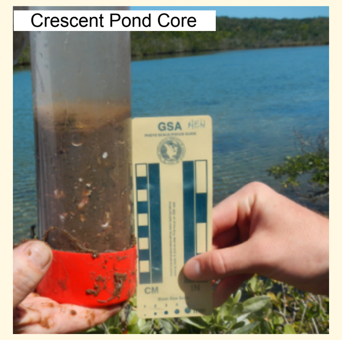


Pinctada longisquamosa (Scaly Pearl Oyster) populated by *Acetabularia* from Oyster Pond.

Moon Rock Pond core of micrite mud with living *Batophora* community.

Osprey Pond core with mangrove peat layer ~25-cm thick, overlain by thin shell-hash layer

Reckley Hill Pond core of shell hash overlain by living gastropods.

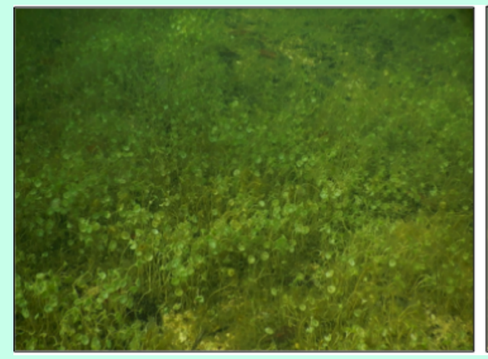


Crescent Pond core is primarily composed of shell hash and floc over bedrock. Only 1 core was successfully recovered.

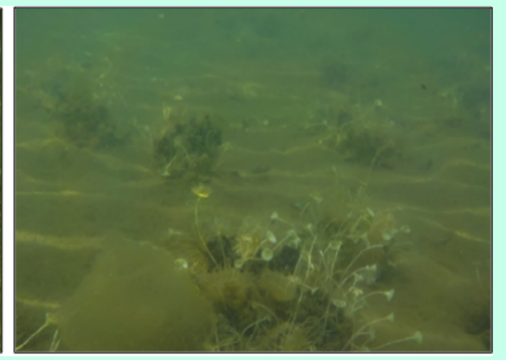
Oyster Pond core of shell hash on bottom, overlain by reddish-brown mud, capped by 1-2 cm thick shell hash, all overlain by thick floc layer. Other parts of Oyster Pond contained only floc over bedrock.

Pain Pond core of brown mud overlain by coarse, light-colored, sand-sized grains, capped by floc and whole gastropods.

Oyster Pond before in 2014 (left column) and after in March 2016 (right column). Hurricane Joaquin hit in October 2015. Bottom row is the entrance to Oyster Pond from the trail side (see map). Top row are prop-root communities. Note the obvious floc layer in the upper right picture.



Oyster Pond benthic algae community in 2014 (pre-hurricane Joaquin). Note dense *Acetabularia* meadows.

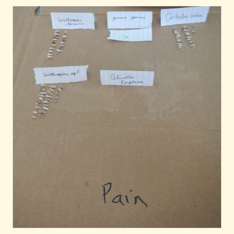


Oyster Pond benthic communities (outcroppings) in 2016 after hurricane Joaquin. Note decrease in *Acetabularia* coverage and thick flocculent layer. Lugworm egg sack in foreground.

Reckley Hill Pond shell hash (left) and identified sp. (right).

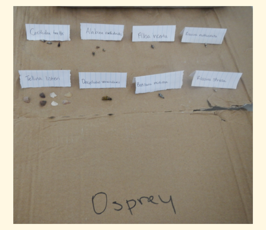
San Salvador beach sediments that normally form tempestite deposits in coastal ponds. None were found in the 6 interior ponds we studied.

Brachidontes domingensis (exustus) disarticulated valves from Moon Rock Pond. The larger valve exhibits abrasion, while the smaller valve does not. Attributed to Joaquin's high energy.



Pain Pond biota taken from the core and identified in the lab.

Moon Rock Pond organisms encountered in the sediment core fresh from the core before identification (right) and after identification in the lab (left).



Osprey biota identified in the lab.

Species	Reckley Hill Pond 1990	Reckley Hill Pond 2016	Pain Pond 1990	Pain Pond 2016	Moon Rock Pond 1990	Moon Rock Pond 2016	Osprey Pond 1990	Osprey Pond 2016
Abra aequalis			X			X		
Alba incerta								X
Albina cerinthoides								X
Anomalocardia auberiana	X							
Batillaria minima	X	X	X		X			X
Batophora oerstedii								
Brachiodontes domingensis						X		
Brachiodontes exustus					X			
Bulla striata					X			
Cerithidea beattyi								X
Cerithidea costata	X		X	X	X			
Cerithiopsis greeni				X				
Cerithiopsis sp?				X				
Cerithium lutosum	X		X		X	X		
Codakia orbiculata					X			
Dasycladus vermicularis								X
Gemma gemma				X	X			
Ilynessa obsoleta		X						
Olivella perplexa		X		X				
Polymesoda maritima	X							
Rissoina multicostata								X
Rissoina striosa								X
Tellina listeri		X						X
Tellina mera			X		X			

Pond taxa noted in Godfrey et al., 1994 and compared to March, 2016 identifications from Reckley Hill, Pain, Moon Rock and Osprey ponds.

Water Chemistry Data

Below: pH values for Oyster Pond varied slightly on the basic side of neutral. Oyster Pond naturally mimics normal marine salinities due to the conduits that connect it to open marine waters (Godfrey et al., 1994; Cole et al., 2007; Rothfus, 2012; Ford and Abernathy, 2014 and their unpublished data from 2015).

Oyster Pond	2012	2015	2016
pH	NA	7.74	7.54
salinity	35.5 ppt	34.45 ppt	37.1 ppt

2016 unpublished Data	Reckley Hill	Crescent	Pain	Moon Rock	Oyster	Osprey
salinity	49.7	42.2	44.8	41.9	42.9	66.7
2012 Rothfus Data						
salinity	41.4	35.5		35.4	37.1	52.1

Left: Salinity values from several ponds are compared to Rothfus (2012) values against unpublished student-measured data from 2016

Species	2014	2015	2016
GREEN ALGAE			
Acetabularia crenulata	x	x	x
Acetabularia calyculus			x
Anadyomene	x	x	
Batophora oerstedii		x	x
Cladophoropsis macromeres	x	x	x
Dictyosphaeria		x	x
Microdictyon marinum	x		
Pedobesia		x	
RED ALGAE			
Dasya crovaniana		x	
Polysiphonia		x	
Spyridia spp.	x		
CNIDARIA			
Aiptasia pallida	x	x	x
Bartholomea annulata	x	x	x
Bougainvillia spp.	x	x	x
ECHINODERM			
Synaptula hydriformis	x	x	x
Brittle star		x	x
MOLLUSCA			
Isognomon alatus	x	x	x
Pinctada longisquamosa	x	x	x
Gastropds			x
PORIFERA			
Chondrilla nucula	x	x	x
ANNELIDA			
Trypanosyllis spp.		x	x

List of taxa from Oyster Pond's benthic outcropping communities, which compares 2016 taxa from Ford and Abernathy's 2014 and unpublished 2015 data.

Observed Species	Pre Hurricane Ford and Abernathy 2014-15	Post Hurricane Observations 2016	Average Percent Coverage Post Hurricane 2016
Batillaria minima (snail)		X	2.5%
Eggsacks		X	10%
Isognomon alatus (black mangrove oyster)	X	X	9%
Pinctada longisquamosa (scaly pearl oyster)	X	X	10.3%
Unknown hydroid	X	X	12.5%
Acetabularia calyculus (green algae)	X	X	48.7%
Acetabularia crenulata (green algae)	X	X	48.7%
Anadyomene stellata (green algae)	X		
Batophora oerstedii (green algae)	X	X	60.7%
Cladophoropsis macromeres (green algae)	X		
Dasya crovaniana (red algae)	X		
Dictyosphaeria ocellata (green algae)	X		
Microdictyon marinum (green algae)	X		
Pedobesia lamourouxii (green algae)	X		
Polysiphonia subtilissima (red algae)	X		
Spyridia spp. (red algae)	X		
Species Richness	14	8	

List of taxa from Oyster Pond mangrove prop-root communities comparing 2016 taxa from 2014 and 2015 taxa (from Ford and Abernathy, 2014 and pers. commun.).

CONCLUSIONS

In comparing pre-hurricane and post-hurricane levels of outcropping biota of the normal marine Oyster Pond, Previous data for pH, salinity, and nutrients (nitrate, nitrite, and ammonia) showed little to no change in water chemistry 6 months after the hurricane, though a decrease in species richness was noted. Algae populations shifted after Joaquin with an absence of the previously observed red algae, *Dasya crovaniana*, *Polysiphonia subtilissima*, and green algae, *Anadyomene stellata* and *Pedobesia lamourouxii*.

There were major changes in the number of species on mangrove prop-roots in Oyster Pond. This group found less variety in macroalgae, and the roots were dominated by scaly pearl oysters and black mangrove oysters; we found no burnt mussel communities along our mangrove transect. The 2016 percent-coverage of prop-roots decreased from 2014-2015 survey values of Oyster Pond (Ford and Abernathy, 2014 and pers. commun.). These data also vary from 2005-2007 observations by Cole et al., (2007), where burnt mussels dominated prop-root bivalve communities. Our 2016 data show some parallels with the observations from Cole et al. (2007) data.

Sediment group found no tempestites in any interior pond core. We suggest that the interior ponds are too far from coastal areas and protected behind fossilized Pleistocene eolianite ridges to receive beach sediment. However, there were shell hash accumulations in every pond except Moon Rock Pond, and we suggest that the origin of the broken shells formed *in-situ* during large storm events. Large, abraded *Brachidontes domingensis* (burnt/scorched mussel) disarticulate valves were found in Moon Rock Pond with small disarticulate valves that had not been abraded. We attribute this abrasion of large valves to high energy generated in lakes during storms. Reckley Hill Pond core had the greatest abundance of mollusks (122 specimens), 89 mollusks in Pain Pond, Moon Rock core contained 49 mollusks and Osprey had 7 mollusks. In every pond listed on the green table, a decrease in species richness is noted, comparing Godfrey et al. (1994) data and our preliminary surveys in 2016.

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