PROCEEDINGS

OF THE

SECOND JOINT SYMPOSIUM

ON THE

NATURAL HISTORY AND GEOLOGY OF THE BAHAMAS

Edited by
Tina M. Niemi
and
Kathleen Sullivan Sealey

ORGANIZER:

Troy A. Dexter

Executive Director
Gerace Research Centre
University of The Bahamas
San Salvador, The Bahamas

2020

ISBN: 978-0-935909-67-8

HURRICANE JOAQUIN IMPACTS ON OYSTER POND, SAN SALVADOR, THE BAHAMAS

Dawn M. Ford, Jalana Abernathy, Luke Black,
Ann Holmes, Ashton Mitchell, Sabrina Novak, and Alex Schwartz

The University of Tennessee at Chattanooga
615 McCallie Avenue, Chattanooga, TN 37403

ABSTRACT

In 2015, Hurricane Joaquin directly impacted San Salvador and disturbed the mangrove vegetation, pond biota, and sediment of many interior ponds, including Oyster Pond. Oyster Pond is a fully marine pond lined by red mangroves (*Rhizophora mangle*) and has several conduits connecting the pond to the ocean and perhaps to other ponds. The post-hurricane recovery of pond biota, specifically those species living on biotic outcroppings and mangrove prop roots, was investigated with a focus on macroalgae and macroinvertebrates. Comparisons with pre-hurricane data reveal that while there was not a reduction in macroinvertebrate species richness, there has been a loss of three red macroalgal species and one green algae since the hurricane. Further, in comparing the western side of the pond to the less impacted eastern side of the pond, the data suggest that more damaged mangroves can support fewer algal and macroinvertebrate species and in less abundances than healthier mangroves. The detrital nature of mangrove systems may explain this finding. An interesting discovery was a small crab documented for the first time in Oyster Pond and the identification of this species is still being investigated.

INTRODUCTION

Impacts of hurricanes on natural systems

Hurricanes occur commonly in The Bahamas, and on average, a tropical storm or hurricane has impacted San Salvador every 2.42 years since 1851 (Hurricanecity.com, 2017). Hurricanes cause large-scale disturbance to coastal ecosystems. For example, a meta-analysis of data from over 280 coral reef sites revealed that coral cover declines an average of 17% in the year following a hurricane impact (Gardner et al., 2005). The loss of coral increases with hurricane intensity and with time passed since impact; reefs seem to take at least eight years to recover to the pre-hurricane state (Gardner et al., 2005).

Hurricane impacts on seagrass beds have been studied extensively (Anton et al., 2009; Carlson et al., 2010). Seagrass beds are relatively resistant to storms as seagrasses have a deeply rooted rhizome system. In Florida and the Caribbean, seagrass beds are dominated by *Thalassia testudinum* (turtle grass) and are mixed with two other seagrass species and many macroalgal species. Studies have shown that seagrass coverage declines by only a few percent after a hurricane while the green calcareous macroalgae show much greater losses (24%-70%) (Cruz-Palacious and Van Tussenbrock, 2005; Fourqurean and Rutten, 2004).

In mangrove forests, hurricanes can cause mangrove trees to be broken, defoliated, and killed by high winds, storm surge, and lightning strikes (Zhang et al., 2016). Some species of mangroves are more susceptible to disturbances than others. For example, rhizophoraceae mangrove species, like the red mangrove, have higher mortality rates from hurricanes as compared to non-rhizophoraceae groups (Wang et al., 2014). Hurricane damage to red mangroves takes 4-7 months to reach full extent and trees take 2-6 years to recover (Feller et al., 2015).

While much research has been done on the hurricane impacts of coral reefs, seagrass beds, and mangroves, few studies have focused on inland ponds and lakes. San Salvador's landscape has high ridges and a high density of inland lakes and ponds. Often these ponds and lakes offer unique archives of storm records in the form of tempestites

(Park et al., 2009; Mattheus and Fowler, 2015). Tempestites are sedimentary layers composed of grains, including ooids, rounded shell fragments, etc., that originated in a beach environment and have been transported by storms into low-energy environments such as marshes and ponds. Tempestites have been reported from many coastal San Salvador ponds (Button et al., 2007; McCabe and Niemi, 2008; Park et al., 2009; Sipahioglu et al., 2010; Park, 2012; Dalman and Park, 2012; Mattheus and Fowler, 2015; Billingsley and Niemi, 2016).

Previous studies of inland ponds and lakes have been focused on specific groups of organisms. Park et al. (2009) found that ostracods in a hypersaline lake increase in abundance and diversity after storm events. Yannarell et al. (2007, p. 576) reported that microbial mats in a hypersaline pond experienced a "significant shift" in the cyanobacteria and diazotrophs post-hurricane, with a dominance of organisms that were rare before the hurricane. Cole et al. (2007) compared a modestly hypersaline pond lacking outlets to the sea with a marine pond served by numerous conduits and found that the scaly pearl oyster responded differently depending on how quickly marine salinity was restored following heavy rainfall. The current study adds to the work of hurricane impacts on interior ponds, but focuses on the broad biotic response of macroinvertebrates and macroalgae in an interior marine pond. Specifically, we compared the macroalgal and macroinvertebrate species richness and species composition before and after the hurricane in Oyster Pond.

Hurricane Joaquin

Hurricane Joaquin was a Category 4 storm (Saffir-Simpson Hurricane Wind Scale) when it affected the central and southeastern Bahamas (Figure 1; Berg, 2016). It was the strongest October hurricane impacting The Bahamas since 1866 and made landfall as a major hurricane on San Salvador on October 2, 2015. The eyewall passed directly over the island. Hurricane Joaquin had estimated maximum sustained winds of 138 mph when the eye of the storm passed between Crooked Island and Long Island. Joaquin produced storm surges of 4-5 m (12-15 ft), and while there were no official rainfall measurements, the Bahamas Department of Meteorology estimated 130-260 mm (5-10 inches) (Berg, 2016). The impact of this storm to San Salvador has been mostly described in terms of infrastructure. The National Hurricane Center reported that San Salvador's roads were impassable, the airport was destroyed, homes were damaged, and power lines were downed (Berg, 2016). Since the storm, the airport has been rebuilt, power lines repaired, and most roads are passable again.

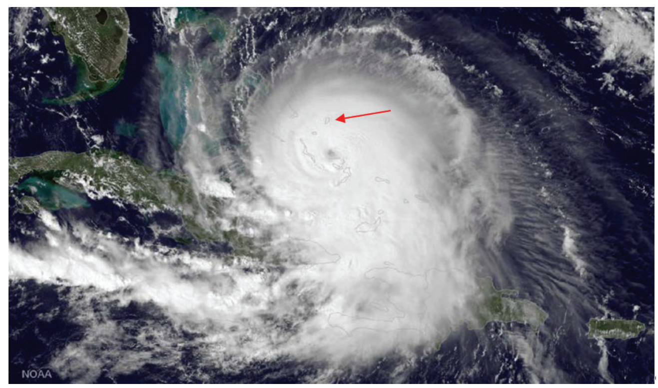

Figure 1. NOAA satellite image, October 1 2015, near central and southeastern Bahamas. Arrow points to San Salvador.

For this study, our research question was: How did Hurricane Joaquin impact Oyster Pond? To address this question, we analyzed the macroinvertebrate and macroalgal species composition, sediment (for tempestites), and water chemistry of the pond.

FIELD SITE DESCRIPTION

Oyster Pond is a marine pond on the north end of the island of San Salvador (Figure 2). This pond is a dissolution and collapse feature that formed from the dissolution of diagenetically immature eogenetic limestones (Park Boush et al., 2014). The pond has conduits that connect it with the ocean and therefore, has a marine salinity and diurnal tidal fluctuations of 20-30 cm. Oyster Pond, like many interior ponds, contains several microhabitats (Figure 3). Red mangroves and their prop roots ring the pond's margin, protecting the pond from strong winds and erosion. Many epibiota make their home on the prop roots. Away from shore, an organic flocculent layer rests along the hard carbonate bottom of the pond and is made up of decomposing organisms and mangrove leaves. Outcroppings emerge from the carbonate bottom as an accumulation of biotic growths consisting of a variety of algae and invertebrate species. Conduit mouths, which connect Oyster Pond to the ocean, are also home to a few species.

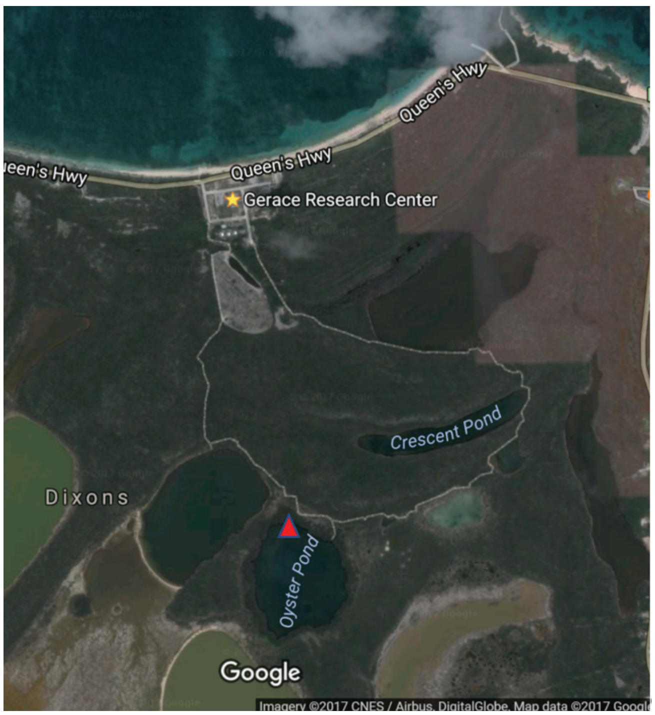

Figure 2. Oyster Pond (marked by red triangle) is approximately one mile south of the Gerace Research Centre (marked by yellow star), along the GRC trail (shown as a white line).

METHODS

The epibiota of mangrove prop roots, the biota of outcroppings, water chemistry, and sediment content were evaluated post-hurricane in March 2016, March 2017, and June 2017. The biota and water chemistry data were compared to pre-existing pre-hurricane data from March 2015. Pre-hurricane data were from a visual survey and not separated by microhabitat type, so comparisons to 2015 are limited to overall species presence/absence and species richness.

In March 2016 and 2017, 20 m transects were established along the shoreline of the pond. Four were sampled in 2016 (east and west of pond entrance) and four were sampled in 2017 (east, west, north, and south sides of the pond). At 5 m intervals, a 1-m^2 quadrat was used (0.25 m^2 quadrant used in 2016). Within each quadrat, percent coverage of species was estimated and all visible macroinvertebrate and macroalgae species were documented. The quadrats formed a vertical window against the prop roots.

In March 2016 and 2017, outcroppings were surveyed *in situ* using the line intercept method with transects starting from the north edge of the pond toward the middle of the pond until the outcroppings disappeared (approximately 25 m). Three transects were sampled in 2016 and four transects in 2017. Within 1 m quadrats, species were identified, and percent coverage was estimated.

Additional data collection: In March 2017, conduit mouths and the flocculent layer were studied through a brief visual survey (no transects or quadrats). In June 2017, a brief visual survey of mangrove prop roots and outcroppings was conducted, and these additional documented species are included in the results. All of these post-hurricane data were compared to March 2015 data reported by Ford and Abernathy (2017).

During every data collection period, biotic samples and photographs of the outcroppings and mangrove roots were taken for further identification and analysis using webpages, a digital microscope (Plugable USB 2.0), and identification books and field guides including *Marine Plants of the Caribbean* (Littler et al., 1989), *Caribbean Reef Plants* (Littler and Littler, 2000), and *Natural History of Northeastern San Salvador Island* (Godfrey et al., 1994). Also during every data collection period, two water samples were collected within 1 m of the water surface of the pond for testing. The pH and salinity of the water samples were measured using a standard calibrated pH meter and refractometer (salinity).

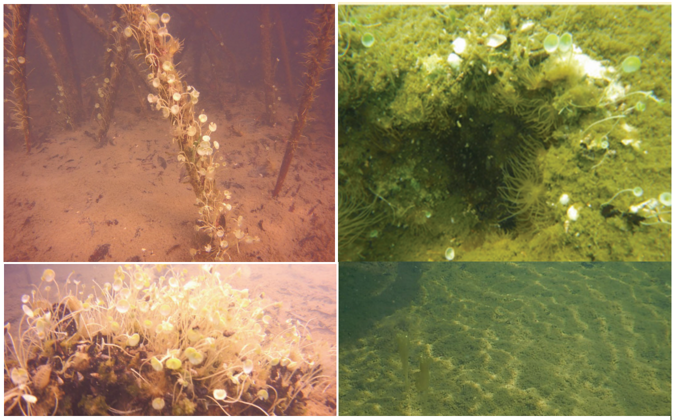

Figure 3. Microhabitats found in Oyster Pond: a) Red mangrove prop roots, b) Conduit mouth, c) Biotic outcropping, d) Flocculent layer.

For the sediment core in March 2016, a clear 3 inch diameter, 30-cm-long polycarbonate tube was used. The tube was pushed into the pond's bottom layers. A plastic cap was applied to the top of the tube creating suction, and the core was slowly extracted. Another plastic cap was placed on the bottom of the core before removing from the pond to better contain the unconsolidated core constituents.

RESULTS

Pre-Hurricane Biota

In March 2015, we documented a total of 24 macroinvertebrate and macroalgal species on mangrove roots, biotic outcroppings, and the flocculent layer. These organisms included 3 species of red algae and an uncommon type of green algae, *Pedobesi*a (Table 1) which were all found on the mangrove roots. General observations and photographs indicate that the water was very clear and the flocculent layer had some lugworm egg sacs.

Post-Hurricane Biota

Overall Oyster Pond species presence & richness

Post-hurricane, a total of 19 macroinvertebrate and macroalgal species were identified in 2016 and 23 species in 2017 (Table 1). The macroinvertebrate species richness stayed consistent in 2016 (no decrease after hurricane). However, a higher number of invertebrate species were documented in 2017, which is probably due to the researchers spending more time in Oyster Pond. For macroalgae, the number of species documented in 2016 (5) was half of pre-hurricane numbers and in 2017, that number increased to 6. All red algae species identified in 2015 have not been seen since the hurricane.

Mangrove prop roots

In 2016 and 2017, red mangroves were visibly impacted (defoliation and broken branches) compared to pre-hurricane conditions (Figure 4). The impact was more severe on the western and northern sides (pond entrance is on the north end), as compared to the eastern and southern sides of the pond. This trend is also reflected in the biotic coverage of the prop roots sampled in 2017 (Table 2).

The dominant macroalgae and invertebrate species on mangrove prop roots post-hurricane varied across areas of the pond, but there were some species in common (Table 1). Two species of *Acetabularia*, a common green alga, were very abundant in all sampled areas along with *Isognomon alatus* (black mangrove oyster).

Biotic outcroppings

The species that dominated biotic outcroppings post-hurricane were like those that dominated the mangrove prop roots. *Pinctada longisquamosa*, *Isognomon alatus,* species of *Acetabularia,* and species of sea anemone (*Bartholomea annulate*, *Aiptasia pallida*) (Table 2). A new species found on outcroppings not documented before in Oyster Pond was an undetermined crab in summer 2017. This crab was very small with a carapace approximately 0.75 cm in diameter.

Water chemistry and sediment

Water chemistry in Oyster Pond has slightly varied over time (Table 3). It seems that the pond recovered quickly after the hurricane in October 2015 as the post-hurricane data are very similar to the pre-hurricane data. The pH is slightly basic, and salinity is marine.

Scientific Name	2015 Pre-Hurricane	2016 Post-Hurricane	2017 Post-Hurricane	Microhabitat*
MACROINVERTEBRATES				
Annelids				
Trypanosyllis spp., Claparède, 1864	x	x	x	OC
Arenicola cristata, Simpson 1856	x	x	x	CM, FL
Harmothoe spp., Kinberg, 1856			x	OC
Arthropods				
Gammarus spp., Fabricius ,1775	x	x	x	OC
Undetermined crab species			x	OC
Cnidarians				
Aiptasia pallida, Agassiz in Verrill 1864	x	x	x	CM, MR, OC
Bartholomea annulate, Le Sueur 1817	x	x	x	MR, OC
Bougainvillia spp., Lesson 1830	x	x	x	MR
Echinoderms				
Synaptula hydriformis, Lesueur, 1824	x	x	x	OC
Ophiuroidea spp., Gray 1840	x	x	x	OC
Mollusks				
Batillaria spp., Benson 1842	x	x	x	MR, OC
Bulla umbilicate, Montagu, 1803			x	OC
Cerithium lutosum, Menke 1828	x	x	x	CM, MR, OC
Isognomon alatus, Gmelin, 1791	x	x	x	CM, MR, OC
Pinctada longisquamosa, Dunker 1852	x	x	x	CM, MR, OC
Sponges				
Chondrilla nucula, Schmidt, 1862	x	x	x	MR, OC
Unknown sponge species	x	x	x	OC
Macroinvertebrate Species Richness	**14**	**14**	**17**	
MACROALGAE				
Green Algae				
Acetabularia crenulate, J.V. Lamouroux, 1816	x	x	x	CM, MR, OC
Acetabularia calyculus, J.V. Lamouroux 1824	x	x	x	CM, MR, OC
Anadyomene stellate, (Wulfen) C. Agardh 1823	x		x	CM, MR
Batophora oerstedii, J. Agardh 1854	x	x	x	MR, OC
Cladophoropsis macromeres, W.R. Taylor 1928	x	x	x	OC
Dictyosphaeria ocellata, (M. Howe) Olsen-Stojkovich 1985	x	x	x	MR, OC
Pedobesia spp., MacRaild & Womersley, 1974	x			MR
Red Algae				
Dasya crouaniana, Agardh, 1890	x			MR
Polysiphonia spp., Greville 1823	x			MR
Spyridia spp., Harvey 1833	x			MR
Macroalgae Species Richness	**10**	**5**	**6**	
TOTAL SPECIES RICHNESS	**24**	**19**	**23**	

*Table 1. Oyster Pond species richness data. Microhabitat codes: CM (conduit mouth), FL (flocculent layer), OC (outcropping), MR (mangrove root). * The three color morphs of the naked sea cucumber (clear, brown, and tiger-striped) were documented*

	North	West	South	East
Total Biotic Coverage of Prop Roots	50%	40%	80%	70%
Dominant Species by Percent Coverage (in order)	*Acetabularia spp.* *Isognomon alatus* *Pinctada longisquamosa* *Batophora oerstedii*	*Bougainvillia spp.* *Acetabularia spp.* *Isognomon alatus*	*Isognomon alatus* *Bougainvillia spp.* *Acetabularia spp*	*Acetabularia spp.* *Pinctada longisquamosa* *Isognomon alatus* *Batophora oerstedii*

Table 2. Mangrove prop root biotic coverage and dominant species in areas of the pond (March 2017).

The Oyster Pond sediment core contained 3.5 cm shell-hash layer resting directly on bedrock, capped by ~10 cm of reddish-brown clay, which was overlain by ~2 cm of a second shell hash layer, topped by ~2 cm of flocculent layer (Figure 5). There was no evidence of tempestites in this core.

	2012* (pre-hurricane)	2015 (pre-hurricane)	2016 (post-hurricane)	2017 (post-hurricane)
pH		7.74	7.45	7.49
Salinity (ppt)	37.1	34.5	35.0	37.0

Table 3. Water chemistry results, 2012-2017 Rothfus (2012).

Oyster Pond has an interesting and unique set of organisms that inhabit the mangrove prop roots, biotic outcroppings, the conduit mouths, and flocculent layer. While there were obvious biological impacts from the hurricane, it is important to note that the biota of the pond seem to naturally change from year to year without disturbance. For example, the first year we explored the pond in 2014, there was an extensive sponge garden on the north end that we have not seen since. The water quality data showed little variation over time which demonstrates that despite heavy rainfall in a short period of time, the conduits provide enough connection to the ocean to recover a marine salinity and pH quickly.

Overall, the impact of Hurricane Joaquin caused a decline in macroalgae, especially species of red algae. After the hurricane, the red mangrove prop roots were more populated by epibiota on the south and east sides of the pond as compared to the north and west areas of the pond. This could be explained by the direction of the winds as the Category 4 hurricane moved over the island. The mangrove prop roots had robust populations of scaly pearl oysters and black mangrove oysters; but few burnt mussels. Cole et al. (2007) found that the scaly pearl oyster population was "relatively intact" after Hurricane Frances and found that burnt mussels dominated prop root communities (by counts, not percent coverage), which contradicts findings of this study. It seems there has been a shift in the dominant oyster species in the pond since the Cole et al. (2007) study.

Acetabularia is a very hardy green macroalgal species and is consistently the most abundant macroalgae in Oyster Pond, pre- and post-hurricane. Its thallus is calcified, and it attaches firmly by its rhizoids to substrates such as mangrove prop roots, bivalve shells, and biotic outcroppings which may contribute to its ability to withstand stressors. On the other hand, some fleshy red macroalgae (*Dasya spp.*, *Polysiphonia spp.*, *Spyridia spp.*) were seemingly wiped out by the hurricane and have not re-established as of summer 2017. These fleshy macroalgae are easily removed from substratum (Precht et al., 2009). There may be factors other than mechanical stress, such as nutrient levels, that influence the presence of these red algal species after a disturbance (Bertocci et al., 2017).

Figure 5. Oyster Pond southern conduit core taken in 2016. Shell-hash layer on bottom not visible due to lower core cap. Upper shell hash is likely hurricane deposit.

The presence of shell-hash layers along the bottom of Oyster Pond is attributed to storm events, which create high energy in a normally low-energy environment subjected only to tidal fluctuations. However, no tempestites were found in Oyster Pond. We believe this is due to the position of the pond behind high ridges and being farther inland than other coastal ponds where tempestites have been found.

A discovery of a species that has not, to our knowledge, been documented in Oyster Pond before is a very small marine crab. While we were not able to identify the crab due to its small size and condition, there are a couple of possibilities to investigate further. More than 20 years ago, Godfrey et al. (1994) documented *Armases miersii* in the Crab Hole (tidal pool) along the same interior trail. In addition, there is a pea crab species (*Pinnixa cylindrica*) known to have a commensal relationship with lugworms that may live in the worm burrow for protection (Ruppert and Fox, 1988).

An interesting finding was the change in quantity of lug worms egg sacs over time. Lugworms are organisms that burrow into the flocculent layer of the pond. In the spring, lugworms release a gelatinous egg mass that is connected at one end to the burrow opening (Ruppert and Fox, 1988). In March 2015 – before the hurricane - there were lug worm eggs sacs present, but not in abundance. Six months after the hurricane, in March 2016, there was a high density of lug worm eggs sacs. Did the disturbance cause the lugworms to reproduce more than normal? This could be the focus of future research.

A limitation of this study is that because this study used visual and transect sampling methods, there are likely species there were not documented. Another limitation is that our sampling methods varied over time.

ACKNOWLEDGMENTS

We would like to thank the Gerace Research Centre for graciously hosting our UTC groups each year and providing much needed assistance in completing this work. This research was performed by permission of the The Bahamas Environment, Science, and Technology (BEST) Commission, Nassau, the Bahamas.

REFERENCES

Anton, A., Cebrian, J., Duarte, C.M., Heck, J., Kenneth, L., and Goff, J. 2009. Low impact of Hurricane Katrina on seagrass community structure and functioning in the northern Gulf of Mexico. *Bulletin of Marine Science 85*(1): 45-59.

Berg, R. 2016. National Hurricane Center Tropical Cyclone Report: Hurricane Joaquin. National Hurricane Center, January 12, 2016. Available: https://www.nhc.noaa.gov/data/tcr/AL112015_Joaquin.pdf.

Bertocci, I., Domínguez Godino, J. A., Freitas, C., Incera, M., Bio, A., and Domínguez, R. 2017. Compounded perturbations in coastal areas: contrasting responses to nutrient enrichment and the regime of storm-related disturbance depend on life-history traits. *Functional Ecology* 31(5): 1122-1134.

Billingsley, A.L. and Niemi, T.M. 2016. Paleoenvironmental reconstruction of Triangle Pond (San Salvador Island, Bahamas) through stratigraphic and elemental analysis of a sediment core. Pp. 84-94. In B. Glumac and M. Savarese, (Eds.). *Proceedings of the 16th Symposium on the Geology of the Bahamas and other Carbonate Regions*. Gerace Research Centre, San Salvador, The Bahamas.

Button, J.A., Lanterman, L.L., and Erdman, R.B. 2007. Physical and geological characteristics of Mermaid Pond, an anchialine lake on San Salvador Island, Bahamas. Pp. 14-20. In B.J. Rathcke and W.K. Hayes (Eds.). *Proceedings of the 11th Symposium on the Geology of the Bahamas and other Carbonate Regions*. Gerace Research Centre, San Salvador, The Bahamas.

Carlson, P.R., Yarbro, L.A., Kaufman, K.A., and Mattson, R.A. 2010. Vulnerability and resilience of seagrasses to hurricane and runoff impacts along Florida's west coast. *Hydrobiologia* 649(1): 39-53.

Cole, E., Hoft, N., Campion, J., and Cole, B. 2007. The effect of hurricane activity on scaly pearl oysters, *Pinctada longisquamosa*, in two dissimilar inland marine ponds on San Salvador

Island, Bahamas. Pp. 78-89. In B.J. Rathcke and W.K. Hayes (Eds.). *Proceedings of the 11th Symposium on the Natural History of the Bahamas.* Gerace Research Centre, San Salvador, The Bahamas.

Cruz-Palacios,V., and Van Tussenbroek, B.I. 2005. Simulation of hurricane-like disturbances on a Caribbean seagrass bed. *Journal of Experimental Marine Biology and Ecology* 324(1): 44-60.

Dalman, M.R., and Park, L.E. 2012. Tracking hurricane and climate change records in a Bahamian coastal lake: Clear Pond, San Salvador Island, Bahamas. Pp. 15-32. In D.W. Gamble and P. Kindler (Eds.). *Proceedings of the 15th Symposium on the Geology of the Bahamas and other Carbonate Regions.* Gerace Research Centre, San Salvador, The Bahamas.

Feller, I.C., Dangremond, E.M., Devlin, D.J., Lovelock, C.E., Proffitt, C.E., and Rodriguez, W. 2015. Nutrient enrichment intensifies impact in scrub mangrove ecosystems in Indian River Lagoon, Florida, USA. *Ecology* 96(11): 2960-2972. doi: 10.1890/14-1853.1.

Ford, D., and Abernathy, J. 2017. Algae, fish, and invertebrate survey of Reckley Hill, Crescent, and Oyster Ponds. Pp. 188. In C.L. Landry, L.J. Floreas, and D.S. Kjar (Eds.) *Proceedings of the 1st Joint Natural History and Geology of the Bahamas Conference* [abstract].

Fourqurean, J.W., and Rutten, L.M. 2004. The impact of Hurricane Georges on soft-bottom, backreef communities: site- and species-specific effects in south Florida seagrass beds. *Bulletin of Marine Science* 75(2): 239-257.

Gardner, T.A., Cote, I.M., Gill, J.A., Grant, A., and Watkinson, A.R. 2005. Hurricanes and Caribbean coral reefs: impacts, recovery patterns, and role in long-term decline. *Ecology* 86(1): 174-184.

Godfrey, P.J., Edwards, D.C., Smith. R.R., and David, R. Laurence. 1994. *Natural History of Northeastern San Salvador Island: A "New World" Where the New World began.* Bahamas Field Station, San Salvador, Bahamas.

HurricaneCity.com. (2017). San Salvador Island Bahamas history with tropical systems. Available at http://www.hurricanecity.com/city/sansalvador.htm.

Littler, D.S., and Littler, M.M. 2000. *Caribbean Reef Plants*. Offshore Graphics.

Littler, D.S., Littler, M.M., Bucher, K.E., and Norris, J.N. 1989. *Marine Plants of the Caribbean; a Field Guide from Florida to Brazil*. Smithsonian Institution Press.

Mattheus, C.R., and Fowler, J.K. 2015. Paleotempestite distribution across an isolated carbonate platform, San Salvador Island, Bahamas. *Journal of Coastal Research* 31: 872-858. doi 10.2112/JCOASTRES-D-14-00077.1

McCabe, J.M., and Niemi, T.M. 2008. The 2004 Hurricane Frances overwash deposition in Salt Pond, San Salvador, Bahamas. Pp. 25-41, In L.E. Park and D. Freile (Eds.). *Proceedings of the 13th Symposium on the Geology of the Bahamas and other Carbonate Regions*. Gerace Research Centre, San Salvador, The Bahamas.

Park, L.E., Siewers, F.D., Metzger, T., and Sipahioglu, S. 2009. After the hurricane hits: recovery and response to large storm events in a saline lake, San Salvador Islands, Bahamas. *Quaternary International* 195: 98-105. doi: 10.1016/j.quaint.2008.06.010

Park, L.E. 2012. Comparing two long-term hurricane frequency and intensity records from San Salvador Island, Bahamas. *Journal of Coastal Research* 28: 891-902. doi:10.2112/jcoastres-d-11-00065.1

Park Boush, L.E., Myrbo, A., and Michelson, A. 2014. A qualitative and quantitative model for climate-driven lake formation on carbonate platforms based on examples from the Bahamian archipelago. *Carbonates Evaporites* 29: 409-418.

Precht, W., Aronson, R., and Deslarzes, K. 2009. Post-hurricane assessment of sensitive habitats of the Flower Garden Banks Vicinity. NOAA Report 39574 (MO6PC00003).

Rothfus, E. 2012. Water quality monitoring of San Salvadorian inland lakes. Pp. 129-138. In D.W. Gamble and P. Kindler (Eds.). *Proceedings of the 15th Symposium on the Geology of the Bahamas and other Carbonate Regions*. Gerace Research Centre, San Salvador, Bahamas.

Ruppert, E.E., and Fox, R.S. 1988. *Seashore Animals of the Southeast: A Guide to Common Shallow-water Invertebrates of the Southeastern Atlantic Coast*. University of South Carolina Press.

Sipahioglu, S.M., Park, L.E., and Siewers, F.D. 2010. Tracking storms through time: Event deposition and biologic response in Storr's Lake, San Salvador Island, Bahamas. Pp. 220-236. In F.D. Siewers and J.B. Martin (Eds.). *Proceedings of the 14th Symposium on the Geology of the Bahamas and other Carbonate Regions.* Gerace Research Centre, San Salvador, The Bahamas.

Wang, X., Wang, W., and Tong, C. 2016. A review on impact of typhoons and hurricanes on coastal wetland ecosystems. *Acta Ecologica Sinica* 36(1): 23-29. doi: 10.1016/j.chnaes. 2015.12.006.

Yannarell, A.C., Steppe, T.F., and Paerl, H.W., 2007. Disturbance and recovery of micro- bial community structure and function fol- lowing Hurricane Frances: *Environmental Microbiology* 9(3): 576-583.

Zhang, K., Thapa, B., Ross, M., and Gann, D. 2016. Remoting sensing of seasonal changes and disturbances in mangrove forest: A case study from South Florida. *Ecosphere* 7(6): e01366. doi: 10.1002/ecs2.1366.