# PROCEEDINGS

# OF THE

# 12th SYMPOSIUM

# ON THE

# NATURAL HISTORY OF THE BAHAMAS

Edited by
**Kathleen Sullivan Sealey**
and
**Ethan Freid**

Conference Organizer
**Thomas A. Rothfus**

Gerace Research Centre
San Salvador, Bahamas
2009

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

ISBN 0-935909-89-3

# CORRELATING MOLLUSCAN SPECIES WITH WATER CHEMISTRY IN THE SALTWATER PONDS OF SAN SALVADOR ISLAND, BAHAMAS.

Anna K. Dutke, John Schade and Eric S. Cole

Biology
St. Olaf College
1500 St. Olaf Avenue
Northfield, MN 55057

## ABSTRACT

Molluscs represent key species within marine ecosystems. Their restricted tolerance for certain environmental conditions allows differences in relative abundance to serve as environmental indicators. By understanding living molluscan tolerances, one could also use shell-hashe relics to reconstruct past environments. On San Salvador Island, Bahamas, many molluscan species residing in the island's ponds have undergone dramatic changes in abundance over relatively short periods of time. Some species appear to have been driven to local extinction from specific ponds. The leading factor behind the changing molluscan population demographics is most likely salinity. In 2006 we documented the salinity of nineteen ponds on San Salvador Island. Data was again taken in January 2007, along with a survey of both the live molluscan species and species present in the corresponding dead shell hashes along the shoreline in order to explore correlations between mollusc distribution and salinity. We found evidence for distinguishing three ranges of salt tolerance among mollusc species, <35 g/L, 35 g/L to 50 g/L and >50g/L. *Battilaria minima* and *Anomalocardia auberiana* appear to be quite euryhaline, (tolerating very hypersaline conditions). *Brachiodontes exustus, Isognomon alatus, Tellina and Gemma gemma*, on the other hand, appear quite stenohaline, (tolerating only a narrow range of saltwater conditions). *Cerithidea costata*, *Polymesoda maritima*, *Pinctada longisquamosa*, and *Cerithium lutosum* demonstrated an intermediate level of salt tolerance among living specimens. We also explored other aspects of water chemistry. After determining salinity, pH and dissolved nitrogen for each pond, it seemed clear that salinity was the most important determinant of molluscan diversity. In two cases we chronicle evidence of dramatic changes in pond habitat over recent years. An interesting trend was discovered in the relationship between the dominant form of nitrogen in ponds exhibiting a range of salinities. When salinity dropped below 40 g/L nitrate was the more abundant form of nitrogen, and when salinities rose above 40 g/L, ammonia was more abundant. We hypothesize that this represents salt tolerance of the nitrogen-processing microbes that inhabit these ponds.

## INTRODUCTION

The Island of San Salvador is one of 700 Islands that make up the Bahamian Archipelago. The Island itself is approximately 11.2 km east to west, and 19.25 km north to south. The Island contains numerous saltwater lakes and ponds, the majority of which are minimally affected by resident Bahamians and visitor researchers due to relatively difficult access. We explored nineteen of these bodies of water (Figure 1.), discovering a wide range of salinity levels and invertebrate diversity.

The ponds are relatively young, having begun to fill with seawater following the last glacier age less than 7,000 years ago. There is evidence based on ostracod shell remains that a number of these ponds have followed a salination trajectory from freshwater, to brackish, to marine, and some to hypersaline (Sanger & Teeter, 1982). This trajectory is to be expected if one imagines rising sea levels pushing a freshwater lens up through the island's somewhat permeant bedrock. In the low lying inter-dune swales, the first water to breach the surface would be from the freshwater lens itself (Mylroie, 2004). As sea levels continues to rise, the halocline would eventually breach the pond floor and the water would begin to grow brackish. In ponds lacking conduits or receiving little freshwater in the form of rain drainage, evaporation would concentrate these salts, and a given pond would grow saltier from brackish, to fully marine, to hypersaline.

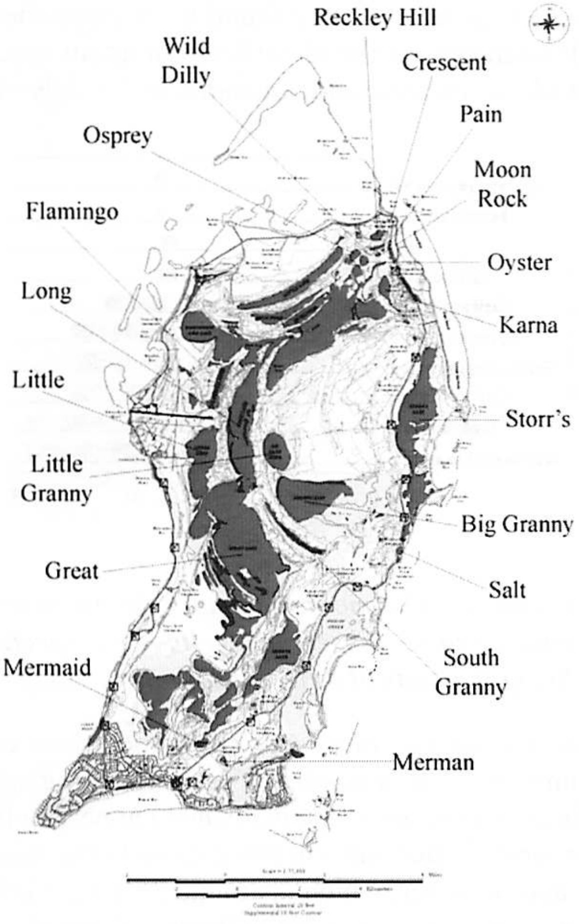

*Figure 1. Map of San Salvador Island, Bahamas. Study sites indicated. From: Robinson and Davis, 1999, San Salvador Island GIS Database. University of New Haven and Gerace Research Center (formally Bahamian Field Station).*

Mollusc assemblages can be found living in many of the inland ponds, and their remains are found in shell-hashes forming beaches encircling the inland ponds. In some cases, molluscan shell assemblages line the shores of ponds that have long since exceeded the salinity tolerated by living molluscs.

We examined a number of water-chemistry parameters: salinity, pH, and dissolved nitrogen, and surveyed molluscan diversity (both living and dead) within a series of these inland ponds. We hope to use molluscan diversity as a proxy for habitat characteristics in tracing the natural history of these inland ponds.

## MATERIALS AND METHODS

### Mollusc Identification

A random sampling of shell hash was collected from a variety of spots including from sites both in the water as well as along the shores of Merman, Mermaid, Little Granny, Big Granny, Little Lake and Flamingo ponds. Dip nets and snorkel gear were used to search for live molluscs in each pond. Shell hash was brought back to the lab, with wet samples kept separate from samples taken from the shoreline. A sample was taken from each of the collections for identification. Specimens were identified using stereo microscope. For ponds other than those listed above, data was collected from research published in Natural History of Northeastern San Salvador Island: A "New World" Where the New World Began (Godfrey et al., 1994).

### Water Chemistry

The chemistry of the water, including pH, and salinity, was assessed for each of these ponds, using a Quanta Probe™ from Hydrolabs. The water chemistry data was compiled and compared to data collected in 2006 by St. Olaf researchers. For nitrogen analysis, water samples were filtered and stored frozen until returning to the mainland. At St. Olaf College, we analyzed dissolved inorganic nitrogen (DIN as $NH_4 + NO_3$), to determine nutrient availability. This involved use of a Lachat Quikchem 8000.

## RESULTS

### Molluscs and Salt Tolerance

The salinity data appears in both figures 2 and 3. Data gathered in 2006 varied slightly from

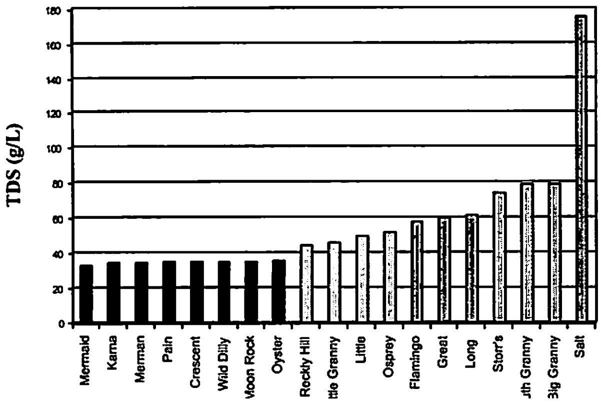

*Figure 2. Salinity measurements of 19 anchialine ponds located on San Salvador Island, Bahamas (2/1/06).*

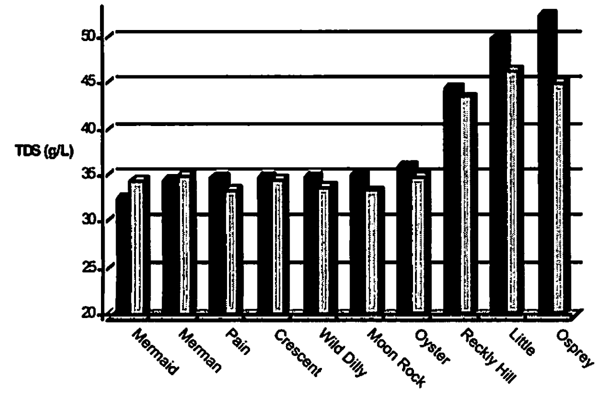

*Figure 3. Comparison of the Salinity of several of San Salvador's inland ponds Dry-year: February 2006 (black) and wet year: January 2007 (gray).*

the measurements taken during 2007 (Figure 3). The greatest fluctuation was seen in Osprey and Little Lake with a decrease of 7.2 g/L and 3.2 g/L respectively. The salinity was generally lower in 2007, with the exception of Mermaid and Merman Ponds. This likely represents differences in rainfall for these two years. Crescent pond had the smallest variation of just 0.2 g/L.

The salinity for the ponds ranged from Salt Pond's salinity of 175.9 g/L to Mermaid pond's salinity of 32.7 g/L. The change in salinity from a relatively dry period (February 2006), to a relatively wet period, (January 2007), was most evident in the more hypersaline ponds lacking significant conduit activity.

Live molluscs were recorded for each pond in which they were found. A conspicuous trend between molluscan species present and pond salinity was seen, suggesting that individual species had characteristic ranges of salt tolerance. As seen in figure 4, we found three categories of salt tolerance for the identified molluscan species. *Battilaria minima* and *Anomalocardia auberiana* can tolerate the most extreme hypersaline environments. *Brachiodontes exustus, Isognomon alatus, Tellina and Gemma gemma* appear to have the most limited salt tolerance close to the salinity of marine water, which is around 35 g/L. *Cerithidea costata, Polymesoda maritime, Pinctada longisquamosa* and *Cerithium lutosum* fell in the middle range that could tolerate salinity from 35 g/L up to 50 g/L. *Battilaria minima* and *Anomalocardia auberiana* represented the hardiest species tolerating salt as high as 60 g/Liter.

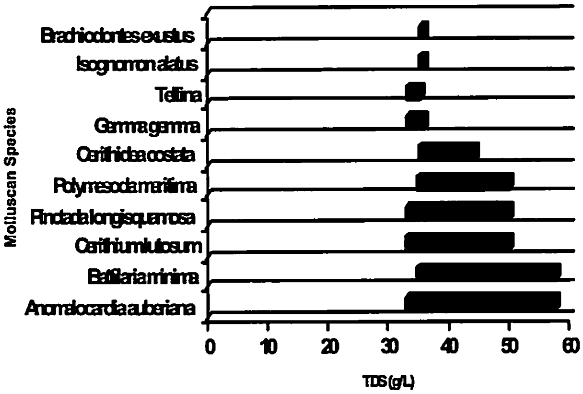

*Figure 4. The molluscan salt tolerances according to the observed live mollusc species living in ponds of different salinities.*

Dead shell-hashes from each pond provided glimpses into past conditions. Though we typically found dead representatives of molluscs still inhabiting a pond, we also discovered dead shells of species not currently alive in a given pond. The most extreme example of this was Big Granny Pond whose waters during the past few years have registered a salinity of 80 g/L (over twice the salinity of sea water). Big Granny yielded no live molluscs during our reconnaissance, yet its shores are thick with shell hash materials. Figures 5 – 9 detail the identified species in each pond's dead shell hash.

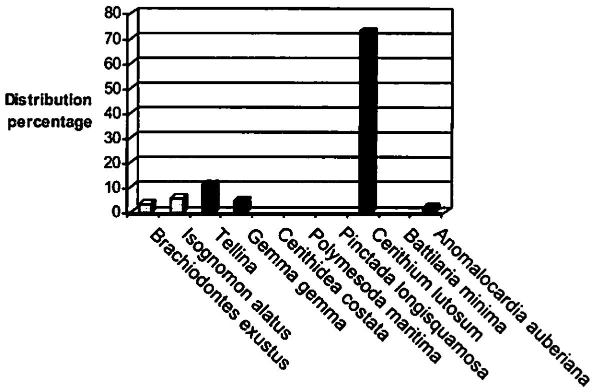

*Figure 5. Distribution of molluscan species in* <u>*Mermaid Pond*</u> *shell hash. Species with a black bar indicate those also found during the live sampling (true for figs. 5-9).*

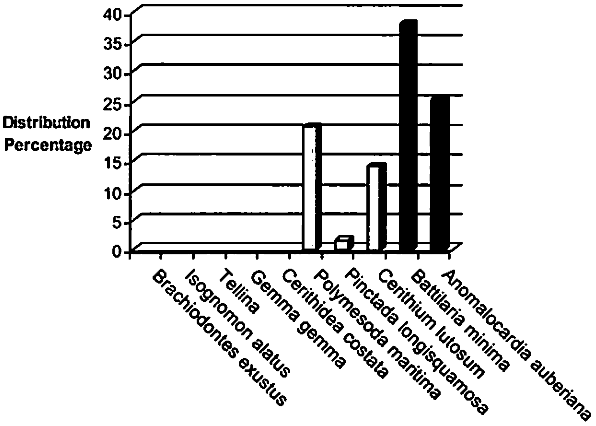

*Figure 8. Distribution of molluscan species in* <u>*Flamingo Pond*</u> *shell hash.*

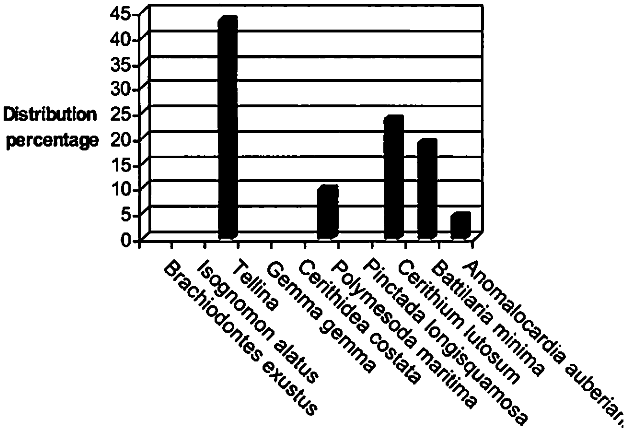

*Figure 6. Distribution of molluscan species in* <u>*Merman Pond*</u> *shell hash.*

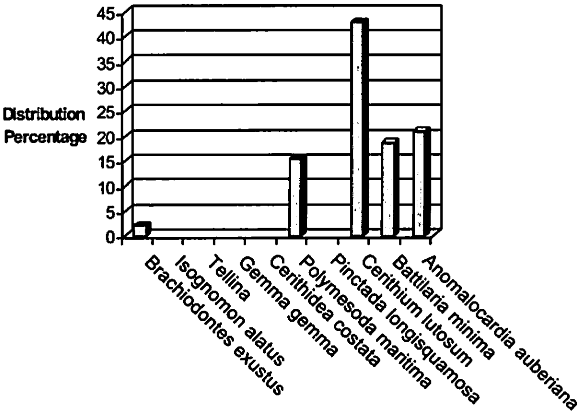

*Figure 9. Distribution of molluscan species in* <u>*Big Granny Pond*</u> *shell hash. There were no live mollusc species present.*

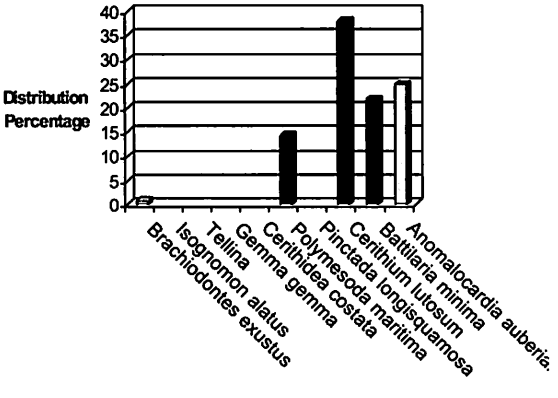

*Figure 7. Distribution of molluscan species in* <u>*Little Lake*</u> *shell hash.*

## pH and Nitrogen

Variation in pH was minimal between ponds. The ponds that were more hypersaline generally had a more basic pH ranging from 7.64 to 8.28, (Figure 10). The most exceptional case was Karna Pond with a slightly acidic pH of 6.8-6.96. (Karna also proved to be nearly anoxic, suggesting a great deal of organic decomposition).

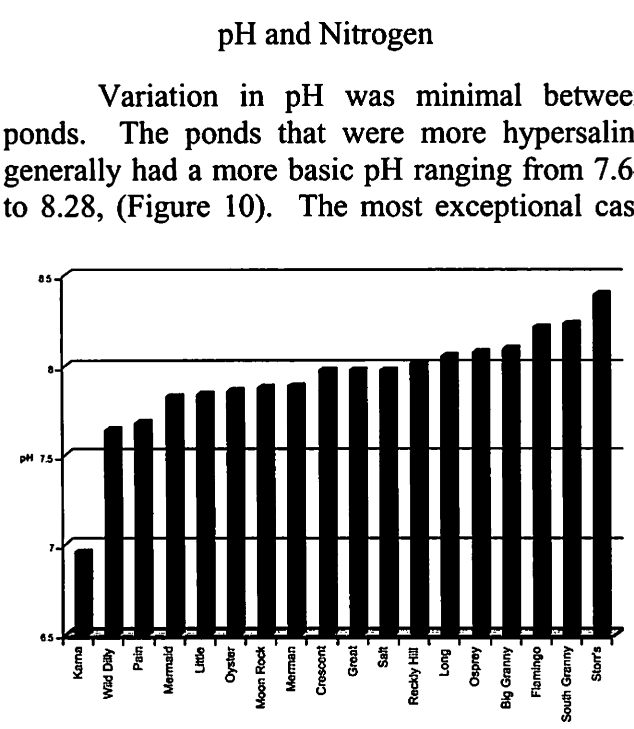

*Figure 10. The pH of San Salvador's inland ponds.*

Nitrogen levels were monitored as both ammonia and nitrate. In general, ponds showed low levels of nitrogen (with the exception of Little Lake) (Figure 11).

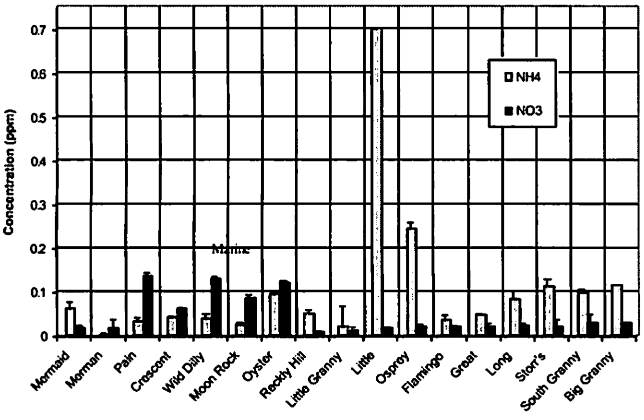

*Figure 11. Concentrations of nitrate ($NO_3$) and Ammonia ($NH_4$) in samples collected from San Salvador's inland ponds during 2006.*

The ponds with a salinity under 40 g/L tended to have a higher abundance of nitrate compared to ammonia, whereas ponds that were greater than 40 g/L had a higher concentration of ammonia than nitrate. Mermaid pond was the one exception showing a greater abundance of nitrate than ammonia. Little Lake was seemed abnormal in that it had a much higher abundance of ammonia.

## DISCUSSION

Since the Wisconsin glaciation period, sea levels have been rising from their levels of 80 meters below present. For an island such as San Salvador Island, the rising sea levels during the current interglacial period are responsible for the formation of San Salvador's anchialine ponds and lakes. Marine water has seeped through the ground collecting in the areas of the island that remain at or below current sea level.

In the case of some ponds, underground conduits have formed linking the pond to the Atlantic Ocean. The ponds that have conduits are typically those whose salinity is closest to that of ocean water: 35 g/L.

In ponds with no conduit, (or minimal conduit exchange), we've measured salinities ranging from 40 g/L all the way to 180 g/L for the appropriately named, Salt Pond (though even higher levels have been recorded, see Trubee & Park, In Press). In these instances, seawater isn't regularly replaced by water directly from the ocean and consequently evaporation gradually increases the overall salinity of the pond. This can be ameliorated by rainfall, depending on the size of a ponds' catchment.

### Establishing Salinity Tolerances in Living Marine Molluscs.

There is little published research on the salt tolerance of the molluscan species present in the anchialine ponds of San Salvador Island. One study, completed by Craig Edwards, examined the relationship between salinity and resident mollusk species found in several ponds and blue holes

(Edwards, 2001). The molluscs were placed into categories of salinity tolerance based on the salinity levels of the water in which they were found. *Cerithium lutosum, Cerithidea constata* and *Anomalocardia auberiana* were all species tolerant of Hypersaline waters. These findings were largely confirmed in our study, though we also found that *Batillaria minima* can tolerate hypersaline waters, as evidenced by its presence in Flamingo Pond. Edwards also suggested that *C. costata*, is one of the most euryhaline species of gastropods (Edwards, 2001). While we didn't locate *C. costata* in the ponds we sampled, data collected by Godfrey et al. also suggest that this species should be considered tolerant of hypersaline conditions (Godfrey et al., 1994).

*Anomalocardia auberiana*, *Battilaria minima* and *Brachiodontes exustus* have been researched in the bays of southern Florida, but these study sites exhibited much milder ranges of salinity. In one study, the maximum salinity in which *Anomalocardia auberiana* was present was 39.3 g/L. *Battilaria minima* were recorded surviving in water with a salinity of 41 g/L, in the case of *Brachiodontes exustus,* 41.3 g/L (Brewster-Wingard, 2001). Our data also support placement of these three species as reasonably tolerant of hypersaline conditions with the exception of *Brachiodontes*. It is worth pointing out that our study relies solely on the presence or absence of a species within a given pond in assigning salt tolerance. This should be viewed cautiously for two reasons. First, the current salinity of a pond supporting a given species does not reveal the upper or lower limits a species might be able to endure. Second, the presence or absence of a species may not be determined solely by a ponds' characteristics, but by accidents of colonization. This was particularly well demonstrated in a study of ostracod distribution in the ponds of San Salvador (Trubee & Park, In Press).

In our study, we selected ponds that ranged rather widely in salinity. Mermaid and Merman represent ponds with fully marine salinities. Little Lake, Flamingo Pond and Big Granny Pond represent a series of increasingly hypersaline water bodies. Flamingo, in particular, represents a pond on the very edge of hospitability. It had a salinity of 57.8 g/L, and only two living inhabitants were found, *Anomalocardia auberiana* and *Battilaria minima.* (Both species were uncommon). These observations suggest that these species represent the most salt-tolerant as there were no signs of the other living molluscs including *Cerithium lutosum, Polymesoda maritima,* that were identified in the Flamingo Pond dead-shell-hash. The large numbers of these two species in the shell hash suggest that the pond is reaching a salinity that is no longer tolerable for even the most saline tolerant species. In Big Granny Pond, the salinity had clearly exceeded the tolerance of all resident mollusc species resulting in entire beaches comprised of their dead shells.

## Evidence of Recent Changes in Pondwater Salinity

Big Granny Pond. Shell hashes located on the shores of ponds that no longer support molluscan life provide one piece of evidence supporting the progressive environmental change these ponds have undergone in recent history. Big Granny pond is an extreme example of this. It typically has a salinity of about 80 g/L and no sign of molluscs living in its waters, yet its shoreline is composed of a shell hash that is over a meter thick and up to five meters wide. At one time, the waters of Big Granny were able to support living *Anomalocardia auberiana*, *Battilaria minima, Cerithium lutosum, Polymesoda maritima,* and even *Brachiodontes exustus*. The latter species, (the "burnt mussel") is one of our more stenohaline species, as evidenced by the narrow range of salinities we find them in today. These remnants suggest that Big Granny pond must have seen far more benign conditions within recent history. The fact that the shell hashes appear relatively unweathered, and even possess remnants of proteinaceous hinge material suggest that they are of relatively recent origin. A recent account might shed light on this. John Winter noticed, when flying off island in June, 2007, that a substantial water-way had been formed linking Big Granny to Little Granny Pond (personal communication). This is likely a recurrent phenomenon, and the effects on salinity would be profound. One thing unique to Little Granny is that, while lacking any conspicuous conduit, it drains rainwater from a large catchment. This supply of freshwater seems to keep the pond's salinity low. Otherwise, Little Granny would be expected to be one of the more hypersaline ponds.

We can envision a dilution-effect working in two ways: heavy rainfalls would lower the salinity of Big Granny Pond, and establish a waterway linking it to the less saline Little Granny Pond. The combination could drop the salinity of Big Granny Pond to a level capable of sustaining life. Little Granny could then easily serve as a species bank, repopulating Big Granny during such periods. With a series of subsequent dry years, the two ponds would again become isolated, and differential evaporation and rainwater catchments would re-establish the disparity between the two. Big Granny might experience windows of molluscan colonization and expansion followed by catastrophic annihilation as salinity levels once again exceeding tolerance.

It is interesting to note that the species distribution in the dead shell hash surrounding Big Granny almost perfectly resembles the live shell representation of Little Lake. Little Lake is the water body that most closely resembles Big Granny's neighbor, Little Granny Pond. It will be valuable to assess the molluscan assemblage in Little Granny Pond as well to see if we are beginning to discern a fingerprint for a particular kind of pond environment characterized by large size, little marine turn-over, mostly soft substrate, and little or no submerged mangrove prop-root habitat.

*Merman Pond.* When first encountered, we were surprised by the relative paucity of species on the mangrove roots of Merman Pond. This is due, in large part, we assumed, to the fact that tidal changes leave the mangrove prop-roots fully exposed. This does not explain why this pond, (one of the least saline), is populated almost exclusively by the most euryhaline species (with the exception of *Tellina*). This may have something to do with unexpected changes in the ponds' salinity. In both the winter of 2006 and 2007 Merman registered near marine salinities leading us to believe this was its stable condition. With the dramatic rainfall in the spring of 2007, a tremendous amount of freshwater drained from the surrounding terrain and washed into Merman Pond. Despite its significant conduit system (Three Roses Cavern, See White & Cole, this volume) and tidal fluctuation, we recorded a salinity drop to 14.1 g/L (less than half marine) and zero visibility due to the tannins that had flushed into the system. Clearly, this pond is vulnerable to dramatic shifts in salinity in the other direction driven by rainwater catchment. (We expect it rarely drifts into the hypersaline state due to daily tidal exchange.) We suspect that the unusual mollusc assemblage seen in this pond reflects survival of those species capable of surviving wide fluctuations in salinity. Broad salinity tolerances work both ways.

## Other Parameters of Water Chemistry

In addition to salinity, we followed pH and dissolved nitrogen in the form of nitrate and ammonia in the various ponds. Ponds that were more hypersaline typically had a more basic pH. One exception was Flamingo Pond, which, though less saline than Big Granny, exhibited a higher pH. The ponds with lower pH tended to also exhibit higher mollusc diversity. This suggests that pH could be a contributing factor to their dispersal, yet we think it more likely (given the modest range of pH values) that salinity is the principle factor limiting species distribution.

We also measured dissolved nitrogen to estimate nutrient levels in the various ponds. Most ponds showed similar levels of dissolved nitrogen with two exceptions. Little Lake had a remarkable spike in dissolved nitrogen, and nitrogen in Osprey Pond was also unusually high. We suspect that the spike of nitrogen in Little Lake may be explained by the existence of a dump serving Cockburn Town that connects directly with the Lake. A possible source of nitrogen for Osprey Lake might be the substantial rookeries of Cormorants and other shore birds that congregate in the mangrove surrounding its waters.

A curious trend in Nitrogen was discovered involving the amount of nitrate compared to ammonia (Fig. 11). Salinity appeared to be the determining factor, as the ponds with salinity under 40 g/L tended to have a higher abundance of nitrate compared to ammonia, whereas ponds that were greater than 40 g/L had a higher concentration of ammonia than nitrate. We suspect that somewhere between 36 and 44.4 g/L TDS, there is a microbial limit. The microbes responsible for converting nitrate to ammonia may have a sharply defined salt tolerance. Thus every pond greater than 44.4 g/L TDS has the higher presence of ammonia. The mollusc diversity of each pond generally has a positive correlation with the amount of Nitrate over ammonia. The ponds with more nitrate than ammonia typically had a greater number of living mollusc species. Since Mermaid Pond, Little Lake and Little Granny Pond all had higher levels of ammonia, yet were still able to support mollusc life, it doesn't appear that the nitrate/ammonia relationship is a determining factor for mollusc survival. Furthermore, since the predominant form of dissolved nitrogen follows salinity so closely, any trends seen coupling mollusc diversity to nitrogen are more likely driven by salinity.

In summary we find that establishing molluscan diversity profiles for both living collections and dead shell-hashes is helpful in developing a picture of the natural history of San Salvador's inland ponds. The picture that is emerging reveals dramatic and unexpected changes occurring over relatively brief periods of time. Rich invertebrate assemblages can go extinct locally following a few dry years (Big Granny Pond). The same "dead" ponds can be revived, and repopulated swiftly when transient connections are made to neighboring ponds with more benign conditions. On the other hand, ponds that are fully marine and flushed daily with ocean water, can drop their salinity to less than half marine following one particularly wet rainy season (Merman Pond). Such dramatic changes may have a profound influence in shaping species assemblages based on the breadth of their environmental tolerances. In short, the inland ponds of San Salvador Island represent a wonderful living laboratory for exploring natural experiments in ecological landscaping.

## ACKNOWLEDGMENTS

We would like to thank Brennan Decker (Nitrogen analysis), Ms. Ashley G. Husebye (classifying molluscan shell-hash materials), SCUBA Instructor John Campion, the 2005 & 2007 St. Olaf Island Biology Students, and "Magnus the Good" Award, (St. Olaf College). We especially wish to thank Don Gerace, Chief Executive Officer, Vince Voegeli and Tom Rothfus, past and present Executive Directors of the Gerace Research Center, San Salvador Island, Bahamas for their continued support & encouragement. We would also like to express a deep sense of gratitude to the late Craig Edwards for inspiring interest in the molluscs of the inland ponds of San Salvador Island.

## REFERENCES

Brewster-Wingard, G. Lynn, Jeffery R. Stone, Charles W. Holmes. 2001. "Molluscan Faunal Distribution in Florida Bay, Past and Present: An Integration of Down Core and Modern Data." Bulletins of American Paleontology. Number 361.

Dillon, Robert T. 2000. The Ecology of Freshwater Molluscs. UK: Cambridge University Press.

Edwards, D. Craig. 2001. Effects of Salinity on the Ecology of Molluscs in the Inland Saline Waters of San Salvador Island: A Natural Experiment in Progress. Proceedings of the Eighth Symposium on the Natural History of the Bahamas. Pp 15-26.

Gerace, 2002. "San Salvador Island." Gerace Research Center. 25 March 2007. <http://www.geraceresearchcenter.com>

Godfrey, Paul J., D. Craig Edwards, Robert R. Smith, Davis R. Laurence. 1994. Natural History of Northeastern San Salvador Island. *Bahamian Field Station*, 17.

Mylroie, J.E., Mylroie, J.R, & Jenson, J.W. 2004. Modeling Carbonate Island Karst. Proceedings of the 11th Symposium Geology of the Bahamas. Pp. 135-144.

Sanger, D.B. & Teeter, J.W. 1982. The Distribution of Living and Fossil Ostracoda. Occasional Papers 1982 #1. CCFL Bahamian Field Station. Pp 1-25.

Trubee, K., and Park, L. (In Press). Faunal and geochemical variability of ostracode faunas from saline ponds on San Salvador Island, Bahamas. In: Park, L.E., and Freile, D., (eds.). 13th Symposium on the Geology of the Bahamas and Other Carbonate Regions.