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Front Cover: *Porites* colony encrusted by red algae in waters of San Salvador, Bahamas; see paper by Fowler and Griffing., p. 41. Photograph by Pascal Kindler, 2011.

Back Cover: Dr. Jörn Geister, Naturhistorisches Museum Bern, Keynote Speaker for the 15th Symposium and author of “Keynote Address – Time-Traveling in a Caribbean Coral Reef (San Andres Island, Western Caribbean, Colombia)”, this volume , p. vii. Photograph by Joan Mylroie.

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TAPHONOMIC DYNAMICS OF LACUSTRINE OSTRACODES ON SAN SALVADOR ISLAND, BAHAMAS: LIVE/DEAD FIDELITY AND INTRALAKE VARIABILITY

Andrew V. Michelson¹ and Lisa E. Park²

¹Program in Integrated Bioscience
University of Akron, Akron, OH 44325

²Department of Geology and Environmental Sciences
University of Akron, Akron, OH 44325

ABSTRACT

Paleobiological archives, such as changing abundances of species through time, are increasingly being used to contextualize modern ecological change by providing data on the state of ecosystems and natural variability in the absence of anthropogenic disturbance. However, in order for these archives to be interpreted properly and for potential sources of bias, such as allochthonous transport or *post mortem* degradation, to be identified and corrected for, the processes by which organisms enter the fossil record must be understood. Ostracodes (Phylum: Arthropoda) are widely used indicators of past environments due to their small size and sensitivity to environmental changes. This study focuses on the live/dead fidelity and within-lake variability of ostracode assemblages on San Salvador Island, Bahamas so subfossil archives of ostracodes can be better understood. Sixteen living communities and death assemblages of ostracodes from seven lakes on San Salvador Island were quantified by staining individuals alive at the time of capture. Overall, the correlation between living communities and death assemblages was high, with the one exception occurring in Watling's Blue Hole which had a moderate correlation between living communities and death assemblages, but with much variation that was unrelated to depth or distance from shore collected. Nonmetric multidimensional scaling on the Bray-Curtis dissimilarity matrix of all

112 assemblages collected revealed no variation within-lake, but significant variation in assemblages between lakes. Again, Watling's Blue Hole proved to be an exception as it exhibited higher levels of within-lake variability than other lakes. This variation proved to be due to preferential transport of dead individuals of the ostracode species *Hemicyprideis setipunctata* since this was the only species over-represented in death assemblages. This caused a significant decrease in Simpson's diversity in Watling's Blue Hole with depth due to assemblages being increasingly dominated by *Hemicyprideis setipunctata*. Thus, taphonomic processes that could obscure the paleobiological record of ostracode assemblages are absent from the majority of lakes on San Salvador Island, Bahamas, with Watling's Blue Hole providing a notable exception.

INTRODUCTION

Paleobiological archives, such as changing abundances of species through time, are increasingly being used to contextualize modern ecological change by providing data on the state of ecosystems and natural variability in the absence of anthropogenic disturbance (Smol 2007; Kidwell 2009). Additionally, taxa whose relationships to the abiotic environment are understood today have been used to reconstruct aspects of the past abiotic environment, often with high precision (Saros 2009; Woodbridge

and Roberts, 2010). If paleobiological data on changing community structure through time is to be trusted, then the process by which organisms enter this record must be understood in order to eliminate or correct for sources of preservational bias. Ostracodes (Phylum: Arthropoda) have long been used as indicators of past environments due to their small size allowing for collection of many individuals and their sensitivity to environmental changes (Frenzel and Boomer, 2005). The changing abundances of species and geochemical variability in their carapaces through time in lake sediments on San Salvador Island, Bahamas, have been used as indicators of past environments including changing salinity, sea level, and to identify ecosystem changes brought about by disturbances due to hurricanes (Teeter and Quick, 1990; Teeter, 1995; Park et al., 2009; Park and Trubee 2008). However, a comprehensive taphonomic study of ostracode assemblages has yet to be done on San Salvador Island, Bahamas. Thus, the purpose of this study is to understand the processes by which lacustrine Ostracoda on San Salvador Island become part of the paleobiological record by examining live/dead fidelity and measuring within-lake variability of assemblages. This study is thus a necessary step in using changing species of ostracodes through time to reconstruct past environments as well as an attempt to understand how human modification may have affected ostracode assemblages.

Study Taxa

Ostracodes are a class of bivalved microcrustaceans that live in all manner of aquatic habitats from the deep ocean to ephemeral ponds (Horne et al., 2002). Most ostracode species live as benthic organisms and are sensitive to changes in the abiotic environment such as salinity, water depth, temperature or dissolved oxygen concentration (Frenzel and Boomer, 2005). Their low-Mg calcite shells range from 0.5-2 mm in size, can be preserved as fossils, and have long been used as biological proxies for past environments

(Frenzel and Boomer, 2005). Each individual secretes 8-9 molted shells over its lifetime with the adult stage containing definitive characteristics that often allow for species-level identification (Holmes, 2008). These organisms have been used to reconstruct conductivity (Mezquita et al., 2005; Mischke et al., 2007; Mischke et al., 2010a; Mischke et al., 2010b), water depth (Mourguiart and Carbonel 1994; Mourguiart et al., 1996; Alin and Cohen, 2003), and temperature (Mezquita et al., 2005; Viehberg, 2006) from preserved lake sediments in both temperate and tropical environments.

Assemblages of ostracodes and other benthic organisms are also sensitive to modern pollution (such as heavy metals and anthropogenic eutrophication; Bergin et al., 2006; Kidwell, 2007; Padmanabha and Belagali, 2008). For example, changes in ostracode population densities and species richness have been shown to correlate with pollution load (Padmanabha and Belagali, 2008) and discrepancies in rank-abundance and taxonomic composition of living communities and death assemblages of mollusks correlate with human modification of their ecosystem (Kidwell, 2007). Thus, an understanding of the diversity, population density, and comparison of living communities and death assemblages of ostracodes on San Salvador Island, Bahamas, will not only allow more precise interpretation of the paleobiological record, but also could be used in identifying areas of recent human modification.

Distribution of ostracode assemblages within lakes have also been described as “patchy” with different species or assemblages detected within a few meters of each other (Muller et al., 2002). However, calibration studies of modern ostracode distribution often rely on one or a few samples of ostracode assemblages per lake (Mischke et al., 2010a, b; Michelson and Park, in press). If ostracode assemblages are patchily distributed on San Salvador due to multiple habitats within one lake or species-specific preferences such as substrate or macrophyte presence, then this method of sampling would miss key patterns in

ostracode distribution. Thus, this study will also examine multiple assemblages within lakes on San Salvador to test for this patchy distribution of ostracode assemblages.

METHODS

Samples

In March 2009, we collected sediment samples from seven lakes on San Salvador Island that represent the variation in salinity and lake area across the island (Figure 1). These abiotic factors influence ostracode faunal distribution (Michelson and Park, in press). Sample collections were taken at 4, 9, 14, and 19 m from shore in two replicate transects perpendicular from shore. Individual samples were stained with Rose Bengal to identify live individuals (Corrège, 1993). In all, sixteen sediment samples were collected and stained from each of the seven lakes for 112 total samples. These samples were stored in 125-ml plastic cups, sieved with deionized water using 125 μm (ϕ -size 3) and 63 μm (ϕ -size 4) mesh sieves, and were then dried, and picked for ostracodes. In all cases, at least 400 ostracodes were picked from each sample and all adults

were identified to species level using reference collections at the University of Akron (Trubee, 2002; Park and Trubee, 2008). Juveniles were not identified to species level because of the convergent morphology of juveniles in the Caribbean non-marine ostracode fauna (Park and Beltz, 1998). Stained individuals were counted as alive at the time of collection if they appeared pink and had noticeable soft parts attached. To estimate density of ostracodes in each sample, every valve was counted from a randomly chosen cubic centimeter of sediment. These valves were then classified as live adult, live juvenile, dead adult, and dead juvenile.

Data Analysis

The correlation between living communities and death assemblages was tested using Spearman's rho (Kidwell, 2001) (as calculated in the software Minitab®). The R package "fossil" (Vavrek, 2011) was used to calculate the Jaccard-Chao index of taxonomic similarity between living communities and death assemblages (Chao et al., 2005). Since living communities contained substantially fewer individual valves than death assemblages, the Jaccard-Chao index was used to correct for the discrepancy in sample sizes. This index is the proportion of shared species between the living community and death assemblage with a correction for unseen shared species. Thus, while rho measures the correlation between rank-abundance of the same species in the living community to its rank abundance in the death assemblage, the Jaccard-Chao index measures the taxonomic similarity (presence/absence of species).

A nonmetric multidimensional scaling (NMDS) ordination was carried out on the Bray-Curtis dissimilarity matrix using PAST v. 191® (Hammer et al., 2001) to see which death assemblages were most similar. One-way Analysis of Similarity (ANOSIM) was carried out in PAST v. 191® (Hammer et al., 2001) to test whether lakes contained assemblages distinct from each other. The Simpson univariate diversity index (1-D) was calculated

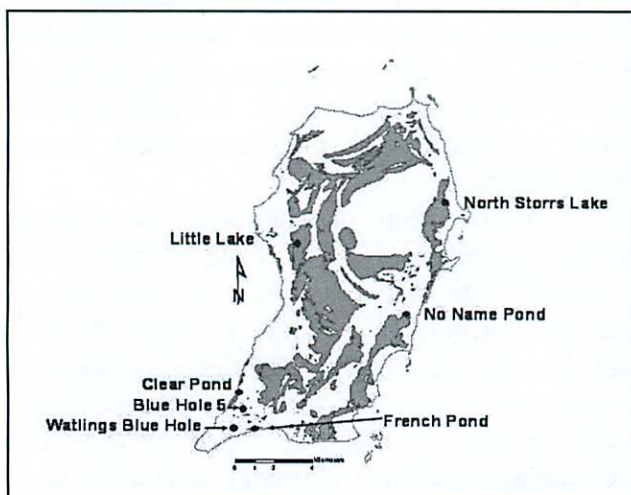


Figure 1. Map of San Salvador Island showing lakes sampled. The seven lakes sampled for this study are indicated by black dots and labeled. The single headed arrow points north.

using PAST v. 191® (Hammer et al., 2001) to determine how diversity varies within individual lakes. Sample rarefaction was carried out in PAST v. 191® (Hammer et al., 2001) to establish how many samples (out of 16) from individual lakes were required to capture all species living in that lake. Finally, one-way ANOVAs were carried out in Minitab® to test for differences in ostracode valves per cubic centimeter in all lakes.

RESULTS

In total, nine ostracode species from nine genera and seven families were found in the seven lakes from this study. These species are members of the Caribbean non-marine fauna of Park and Beltz (1998) and include: *Aurila floridana*, *Cyprideis americana*, *Dolerocypria inopinata*, *Hemicyprideis setipunctata*, *Loxonconcha pursubrhomboidea*, *Paranesidea harpago*, *Perissocytheridea bicelliforma*, *Reticulocythereis multicarinata*, and *Xestoleberis curassavica* (Table 1).

Table 1. Species list of the ostracodes from this study.

Podocopida
Podocopina
Bairdiidae
<i>Paranesidea harpago</i>
Candonidae
<i>Dolerocypria inopinata</i>
Cytherideidae
<i>Cyprideis americana</i>
<i>Hemicyprideis setipunctata</i>
<i>Perissocytheridea bicelliforma</i>
Hemicytheridae
<i>Aurila floridana</i>
Loxoconchida
<i>Loxoconcha pursubrhomboidea</i>
Trachyleberididae
<i>Reticulocythereis multicarinata</i>
Xestoleberideidae
<i>Xestoleberis curassavica</i>

Live/Dead Fidelity

Across all seven lakes, ostracode death assemblages display high correlation to the living community (mean rho = 0.854). Figure 2 shows the distribution of rho within all 7 lakes. Additionally, this correlation is robust with respect to species richness. The mean rho across all lakes, when weighted according to species richness of the sample, is close to the unweighted rho (mean rho weighted by species richness = 0.826). Figure 3 displays mean rho within lakes according to the lake's mean richness. While low-diversity lakes (French Pond, No Name Pond, North Storr's Lake) display high correlation between the living community and the death assemblage, this correlation is based on only 2-3 species. However, Little Lake, the most diverse lake in this study, also displays high mean correlation of the living community and the death assemblage. This accounts for the low difference between the unweighted mean rho across all lakes and the weighted-by-richness mean rho across all lakes.

The only exception to the general high fidelity between the death assemblages to the

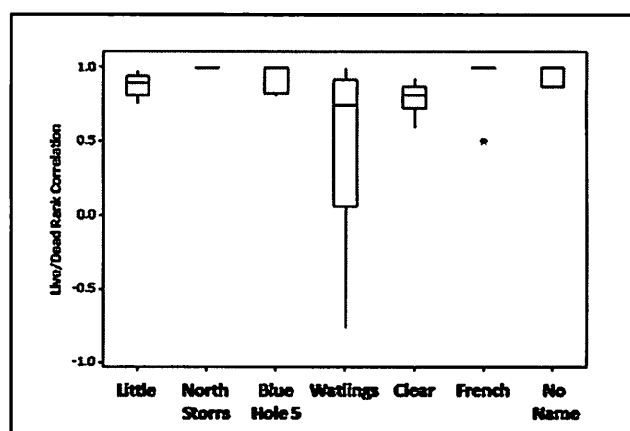


Figure 2. Box plot of rho in all lakes sampled. The y-axis displays Spearman's rho (Pearson's r on rank-order), based on 16 samples per lake. A +1 indicates that the rank-abundances of the dead species match perfectly the rank-abundances of the living species; -1 indicates that the rank-abundances are reversed between dead and living species.

living community is Watling's Blue Hole, where the mean rho is 0.450. Watling's BH also displays a high variability in rho that is unrelated to the locations sampled, the water depth, or distance from shore. In fact, it is the only lake included in this study that displays a negative correlation between the living community and the death assemblage in any one sample. The large variation in Watling's rho can be seen in Figures 2 and 3.

Figure 4 shows the relationship between rho and the Jaccard-Chao index for all 112 samples in this study. All samples, except for some of the samples from Watling's Blue Hole, plot in the upper right quadrant of the biplot. In previous work with molluscan assemblages, this biplot has been used to distinguish pristine ecological settings from those affected by anthropogenic disturbance (eutrophication or bottom trawling), with pristine environments plotting in the upper right quadrant and anthropogenically affected samples plotting elsewhere (Kidwell, 2007; 2009). Thus, samples from Little Lake, French Pond, No Name Pond, North Storr's Lake, Blue Hole 5, and Clear Pond appear to represent environments undisturbed by humans, whereas Watling's Blue Hole shows a live/dead pattern that could be associated with anthropogenic disturbance.

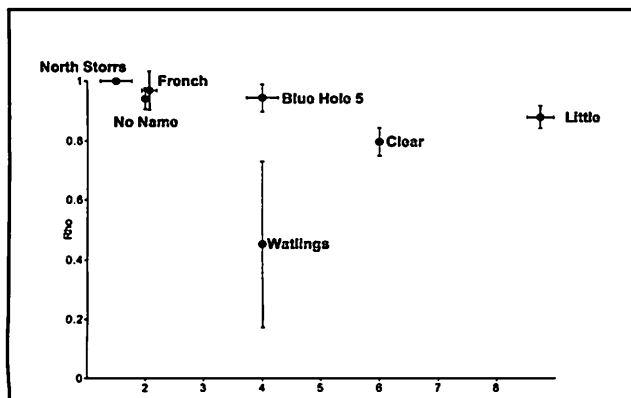


Figure 3. Mean rho of each lake according to its mean species richness. Each dot represents a lake's mean rho (live/dead rank-abundance correlation) and its mean species richness, based on 16 samples. Error bars are 95% confidence intervals about that mean.

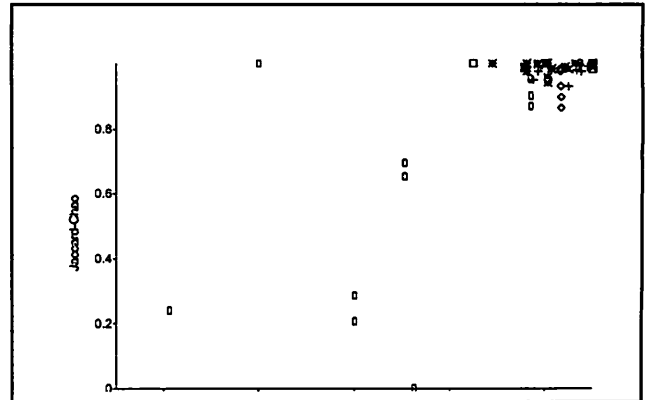


Figure 4. Taxonomic similarity (Jaccard-Chao index) and rank-abundance correlation of 112 samples of living communities and associated death assemblages. The y-axis displays the Jaccard-Chao index for each comparison of living communities and death assemblages. The x-axis displays rho for each comparison of living communities and death assemblages. Dots indicate lakes as follows: Plus Sign: Little Lake, Filled Square: North Storr's Lake, Diamond: No Name Pond, Star: Clear Pond, Cross: Blue Hole 5, Unfilled Rectangle: Watling's Blue Hole, Unfilled Square: French Pond.

Intralake Variability of Death Assemblages

Intralake variability of death assemblages indicates that there is less variability within lakes than between lakes. Figure 5 shows the first two axes of a three-dimensional NMDS plot on the Bray-Curtis dissimilarity matrix of all 112 death assemblages with the lake taken from overlain and corresponding 95% confidence ellipses. The death assemblages from individual lakes plot closer to assemblages from the same lake and ranked-Bray-Curtis distances of assemblages to other assemblages from the same lake are significantly less than ranked-distances to assemblages from other lakes (ANOSM $P < 0.0001$). This indicates that lakes contain distinct death assemblages which are more similar to death assemblages from that lake than death assemblages from any other lake. While this is true of all lakes, Watling's

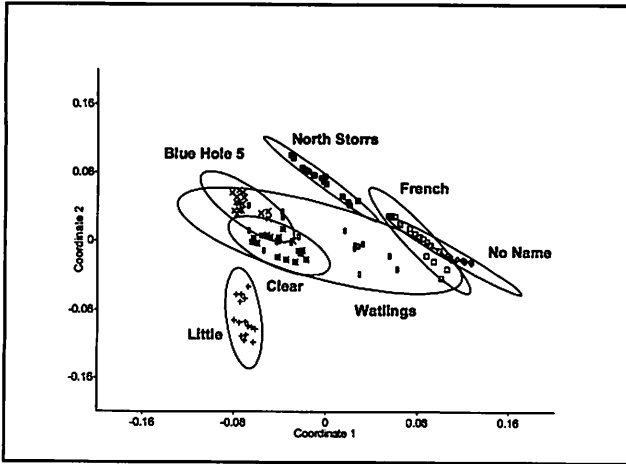


Figure 5. First 2 dimensions of a 3-dimensional nonmetric multidimensional scaling ordination on the Bray-Curtis dissimilarity matrix of all samples with lakes overlain. Stress = 8.8%. Ellipses are 95% confidence areas. Lakes are indicated near ellipse and symbols of lakes are the same as in Figure 4. Ranked Bray-Curtis distances of sampled from the same lake are smaller than ranked distances to samples from other lakes (ANOSM $P < .0001$).

Blue Hole displays much higher variability in death assemblages than any other lake (the area occupied by its 95% confidence ellipse is larger than any other lake's ellipse). Figure 6 displays the first two axes of a three-dimensional NMDS plot on the Bray-Curtis dissimilarity matrix for assemblages only from Watling's Blue Hole with distance from shore of sample overlain. While this ordination does not perfectly separate the deeper (14 and 19 m from shore) sites from the shallower sites (4 and 9 m from shore), there is a strong trend suggesting a difference in death assemblage based on depth and/or distance from shore.

Simpson's diversity index (1-D) was used to investigate how diversity varies in a univariate sense within and between lakes. Within three out of seven individual lakes, Simpson's diversity index varies with distance from shore. Figure 7 displays how Simpson's diversity index varies in all seven lakes. No significant difference in diversity is detected in North Storr's Lake, No Name Pond, Clear Pond, or Little Lake. Diversity decreases significantly

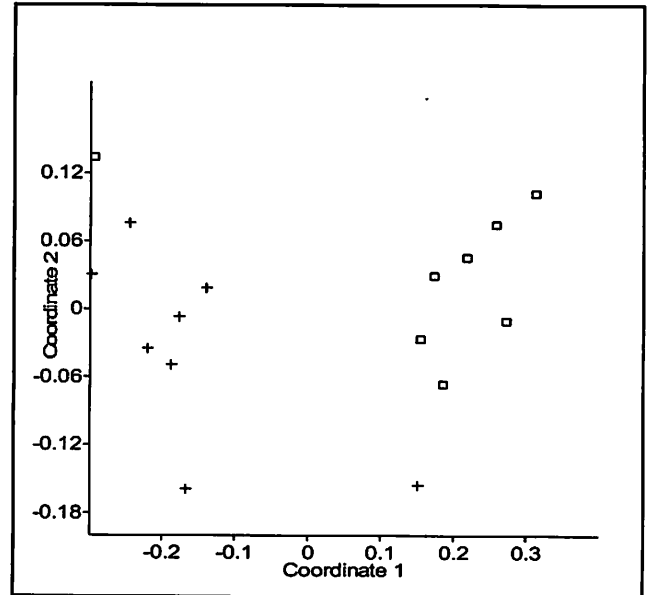


Figure 6. First 2 dimensions of a 3-dimensional nonmetric multidimensional scaling ordination on the Bray-Curtis dissimilarity matrix of all samples from Watling's Blue Hole. Stress = 4.7%. Crosses indicate shallower samples (4 and 9 m distance from shore), Squares indicate deeper samples (14 and 19 m distance from shore). Ranked Bray-Curtis distances of samples from the same depth are smaller than ranked distances to samples from different depths (ANOSM $P = 0.0016$).

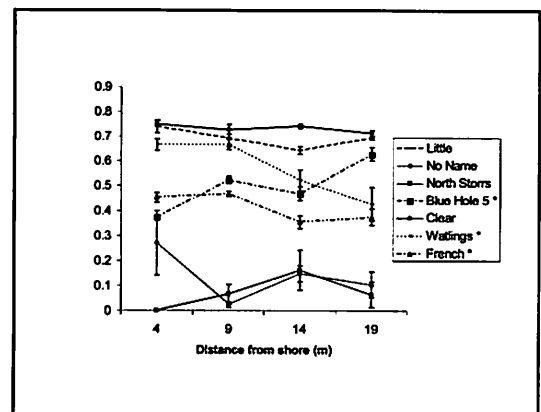


Figure 7. Simpson's Diversity Index by distance for all lakes. Simpson's diversity index is calculated as 1-D. Error bars are 95% confidence intervals about mean, each based on 4 samples. Lakes with an asterisk (*) are those with a significant change in diversity with distance from shore (one-way ANOVA with distance from shore as factors $P < 0.05$).

with distance from shore in Watling's Blue Hole and French Pond, while it increases significantly with distance from shore in Blue Hole 5. Table 2 displays mean and variance in Simpson's diversity index for all lakes. Lower diversity lakes tend to be more variable.

Figure 8 shows sample rarefaction of all lakes. In three out of seven lakes (No Name Pond, Watling's Blue Hole, and Clear Pond), there is no variation in species richness so therefore only one sample is required to sample all species detected in that lake. In the other four lakes, between five to all sixteen samples are required to record all species known to be living in that lake.

Table 2. Mean and variance of Simpson's diversity index for all lakes.

Lake	Mean	Variance
Little	0.6928	0.0030
No Name	0.1360	0.0237
North Storrs	0.0726	0.0114
Blue Hole 5	0.4977	0.0105
Clear	0.7333	0.0007
Watlings	0.5702	0.0165
French	0.4115	0.0041

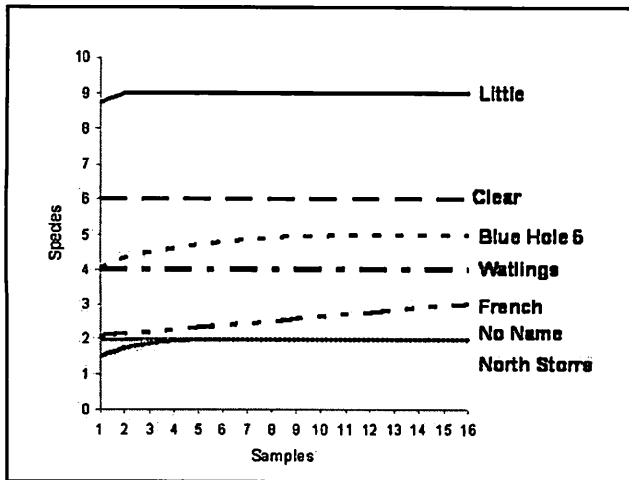


Figure 8. Sample rarefaction of all lakes.

Density of Ostracode Valves

Density of living and dead valves is highly and significantly correlated across all lakes ($r = 0.816$, $P < 0.0001$). One-way ANOVA on total ostracodes per cm^3 shows significant differences between lakes. Little Lake contains the most total ostracodes per cm^3 , followed by North Storrs' Lake, Blue Hole 5, Watling's Blue Hole, and Clear Pond, with significantly less ostracode valves per cm^3 as compared to Little Lake, but more ostracode valves per cm^3 than French and No Name Ponds. One-way ANOVA on live ostracodes per cm^3 , shows the same pattern, except with Little Lake containing more mean live ostracodes per cm^3 , but not statistically significantly. Little Lake, North Storrs' Lake, Blue Hole 5, Watling's Blue Hole, and Clear Pond contain more mean live ostracodes per cm^3 than French and No Name Ponds (Figure 9).

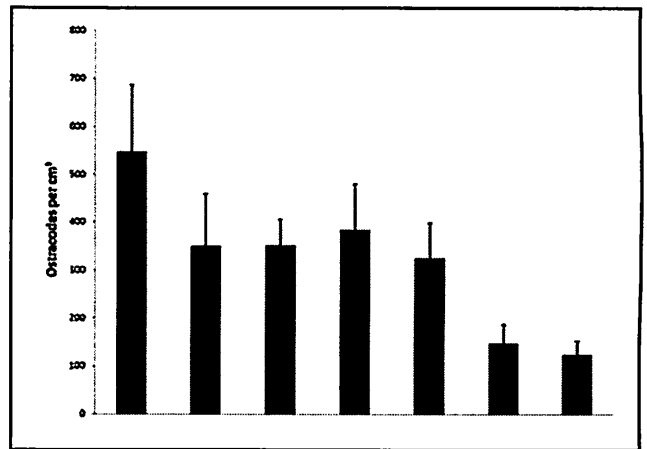


Figure 9. Ostracode valve density in all lakes. The number of ostracode valves per cm^3 is plotted on the y-axis. Grey bars are total ostracodes and black bars are live valves only. Error bars are 95% confidence intervals.

DISCUSSION

Implications for Paleoenvironmental Reconstruction

Changing abundances of ostracode species through time are often used as proxy records for past environments. The generally high fidelity of death assemblages to living communities and the relatively low within-lake variability of ostracode death assemblages on San Salvador Island support their use in paleoenvironmental reconstruction. Specifically, the high fidelity of death assemblages suggests that diversity changes through time captured in sediment cores should reflect biologically meaningful changes in ostracode communities living at the time with little complications from *post mortem* taphonomic processes, such as transport of valves or sorting of valves by size. The burial of recently dead ostracode valves seems to occur on a rapid enough timescale not to be obscured by taphonomic processes.

Differences in ostracode density may reveal a productivity gradient that is related to a previously identified gradient in ostracode β -diversity (Michelson and Park, in press). Additionally, the high correlation between living and dead densities of ostracode valves may mean that density of preserved ostracode valves reflects density at the time of burial; density of preserved ostracode valves may thus contain information of ostracode productivity in the past.

The generally low variability of ostracode death assemblages within lakes means that any sampled location through time should be reflective of diversity changes in the lake as a whole. This also affirms the practice of taking one or a few samples of death assemblages from each lake to build a calibration model for paleoenvironmental reconstruction since little new information on ostracode diversity would be gained by sampling many recent assemblages from one lake. The generally high live/dead correlation additionally allows the study of ostracode modern ecology across the island based on death assemblages since little new information would be gained from collection of

living communities only. This result implies little seasonal change in ostracode communities within lakes on San Salvador Island since the death assemblage, which should integrate seasonal diversity, changes into an average assemblage (Park et al., 2003). This is because if different species dominated the assemblage at different times of the year, a difference in the “snapshot” living community sampled in this study and its time-averaged death assemblage would be observed. The implication of little seasonality in this study will be tested in future work by sampling a single lake at different times throughout the year. The two blue holes in the dataset, Watling's Blue Hole and Blue Hole 5, display live/dead correlations and within-lake diversity patterns at variance to the above conclusions.

Watling's Blue Hole and Blue Hole 5

Watling's Blue Hole provided the only exception to high mean live/dead correlation and was the only lake in this study to exhibit negative live/dead correlation. It also exhibited much higher variance in death assemblages than any other lake as measured by the area its 95% confidence interval encompassed in the NMDS biplot. Watling's Blue Hole and Blue Hole 5 were also the only lakes in this study to show changes in Simpson's diversity with distance from shore (while French Pond also showed significant changes in diversity with distance from shore, this was entirely driven by the recovery of one valve of *D. inopinata* near shore which was not sampled in any other assemblage from French Pond). Finally, Watling's Blue Hole was the only lake in this study in which some samples in the rho vs. Jaccard-Chao biplot (Figure 4) do not fall in the upper right quadrant. Kidwell (2009) has shown that this discrepancy in rank-abundance and taxonomic composition of living communities and death assemblages is characteristic of ecosystems modified by humans such as eutrophication or bottom trawling. In fact, Watling's Blue Hole was used in the past as a turtle pen when the surrounding area was used to grow cotton

(Gerace, 1982). This turtle pen probably involved bottom trawling of the sediment. This anthropogenic modification may explain the dual discrepancies in rank-abundance and taxonomic composition of the living communities and death assemblages seen only in this lake in the study.

The two blue holes have the steepest depth gradients observed in this study, so any changes in live/dead correlation could be due to down-slope transport. Ordination of living and dead assemblages for both Watling's Blue Hole and Blue Hole 5 reveals down-slope transport to be a likely cause in Watling's, but not in Blue Hole 5 (Figures 10 and 11). Living communities in Watling's show no greater similarity to those sampled at the same distance from shore and Watling's death assemblages show less variation than its living communities. This indicates the lack of any biological zonation in Watling's Blue Hole and associated death assemblages that integrate any differences in living communities that appear to be unrelated to distance from shore or depth sampled. A closer look at the distribution of live/dead correlation in Watling's also reveals that while not varying in a systematic way with distance from shore or depth, two species out of the 4 present appear to drive the low correlation and changing diversity with depth. *D. inopinata* and *P. bicelliforma*'s percent abundances stay relatively constant across all samples in Watling's. On the other hand, *H. setipunctata* and *C. americana*'s abundances change with distance from shore. *H. setipunctata* increased in percent abundance with increasing depth, especially in the death assemblages, while *C. americana* decreased in percent abundance with increasing depth. Thus, while the living community in Watling's does not vary much with depth, the percent abundances of these two species do, *H. setipunctata*'s increasing dominance in the death assemblage lowers evenness, driving down Simpson's diversity with depth and its over-abundance in the death assemblage changes rank-abundance distributions between living and dead communities lowering rho in a few locations.

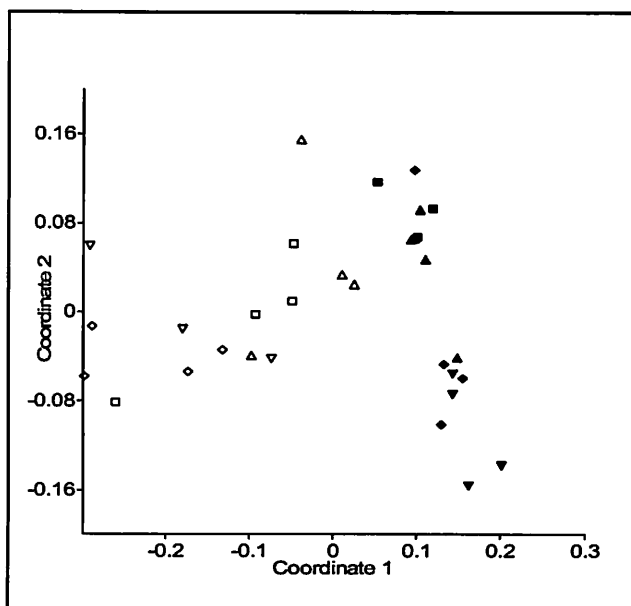


Figure 10. First 2 dimensions of a 3-dimensional nonmetric multidimensional scaling ordination on the Bray-Curtis dissimilarity matrix of death assemblages and living communities from Watling's Blue Hole. Stress = 5.8%. Symbols are as follows: Unfilled Squares: Living Communities at 4 m from shore, Filled Squares: Death Assemblages at 4 m from shore, Unfilled Triangles: Living Communities at 9 m from shore, Filled Triangles: Death Assemblages at 9 m from shore, Unfilled Diamonds: Living Communities at 14 m from shore, Filled Diamonds: Death Assemblages at 14 m from shore, Unfilled Inverse Triangles: Living Communities at 19 m from shore, Filled Inverse Triangles: Death Assemblages at 19 m from shore. Death Assemblages all plot near each other with high values on the first axis, whereas living communities also plot near each other with lower values on the first axis and no systematic difference with distance from shore. There are only 3 pseudoreplicates of living communities at 19 m from shore since one sample contained no live ostracodes at this depth.

What is not clear from these data is why *H. setipunctata*'s percent abundance should increase with increasing depth, while *C. americana*'s does not. These two species are about the same size, yet *H. setipunctata* seems

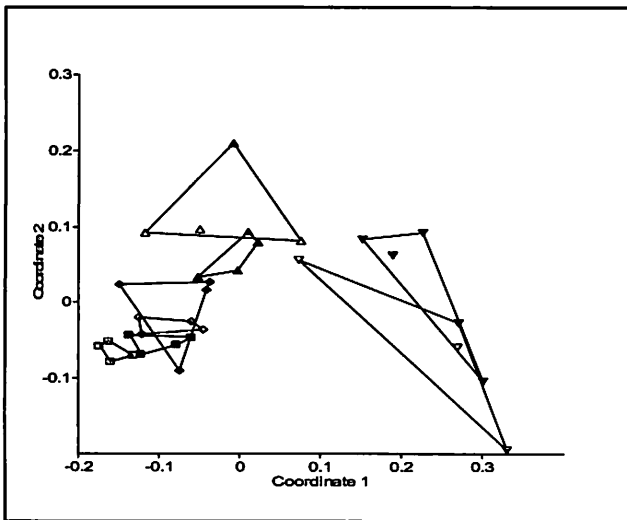


Figure 11. First 2 dimensions of a 3-dimensional nonmetric multidimensional scaling ordination on the Bray-Curtis dissimilarity matrix of death assemblages and living communities from Blue Hole 5. Stress = 5.2%. Symbols are as follows: Unfilled Squares: Living Communities at 4 m from shore, Filled Squares: Death Assemblages at 4 m from shore, Unfilled Triangles: Living Communities at 9 m from shore, Filled Triangles: Death Assemblages at 9 m from shore, Unfilled Diamonds: Living Communities at 14 m from shore, Filled Diamonds: Death Assemblages at 14 m from shore, Unfilled Inverse Triangles: Living Communities at 19 m from shore, Filled Inverse Triangles: Death Assemblages at 19 m from shore. Polygons surround living and dead samples from the same depth. Living communities plot closer to each other than to other living communities and closer to their associated death assemblages than death assemblages from other distances from shore. Note the difference in pattern from Watling's Blue Hole in Figure 10.

to be preferentially transported down-slope in Watling's Blue Hole, while *C. americana* is not. Perhaps this is caused by differences in life histories between the two species, with *H. setipunctata* having little substrate preference, while *C. americana* may have more specific affinities for certain substrates, limiting its down-slope transport.

The distribution of living communities and associated death assemblages in Blue Hole 5 shows a different pattern. Figure 11 shows that living communities in Blue Hole 5 appear more similar to others at the same depth than to those at different depths. This indicates that unlike Watling's Blue Hole where preferential down-slope transport of one ostracode species appears to drive changing diversity patterns with depth, Blue Hole 5 contains distinct communities of ostracodes living at different depths. That this pattern only emerges when Blue Hole 5's assemblages are ordinated by themselves means that when examined in the context of all lakes in this study, this within-lake difference is low compared to differences in community structure between lakes, but high when looking at differences with Blue Hole 5. That Simpson's diversity of death assemblages varies with depth indicates that the death assemblages in Blue Hole 5 records this change in community structure with depth, although transport of ostracode valves appears to homogenize these differences since depth assemblages do not vary with depth in the N-MDS biplot of Blue Hole 5 (Figure 11). Thus, sampling multiple living and dead assemblages from individual lakes can distinguish between differences in assemblages due to transport or multiple distinct, but similar communities in a single lake.

CONCLUSIONS

- Ostracode death assemblages on San Salvador faithfully record living communities from which they are derived, except in Watling's Blue Hole, where there may be species-specific transport down-slope.
- Ostracode death assemblage exhibit low within-lake variability except in the case of Watling's Blue Hole and Blue Hole 5. In Watling's, transport of valves leads to variability in death assemblages, while Blue Hole 5 shows slight differences in

community structure with depth that is not seen in any other lake.

- Changing abundances of ostracode species through time records biologically meaningful changes that may be related to changing abiotic factors through time.
- One death assemblage per lake is sufficient sampling to understand diversity change between lakes, except in the case of blue holes.
- High-diversity lakes and not blue holes may provide the most faithful paleobiological records since they have the highest live/dead correlations and lowest intralake variability in death assemblages.

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REFERENCES

Alin, S.R., and Cohen, A.S., 2003, Lake-level history of Lake Tanganyika, East Africa, for the past 2500 years based on ostracode-inferred water-depth reconstruction: *Palaeogeography,*

Palaeoclimatology, Palaeoecology, v. 199, p. 31-49.

Bergin, F., Kucuksezgin, F., Uluturhan, E., Barut, I.F., Meric, E., Avsar, N., and Nazik, A., 2006, The response of benthic foraminifera and ostracoda to heavy metal pollution in Gulf of Izmir (Eastern Aegean Sea): *Estuarine, Coastal and Shelf Science,* v. 66, p. 368-386.

Chao, A., Chazdon, R.L., Colwell, R.K., and Shen, T.-J., 2005, A new statistical approach for assessing compositional similarity based on incidence and abundance data: *Ecology Letters* v. 8, p. 148-159.

Corrège, T., 1993, The relationship between water masses and benthic ostracod assemblages in the western Coral Sea, southwest Pacific: *Palaeogeography, Palaeoclimatology, Palaeoecology* v. 105, p. 245-266.

Frenzel, P., and Boomer, I., 2005, The use of ostracods from marginal marine, brackish waters as bioindicators of modern and Quaternary environmental change: *Palaeogeography, Palaeoclimatology, Palaeoecology,* v. 225, p. 68-92.

Gerace, K., 1982, Three loyalist plantations on San Salvador, Bahamas: *The Florida Anthropologist,* v. 35, p. 216-222.

Hammer, Ø., Harper, D.A.T., and Ryan, P.D., 2001, PAST: Paleontological statistics software package for education and data analysis: *Palaeontologia Electronica,* v. 4, p. 1-9.

Holmes, J.A., 2008. Sample-size implications of the trace-element variability of ostracod shells: *Geochimica et Cosmochimica Acta,* v. 72, p. 2934-2945.

- Horne, D.J., Cohen, A., and Martens, K., 2002, Taxonomy, morphology and biology of Quaternary and living Ostracoda, *in* Chivas, A., and Holmes, J., eds., *The Ostracoda: applications in Quaternary research: AGU Geophysical Monograph Series*, v. 131, p. 5-36.
- Kidwell, S.M., 2001, Preservation of species abundance in marine death assemblages: *Science*, v. 294, p. 1091-1094.
- Kidwell, S.M., 2007, Discordance between living and death assemblages as evidence for anthropogenic ecological change: *Proceedings of the National Academy of Science of the USA*, v. 104, p. 17,701-17,706.
- Kidwell, S.M., 2009, Evaluating human modification of shallow-marine ecosystems: Mismatch in composition of Molluscan living and time-averaged death assemblages, *in* Dietl, G.P., and Flessa, K.W., eds., *Conservation Paleobiology: Using the Past to Manage for the Future: Paleontological short course*.
- Mezquita, F., Roca, J.R., Reed, J.M., and Wansard, G., 2005, Quantifying species-environment relationships in non-marine Ostracoda for ecological and palaeoecological studies: examples using Iberian data: *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 225, p. 93-117.
- Michelson, A.V., and Park, L.E., in press, Ostracode metacommunity dynamics on San Salvador Island, Bahamas: Discerning patterns of diversity and biogeographical distributions, *in* Baxter, J., and Cole, E., eds., *Proceedings of the 13th Symposium on the Natural History of the Bahamas: Gerace Research Center, San Salvador Island, Bahamas*.
- Mischke, S., Almogi-Labin, A., Ortal, R., Schwab, M.J., and Boomer, I., 2010a, Quantitative reconstruction of lake conductivity in the Quaternary of the Near East (Israel) using ostracods: *Journal of Paleolimnology*, v. 43, p. 667-688.
- Mischke, S., Bößneck, U., Diekmann, B., Herzsuh, U., Jin, H., Kramer, A., Wünnemann, B., and Zhang, C., 2010b, Quantitative relationship between water-depth and sub-fossil ostracod assemblages in Lake Donggi Cona, Qinghai Province, China: *Journal of Paleolimnology*, v. 43, p. 589-609.
- Mischke, S., Herzsuh, U., Massmann, G., and Zhang, C., 2007, An ostracod-conductivity transfer function for Tibetan lakes: *Journal of Paleolimnology*, v. 38, p.509-524.
- Mourguiart, P., and Carbonel, P., 1994, A quantitative method of palaeolake-level reconstruction using ostracode assemblages: an example from the Bolivian Altiplano: *Hydrobiologia*, v. 288, p.183-193.
- Mourguiart, P., Corrège, T., Wirmann, D., Argollo, J., Montenegro, M.E., Pourchet, M., and Carbonal, P., 1998, Holocene palaeohydrology of Lake Titicaca estimated from an ostracode-based transfer function: *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 143, p. 51-72.
- Muller, B. J., Smith, A. J., Palmer, D., Ito, E., and Forester, R.M., 2002, Assessing the value of presence/absence data for ostracode-based paleoenvironmental reconstructions: *American Geophysical Union, Spring Meeting 2002, abstract #GS41A-08*.

- Padmanabha, B., and Belagali, S.L., 2008, Ostracods as indicators of pollution in the lakes of Mysore: *Journal of Environmental Biology*, v. 29, p. 415-418.
- 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 Island, Bahamas: *Quaternary International*, v. 195, p. 98-105.
- Park, L.E., and Trubee, K.J., 2008, 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: Gerace Research Centre, San Salvador Island, Bahamas, p. 11-24.
- Park, L.E., and Beltz, J.F., 1998, Biogeography of Neogene tropical non-marine Caribbean ostracod faunas: *Geological Society of America Abstracts with Programs*, v. 30, p. 287.
- Park, L.E., Cohen, A.S., Martens, K., and Bralek, R., 2003, The impact of taphonomic processes on interpreting paleoecologic change in large lake ecosystems: ostracodes in Lake Tanganyika and Malawi: *Journal of Paleolimnology*, v. 30, p. 127-138.
- Saros, J.E., 2009, Integrating neo- and paleolimnological approaches to refine interpretations of environmental change: *Journal of Paleolimnology*, v. 41, p. 243-252.
- Smol, J.P., 2007, Marine sediments tell it like it was: *Proceedings of the National Academy of Science of the USA*, v. 104, p. 17,563-17,564.
- Teeter, J.W., 1995, Holocene saline lake history, San Salvador Island, Bahamas, in Curran, H.A., and White, B., eds., *Terrestrial and Shallow Marine Geology of the Bahamas and Bermuda: Geological Society of America Special Papers*, v. 300, p. 117-124.
- Teeter, J.W., and Quick, T.J., 1990, Magnesium-salinity relation in the saline lake ostracode *Cyprideis americana*: *Geology*, v. 18, p. 220-222.
- Trubee, 2002, Characterizing the fauna of non-marine ostracode faunas on San Salvador Island, Bahamas: Unpublished M.S. Thesis, University of Akron, Akron, OH, 59 pp.
- Viehberg, F.A., 2006, Freshwater ostracod assemblages and their relationship to environmental variables in waters from northeast Germany: *Hydrobiologia*, v. 571, p. 213-224.
- Vavrek, M.J., 2011, Fossil: palaeoecological and palaeogeographical analysis tools: *Palaeontologia Electronica*, v. 14, p. 1T.
- Woodbridge, J., and Roberts, N., 2010, Linking neo- and palaeolimnology: A case study using crater lake diatoms from central Turkey: *Journal of Paleolimnology*, v. 44, p. 855-871.