1 A quantitative inference model for conductivity using non-marine
2 ostracode assemblages on San Salvador Island, Bahamas: Paleosalinity
3 records from two lakes

4 Andrew V. Michelson*¹ and Lisa Park Boush²

5
6 ¹Department of Geology and Environmental Sciences, University of Akron, Akron, OH 44325-
7 4101, present address: Division of Science, Engineering, and Technology, Thomas Nelson
8 Community College, 4601 Opportunity Way, Williamsburg, VA 23188
9

10 ²Center for Integrative Geosciences, University of Connecticut, Beach Hall Room 225, 354
11 Mansfield Road Unit 1045, Storrs, CT 06269
12

13 *Corresponding Author
14

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Abstract

Quantitative records of past environments are needed to understand natural variability in ecosystems and their responses to climate change. Changes in ostracode assemblages through time can provide such records as ostracode species are sensitive to changes in their local environments. Before they can be used to indicate past environments, however, is it necessary to understand how distributions of assemblages change across environmental gradients. To that end, thirty-two lakes on San Salvador Island, Bahamas were sampled for both ostracodes and nineteen limnological variables. Multivariate fuzzy set ordination indicates that change in ostracode assemblages is significantly and independently correlated with three environmental variables: electrical conductivity (salinity), dissolved oxygen and alkalinity. A transfer function was created to reconstruct past conductivity since changing conductivity of lakes on San Salvador is influenced by changes in climate and sea-level. A 2-component weighted-averaging partial least squares model performed best as a transfer function for conductivity with an apparent r^2 of 0.76 and an r^2 of 0.69 between observed and predicted conductivity, as assessed by leave-one-out cross validation. The resulting transfer function was then applied to two mid- to late-Holocene sediment cores from which ostracode assemblages were sampled. The late Holocene conductivity records show that changes in conductivity of lakes on San Salvador are broadly synchronous with times of enhanced ENSO activity corresponding to elevated conductivity in response to lower Atlantic hurricane occurrence. These results demonstrate that changing ostracode assemblages through time provide a reliable means to reconstruct past salinity and demonstrates the strong effect of ENSO on Bahamian aridity.

1. Introduction

Sedimentary archives from coastal lakes have produced important records of environmental change including: how global cycles affect regional climate patterns (Donnelly and Woodruff, 2007; Mann et al., 2009), how sea-level affects local environments (Teeter 1995; Peros et al. 2007; Gabriel et al., 2009; Kovacs et al., 2013), and how climates have varied through time (Mischke et al., 2014). Limnological conditions are determined by the complex interplay between temperature, precipitation, evaporation, and paleohydrologic conditions, so an understanding of environmental changes and their causes requires a multiproxy approach in a historical context (Peros et al., 2007; Saros, 2009; Sayer et al., 2010). Organism-based calibration datasets can produce high-resolution, quantitative estimates of past environments which allows for the determination of cause and effect relationships (Saros, 2009; Sayer et al., 2010).

Here we develop a robust model to recreate past salinity records from ostracode assemblages contained in lacustrine archives on San Salvador Island, Bahamas. San Salvador is an island with a semi-arid climate where human habitation depends on moisture availability. Additionally, sediments from coastal lakes on San Salvador have produced reliable archives of past hurricane activity (Park, 2012) so if we can understand how past salinity has changed in these lakes, we can understand the relationship between hurricane activity and changes to the local aquatic environment.

The coupled records of hurricane activity and changes to aquatic environments produced by sedimentary archives from San Salvador can provide insight into regional drivers of hurricane activity. El Niño-Southern Oscillation (ENSO) strongly influences tropical cyclone formation in

the Atlantic basin with times of strong El Niño resulting in high wind shear across the Atlantic, inhibiting hurricane formation (Gray, 1984; Pielke and Landsea, 1999; Landsea, 2000; Bell and Chelliah, 2006; Nyberg et al., 2007; Klotzbach, 2011; Wang et al., 2014). Times of strong El Niño events would thus produce less precipitation in the Bahamas, raising conductivity and times without strong El Niño events would be associated with more hurricanes striking San Salvador, resulting in lowered conductivity in our sampled ponds. Other sedimentary records from the coastal ponds in the Caribbean show this consistent relationship between ENSO and hurricane activity (Donnelly and Woodruff, 2007; Mann et al., 2009).

We present a new calibration set using Ostracoda (Phylum: Arthropoda) from lakes, ponds, and blue holes (cenotes) on San Salvador Island, Bahamas to produce quantitative records of past electrical conductivity from two lakes. Because electrical conductivity is determined by the presence of ions dissolved in the lake water, salinity and electrical conductivity in these lakes measure the same variable and thus are perfectly correlated. Ostracodes are a class of bivalved microcrustaceans that live in all types of aquatic habitats, including the deep ocean and ephemeral pools (Horne et al. 2002). Lacustrine ostracode species live benthic or nekton-benthic lifestyles 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 can be preserved as fossils and commonly range in size from 0.5-2 mm and long have been used as biological proxies of anthropogenic change and past environmental conditions (Frenzel and Boomer 2005; Padmanabha and Belagali, 2008; Michelson and Park, 2013). These organisms have already been used in transfer functions (see Viehberg and Mesquita-Joanes, 2012 for a review) in lake sediments to reconstruct conductivity (Mezquita et al., 2005; Mischke et al., 2007; Mischke et al., 2010a; Mischke et al., 2014; Mercau and Laprida, 2016), water depth

(Mourguiart and Carbonel, 1994; Mourguiart et al., 1998; Alin and Cohen, 2003; Mischke et al., 2010b; Peng et al, 2013; Guo et al., 2016), and temperature (Mezquita et al., 2005; Viehberg, 2006).

1.1 Study area

San Salvador is a small (163 km²) carbonate island located within the Bahamian archipelago in the northern hemisphere-southwest Atlantic (Davis and Johnson, 1989; Fig. 1). Throughout the Pleistocene, dune sediments were deposited across the San Salvador platform during times of elevated sea-level. Many lakes on the island today occur between these ancient dunes, as cutoff-lagoons once open to the ocean, or as karst dissolution-and-collapse features in the carbonate bedrock (Bain, 1991; Teeter, 1995; Park and Trubee, 2008; Park et al., 2014). Salinity in these lakes is controlled by basin geomorphology, degree of connection to the ocean, precipitation-evaporation balance, and climate (Teeter, 1995; Park et al., 2009; Park et al., 2014).

We extracted two sediment cores from lakes on San Salvador: one each from Clear Pond and North Storrs Lake. Comparing these two cores allows us to determine whether changes in conductivity are synchronous across lakes on the island and to relate changes in conductivity of individual lakes to sea-level and/or changing climate (Teeter, 1995).

Clear Pond is a small (0.117 km² in surface area), shallow, lake with an ebb-and-flow spring on its eastern shore (Dalman, 2009). Clear Pond's salinity ranges from brackish (~20 ppt) in summer and fall to marine-salinity (35 ppt) in winter and spring (Dalman, 2009). Clear Pond was previously a lagoon with a surficial connection to the ocean, but today is isolated from the

ocean by mid-Holocene eolianite dunes to the north and unlithified dunes to the south (Park, 2012).

Storrs Lake is one of the largest lakes on San Salvador (3.2 km²), also shallow, hypersaline lake that like Clear Pond was once an oceanic lagoon (Park et al., 2009; Park, 2012). Its average salinity is 62 ppt, but it can range from 38.5 to 93.5 ppt (Mann and Hoffman, 1984; Mann and Nelson, 1989). The core used in this study was taken from the northern basin of Storrs Lake, the largest of its three basins. Previous cores from these and other lakes on San Salvador show strong within-lake reproducibility of sedimentological signals; when multiple cores are taken from the same basin, the same facies are generally recovered in each core (Park et al., 2009; Park, 2012).

2. Methods

2.1 Field and laboratory methods

We collected surface sediment and water samples from and measured limnological conditions in 32 lakes on San Salvador Island in June 2008, March 2009, and June 2009 (Fig. 1). Surface sediments were collected by sweeping a net (mesh size 2mm) with attached jar across the sediment-water interface, recovering the upper 1-2 cm of sediment. All samples were collected within the littoral margin, approximately ~10 m from the shore. In a separate study, multiple living communities and death assemblages were collected in seven representative lakes. Except for one lake, Watling's Blue Hole, live/dead agreement in rank-abundance and taxonomic composition was extremely high (Michelson and Park, 2013). Likewise, except for Watling's,

little or no variability was found among death assemblages in these lakes (Michelson and Park, 2013). Thus, the ostracodes in the death assemblages collected by net sweeping were determined to represent “modern” assemblages, typical of the lakes from which they were sampled. These core-top death assemblages are also comparable to the time-averaged death assemblages preserved in sedimentary archives that the resulting transfer function was applied to.

Five lake environmental variables were measured in the field with an YSI 556 field meter, including conductivity ($\pm 0.5\%$), salinity ($\pm 1\%$), total dissolved solids (± 4 g/L), dissolved oxygen ($\pm 2\%$), and water temperature ($\pm 0.15^\circ\text{C}$). Alkalinity was determined in the field using a Hach methyl orange and phenolphthalein (total) acidity digital titration kit (± 0.1 mg/L as CaCO_3). Water depth at each site was measured to the nearest cm using transect tape and a measuring stick. Latitude and longitude as well as lake area were determined using the San Salvador GIS database (Robinson and Davis 1999) and a hand-held GPS unit.

We filtered sediments using $125\text{ }\mu\text{m}$ (ϕ -size 3) and $63\text{ }\mu\text{m}$ (ϕ -size 4) sieves with deionized water. Upon drying, ostracode death assemblages were picked using a dissecting microscope. In all cases, at least 400 ostracode valves were picked from the $> 125\text{ }\mu\text{m}$ fraction of each sample and all adults were identified to species level using reference collections at the University of Akron (Trubee, 2002; Park and Trubee, 2008).

Water samples were analyzed for the concentration of major cations using a Perkin Elmer Analysis 700 atomic absorption (AA) spectrometer at the University of Akron. Water samples were analyzed for chloride and sulfate anions using a Dionex DX-120 ion chromatograph. All major ions concentrations are expressed as mg/L.

Sediment cores were extracted from two lakes on San Salvador and assessed for ostracode assemblages, sediment loss on ignition, and grain size. One 1.23 m core was extracted

from Clear Pond (Dalman, 2009), and one 1.62m core was extracted from the north basin of Storrs Lake (Fig. 1).

Cores were extracted by push-coring techniques, in 2-inch-diameter black acrylonitrile-butadiene-styrene (ABS) tubing, and split and stored in the University of Akron's refrigeration facility. No sediment compaction was evident in either of these cores during coring or extraction. The cores were sampled at 1 cm intervals for ostracode assemblages using standard freeze-thaw techniques (Delorme, 1989; Danielopol et al., 2002).

Sediment loss on ignition was done at 1 cm intervals using standard methods (Heiri et al., 2001). Sediment grain size was analyzed at 1 cm intervals using a Malvern 2000 Mastersizer at Kent State University. Sediment samples were unprocessed other than being sieved to < 1mm before grain size distribution was determined. Grain size was expressed as percent medium to fine sand (62.5 μ m-1 mm) of the sample by volume.

Records of potassium (K) were obtained as a proxy for African dust deposition by x-ray fluorescence of the Clear Pond and North Storrs cores at the University of Minnesota, Duluth using an ITRAX x-ray fluorescence core scanner. Potassium is present in airborne dust of African origin (Prospero and Carlson, 1972; Foos, 1990) and the dust is the only source of aluminosilicate deposition in the Bahamas (Foos, 1990; Muhs et al., 1990). Both cores were scanned at 0.02 cm intervals.

Age models for the cores were constructed using radiocarbon dates on allochthonous (terrestrial) leaf material at six depths in the Clear Pond core, and at six depths in the North Storrs core and sent to Beta Analytic or Lawrence Livermore laboratories to determine their radiocarbon ages.

2.2 Numerical methods

Species were retained in the dataset if they were found in at least three lakes or their abundance exceeded 30% of total adult ostracodes in any one lake. All species' abundances were expressed as percent of total adult ostracodes.

We conducted non-metric multidimensional scaling (NMDS) on the Bray-Curtis dissimilarity matrix as an exploratory method to understand the relationship between species and environment in the dataset. NMDS is an unconstrained ordination technique in that variation in assemblages is displayed according to biotic data only. That variation was then correlated to measured environmental variables. NMDS was undertaken in PAST (Hammer and Harper, 2005).

We then carried out forward multidimensional fuzzy set ordination (MFSO) (Roberts, 2009) using the R package MFO (Roberts, 2008) in order to directly relate environmental variables to variation in ostracode assemblages by reducing the environmental dataset to only those variables that significantly and individually explain how assemblages change across environmental gradients. These variables then became candidate variables to model in the transfer function. NMDS displays all variation in assemblages, whereas MFSO focuses only on that variation in assemblages that can be correlated to measured environmental variables. MFSO was chosen as the preferred method for directly relating environmental variables to change in assemblages since it tests the strength and significance of each individual environmental variable in the dataset. The effect size and significance of each variable in correlating to change in assemblages was then assessed. The single variable with the highest effect size was then retained in the model. The residuals were used to test for correlation with other environmental

variables. In this way, MFSO eliminates model selection problems caused by correlations among measured environmental variables, identifying only those variables that individually correlate to changes in assemblages. All remaining environmental variables were tested for effect size and significance. The process stopped when no other environmental variables significantly correlated to the residuals (Roberts, 2008; 2009).

Taxon optima (niche position) and tolerances (niche breath) were calculated for all taxa using Gaussian logistic regression (GLR) in R. Ter Braak and Looman (1986) was used to convert the regression coefficients from GLR into estimates of species' optima and tolerances.

The program C2 (Juggins, 2003) was used to construct the transfer function through weighted averaging partial least squares regression (WA-PLS). Low root-mean-square-error of prediction (RMSEP), a low maximum bias (ter Braak and Juggins, 1993), and a high coefficient of determination (r^2) between observed and predicted values, estimated by leave-one-out cross-validation (Birks, 1995), as well as the smallest number of 'useful' partial-least-squares components all contributed to the selection of the minimum adequate WA-PLS model. We assessed the predictive ability of the transfer function model by the correlation between the measured and inferred conductivity and the apparent root mean squared error (RMSE) of prediction and the equivalent jackknifed values. Jackknifing is used to predict the conductivity of each sample using only the other samples in the dataset. It proceeds by leaving one lake out of the dataset and then using all 31 other lakes in the dataset to create a model to predict the left out lake's conductivity from its ostracode assemblage. In this way, it is a useful method to assess the predictive ability of the model without collecting independent data. The program C2 (Juggins, 2003) was used to convert the ostracode assemblages at each stratigraphic depth to records of past conductivity using the transfer function model created.

We used the Bray-Curtis dissimilarity metric to assess how well each subfossil assemblage extracted from both cores matched modern assemblages in the training set. At each depth, we calculated the Bray-Curtis distance between the subfossil assemblage and the closest modern assemblage to calculate the minimum Bray-Curtis distance. This minimum distance from the subfossil assemblage to its closest modern analogue was then compared to the distances between the two most similar modern assemblages. Any subfossil assemblage that fell within the 95th percentile of the distances of the two most similar modern assemblage was considered to have a good analogue. Any subfossil assemblage with a distance to its closest modern assemblage greater than the 90th percentile of the distance between the two most similar modern assemblages was considered to lack a modern analogue. This analysis was carried out with C2 (Juggins, 2003).

We used BACON to produce age models for both cores (Blaauw and Christen, 2011). BACON is a flexible method of age-depth modeling using a Bayesian autoregressive gamma process that provides quantitative estimates of error in age modeling, is robust to outlying dates, and avoids simple linear fits or connect-the-dots models in which sedimentation rate changes perfectly coincide with dated horizons. BACON is particularly suited to a system such as these Bahamian lakes in which sedimentation rates change, hiatuses are common, and sedimentation can be episodic due to the influence of large storms, such as hurricanes (Park et al., 2009; Park, 2012).

3. Results

3.1 Modern assemblages

Lakes in this study are alkaline and have a wide range of conductivity (4.9-152 mS/cm). Additional limnological and geographical characteristics of these lakes as well as percent abundances of all species of ostracodes included in the calibration set are listed in Electronic Supplementary Material Table 1.

We found eleven ostracode species from eleven genera and nine families throughout the lakes. These species are members of the Caribbean non-marine fauna of Park and Beltz (1998) (Table 1). All assemblages picked from lakes contained at least 129 valves of adults. All of these samples contained more juveniles than adults; the adult to juvenile ratio ranged from 0.385-0.915, although this certainly represents an underestimate of juveniles since those in the 63-125 μm fraction were not counted. Greater numbers of juveniles than adults indicates the assemblage accumulated where the ostracodes lived and were not transported from another location (Park et al., 2003; Mischke et al., 2007).

MFSO revealed three variables that significantly and uniquely correlate with change in ostracode assemblages: electrical conductivity, dissolved oxygen, and alkalinity, although the effect of alkalinity is low (Fig. 2A). The constrained ordination with these three variables correlate strongly with the Bray-Curtis dissimilarity of the ostracode assemblages ($r = 0.83$, $p = 0.001$, $n = 32$). Assemblages and species are arranged primarily on a conductivity-alkalinity gradient, running from the upper left (high conductivity/low alkalinity) to lower right (low conductivity/high alkalinity) (Fig. 2B). Assemblages and species are secondarily arranged along dissolved oxygen gradient running nearly perpendicular to the conductivity/alkalinity gradient with high dissolved oxygen sites and species found in high abundance in high oxygen sites plotting in the lower left corner of the NMDS ordination and low dissolved oxygen sites and

species found in high abundance in low oxygen sites plotting in the upper right corner of the NMDS ordination (Fig. 2B).

Niche modeling across the conductivity gradient reveals that most species have niche positions tightly clustered in the range of marine salinity (conductivity: 52.5-58.3 mS/cm, Table 2). Exceptions include *Physocypria denticulata* and *Peratocytheridea setipunctata* whose niches are in the brackish range (< 52.5 mS/cm) and *Aurila floridana* whose niche optima (62.68 mS/cm) is positioned within the slightly saline range. The niche breadths, however, are widely divergent. Three species have noticeably broad niches (*Cyprideis americana*, *Perissocytheridea bicelliforma*, and *Peratocytheridea setipunctata*), while other species have narrower niches. All species display patterns of decreasing abundances away from their optima except *P. bicelliforma* which reaches its greatest abundance at very high and very low conductivities; many species have similar abundances in marine conductivity.

A 2-component weighted-averaging partial least squares (WA-PLS) model performed best as a transfer function for conductivity (Table 3, Fig. 3). This model performs well with an apparent r^2 of 0.76 and an r^2 of 0.69 between observed and predicted conductivity, as assessed by leave-one-out cross validation (Table 3; Fig. 3A). There is no systematic relationship between the residuals of the full model and the observed conductivity, although lakes in the middle of the sampled gradient tended to overestimate the conductivity of lower-conductivity lakes and underestimate higher-conductivity lakes (Fig. 3B). Sampling across the conductivity gradient is not even. Bamboo Pond, the sample with the lowest conductivity, is noticeably different; it is a high leverage point in the WA-PLS model, but not a highly influential point. Even though it is the only sample from the very low end of conductivity, its species composition is on-trend with the remainder of the dataset. Most of the samples fall in the mid-range of conductivity and

display lowering residuals with increasing conductivity (Fig. 3B). Three samples fall on the highest end of the conductivity gradient and their residuals display no systematic relationship with observed conductivity.

3.2 Sedimentary archives

Based on six radiocarbon dates, Clear Pond showed the most variation in sedimentation rate; the base of this core at 123 cm dates to 5250 cal yr B.P., resulting in an average sedimentation rate of 0.023 cm/yr (Fig. 4B). Based on six dates, the sedimentation rate in the North Storrs core proved to be nearly linear, with an average sedimentation rate of 0.028 cm/yr and the bottom of the 162 cm core dating to 5560 cal yr B.P. (Table 4, Fig. 4C). Thus, our paleoconductivity records, based on 1 cm-scale sampling of ostracode assemblages, have the resolution to capture changes at multi-decadal scales since 1 cm of deposition occurred, on average, in ~43.4 years in Clear Pond and ~35.1 years in North Storrs. These age models are consistent with other age models developed for similar depositional environments on San Salvador Island (Park et al., 2009; Park, 2012).

In the Clear Pond core, each 1 cm stratigraphic interval yielded between 2 and 77 valves of adult ostracodes (mean = 22.4 valves), while each 1 cm stratigraphic interval in the North Storrs core yielded between 0 and 169 valves of adult ostracodes (mean of ostracode-containing intervals = 15.1 valves). All 123 cm depths in the Clear Pond core yielded adult ostracode valves consequently producing a continuous record of past conductivity (Fig. 5A). 71 out of 162 depths in the North Storrs core failed to yield any adult ostracode valves, producing a discontinuous record where past conductivity was estimated at 91 depths (Fig. 5B). In the North

Storrs record, from 3890 to 1580 cal yr B.P., only few isolated depths yielded adult ostracode valves and from the base of the core at 5568 to 4981 cal yr B.P., adult ostracode valves were only recovered sporadically (Fig 5B).

Subfossil assemblages from the Clear Pond core have good modern analogues. 85% of the subfossil assemblages in the Clear Pond core fall with the 95th percentile of the distances between the two most similar modern assemblages. 96% of the subfossil assemblages in the Clear Pond core fall with the 90th percentile of the distances between the two most similar modern assemblages (Fig. 5A).

Subfossil assemblages from the North Storrs core are more dissimilar to the modern assemblages than the subfossil assemblages from the Clear Pond core. 62% of the subfossil assemblages in the North Storrs core fall with the 95th percentile of the distances between the two most similar modern assemblages. 71% of the subfossil assemblages in the North Storrs core fall with the 90th percentile of the distances between the two most similar modern assemblages. Subfossil assemblages in the North Storrs core become more dissimilar to modern assemblages down core, especially 5374 to 3971 cal yr B.P. (Fig 5B).

In the Clear Pond archives, *C. americana* and *P. setipunctata* vary inversely from the top of the core to 1686 cal yr B.P. Following 1686 cal yr B.P., *C. americana* varies inversely with *P. bicelliforma*. Throughout the North Storrs core, *C. americana* rises in percent abundance at times when *P. bicelliforma* falls in abundance.

Both cores show large fluctuations in conductivity throughout the mid-late Holocene that are mostly synchronous, while Clear Pond shows a secular trend towards lower conductivity (Fig. 5). In both cores, times of elevated conductivity are correlated with high abundances of *P. bicelliforma* (Clear Pond: $r = 0.95$, $p < 0.001$, $n = 123$; North Storrs: $r = 0.93$, $p < 0.001$, $n = 91$).

In both cores, percent organic matter and percent carbonate content vary inversely, but peaks in these records do not seem to correspond with changes in the records of conductivity as determined by ostracode assemblages (Fig. 6). Changes in percent sand by volume correspond to changes in conductivity through time with peaks in the sand record coeval with times of lowered conductivity (Fig. 6).

Records of potassium from Clear Pond and North Storrs show good correspondence to the first 6,000 years of an independently-derived record of El Niño strength (Moy et al., 2002) times of increased potassium deposition are coincident with strong El Niño events (Fig. 7). The ostracode derived record of conductivity from these lakes also shows a positive correlation with the potassium record, peaks in the potassium record correspond to times of elevated conductivity in these lakes (Fig. 7).

4. Discussion

4.1 Performance of transfer function

Compared to published ostracode-based inference models for conductivity (Mezquita et al. 2005; Mischke et al., 2007; Mischke et al., 2010a), this transfer function performs comparably as assessed by the coefficient of determination between measured and inferred conductivity (0.69). Nevertheless, the ostracode assemblages of San Salvador Island, Bahamas do show a strong relationship to conductivity and this study demonstrates their effectiveness as proxy indicators in subtropical environments.

One lake (Bamboo) had higher leverage, i.e. it could have a large effect on the overall regression model, due to its position in brackish water. Nonetheless, it contained an assemblage consistent with other lakes. Two generalist species (*Cyprideis americana* and *Perissocytheridea bicelliforma*) were found in low abundances of this lake, but it was dominated by *Physocypria denticulata* which was found in low abundance in only one other lake. This resulted in *Physocypria denticulata* having a much lower conductivity optimum than all other species as assessed by Gaussian logistic regression according to ter Braak and Looman (1986). Park and Beltz (1998) concluded that ostracode species recovered from non-marine samples in the Caribbean must have invaded from the marine realm since many species reached highest abundances in lakes of marine salinity. *Physocypria denticulata* provides a counter example to this general pattern. It may have exhibited more rapid evolution than other taxa to colonize and dominate brackish lakes or may have invaded via a different route than other species.

No other lakes were noticeable outliers, although lakes in the mid-range of salinity may exhibit the edge effect common to regression techniques that model species with unimodal responses to environmental gradients (Mischke et al., 2007) since lakes in the middle of the sampled gradient tended to overestimate the conductivity of lower-conductivity lakes and underestimate higher-conductivity lakes. However, this effect was not seen in the one lake on the very lowest end of the gradient and the three lakes on the highest end of the gradient.

4.2 Abiotic factors controlling distribution of ostracode assemblages

The environmental variables identified as best able to explain the variation in ostracode assemblages were: conductivity, dissolved oxygen, and alkalinity. Conductivity has been

commonly identified as correlated with ostracode assemblages in disparate environments (Mezquita et al., 2005; Mischke et al., 2007; Mischke et al., 2010a; Pérez et al., 2011). Given that the ostracodes found in lacustrine environments on San Salvador may have invaded from the ocean, it is reasonable to assume that salinity would be a driver of ostracode diversity today since there are ample opportunities for diversification in lakes of divergent conductivity found today on San Salvador. The processes responsible for the formation of lakes on San Salvador led to lakes of differing salinities and hydrologic conditions (Park et al., 2014).

Similarly, previous work (Delorme, 1969; Frenzel and Boomer, 2005) has identified dissolved oxygen as a potential driver of diversity in ostracode assemblages since some species may have differing oxygen requirements. While alkalinity explains a significant and unique proportion of the Bray-Curtis dissimilarity matrix of ostracode assemblages, this proportion is quite small. Like conductivity, the processes responsible for lake formation on San Salvador have led to lakes with different alkalinities, so this may also be an important factor in the evolutionary ecology of ostracodes inhabiting San Salvador lakes.

4.3 Representativeness of modern samples

San Salvador lakes exhibit substantial seasonal variability in salinity (Sipahioglu, 2008; Dalman, 2009). Hypersaline lakes show the largest seasonal swings in salinity with North Storrs in particular varying by as much as 50 ppt over the course of a year (Mann and Hoffman, 1984; Mann and Nelson, 1989). This variation in salinity could then be estimated and utilized as an environmental variable to see if it significantly correlated with changes in ostracode assemblages. It is possible that certain species may be better adapted to this disturbance and may

come to dominate shallow, smaller lakes, or those that lack a robust connection to the ocean. In that case, analyses that use a one-point sample of salinity would miss this potential driver of diversity on San Salvador Island. Bowles (2013) also noted possible seasonal effects on ostracode breeding. Studies are needed to estimate variability in salinity and ostracode breeding season across all lakes to see if this could affect ostracode assemblage distribution.

4.4 Modeling of species niches across the sampled conductivity gradient

This paper presents the first quantitative estimates of responses across a salinity gradient for many species of lake-dwelling ostracodes. Even though an ostracode-based transfer function has been created for a nearby region (the Yucatán Peninsula (Pérez et al., 2011)), this study did not sample species in common with those found on San Salvador Island, with the possible exception of *P. denticulata*. For most species it produces a biologically meaningful model, while it gives a misleading result in at least one case. *P. bicelliforma* is a generalist species found in many of the sampled lakes. However, a Gaussian logistic regression on these data produces a concave niche with increasing probability of being found in lakes on the extreme high and low ends of the sampled gradient. This is the opposite of theoretical unimodal gradients on which this analysis is based. More studies need to be done on the autecology of these species to produce more reasonable models of individual species' niches as this time of modeling may be inappropriate for generalist species or species adapted to extreme environments.

For eight out of eleven species sampled, these estimates of their response to salinity and thus their use as an indicator of salinity matches those from previous studies. *Physocypria denticulata* has been sampled from Central Mexico (Bridgewater et al., 1999) and Florida

(Teeter, 1980) where it is characteristic of brackish water environments. *Peratocytheridea setipunctata* has previously been described as a brackish water species (van den Bold, 1976). While it reached its highest abundance in brackish water, in this study we found *P. setipunctata* to have a very broad niche, being found in the majority of lakes sampled (20/32). As in a previous study in Texas bays (Garbett and Maddocks, 1979), *Cytherella arostrata* was indicative of slightly below marine salinity conditions, just as the marine niche of *Paranesidea harpago* matched its occurrence in Bermuda (Maddocks and Iliffel, 1986) and Bimini (Kornicker, 1961). Similarly, we found that the occurrence in marine salinity of the three species: *Climacoidea (Reticulocythereis) multicarinata* (Garbett and Maddocks 1979), *Xestoleberis curassavica* (Ishmann et al., 1998), and *Loxoconcha pursubrhomboidea* (Garbett and Maddocks, 1979) matched those from previous studies. We also find that *Aurila floridana* is indicative of hypersaline conditions (Kornicker, 1964).

The notable exceptions to this pattern were three generalist species: *Paracyprina inopinata*, *Perissocytheridea bicelliforma*, and *Cyprideis americana*. *P. inopinata* has previously been interpreted as a hypersaline species, yet we find it in over half (18/32) of lakes sampled ranging from 30.8 - 73.2 mS/cm and that it reached its optimum salinity in marine waters. *P. bicelliforma*, on the other hand, was previously regarded as a species characteristic of brackish waters (Garbett and Maddocks, 1979; Teeter, 1995; Park et al., 2009). Here we find this species in 23 out of 32 lakes sampled, spanning the full range of measured conductivity (4.9 - 152 mS/cm) and that it dominated the most hypersaline lakes. Consequently, times of high abundance of *P. bicelliforma* are reconstructed in both cores as times of raised conductivity. Instead of being a brackish species (Sanger and Teeter, 1982; Rasmussen et al., 1990; Muñoz-Torres et al., 2006) we sampled *C. americana* in every lake except one, spanning the full range

of conductivity and thus estimate its niche to be extremely broad. While the majority of modeled niches correspond to occurrences elsewhere, this study highlights the need for site-specific calibration studies and casts doubt on calibrating species response to environmental variation based on global datasets (i.e. mutual climate range models Horne (2007) and Horne et al. (2012) as metapopulations in different regions may have evolved different responses to these environmental variables. Had we used salinity-abundance calibrations based on global species distributions, we may have gotten different results of salinity variations though time since the species we found to vary most from other areas were among the most abundant in our study area.

4.5 Conductivity records from San Salvador lakes

Changes in conductivity in lakes on San Salvador have been broadly synchronous across the late Holocene (Figs. 5, 6, 7). Only Clear Pond shows a secular trend across the time period represented. The archives from North Storrs Lake is somewhat limited due to the low number of adult ostracode valves recovered per stratigraphic interval, the high percentage of subfossil assemblages that lack modern analogues recovered, especially from 5374 to 3971 cal yr B.P., as well as the paucity of assemblages recovered, particularly during the time period 3890 to 1580 cal yr B.P (Fig. 5B). Since the majority of the sections in the North Storrs lake core from which no adult ostracodes were recovered were associated with evaporite minerals (principally gypsum and halite), these times may represent lower lake levels and thus periods of aridity.

Deposition of beach sand in these lakes is due to infrequent large storms which contribute large amounts of fresh water to these lakes and alter their species composition (Park et al., 2009). Therefore, times of increased sand input should be linked to a drop in the conductivity of the

lakes as determined by ostracode assemblages. This relationship is evident in both cores, peaks in sand generally correspond to drops in conductivity (Fig. 6). This relationship can be offset though as the allochthonous sand records and autochthonous ostracode assemblages exhibit different degrees of time-averaging. The sand records are highly-pulsed while the ostracode records accrue more evenly through time. Any offset between peaks in sand and dips in the ostracode-derived records of conductivity reflects this differential degree of time averaging. The weaker relationship between peaks in the sand content of the cores and changes in conductivity in North Storrs Lake is because this core was taken furthest from the ocean, so sand deposition due to hurricane overwash would only make its way to this position with the largest storms.

Clear Pond's overall freshening trend may be caused by the gradual rise in sea-level for the Caribbean basin (Lidz and Shinn, 1991; Milne and Peros, 2013; Khan et al., 2017). Before 3400 cal yr B.P., Clear Pond was a lagoon with a surficial connection to the ocean (Dalman, 2009). At 3400 years before present, Clear Pond closed to the ocean through dune progradation, but seawater continued to flow to the pond through an ebb-and-flow spring on its eastern shore (Dalman, 2009; Park, 2012). Rising sea-level would also raise the fresh groundwater lens (Carew and Mylorie, 1994), diminishing the impact of sea water on the pond's water budget causing the observed freshening trend.

Clear Pond records a period of damped climate oscillations and lower conductivity levels between 3600 and 2200 cal yr B.P. (including in three grey bar in Fig. 6A). Most of this period is included in the "hurricane hyperactivity" period, 3400 to 1000 cal yr B.P., described for Florida by Liu and Fearn (2000) and has been reported previously for San Salvador (Park, 2012). Unfortunately, this same period in North Storrs is recorded as a time with no ostracodes recovered (see above).

The variation in hurricane activity in the Atlantic, driven by changes in ENSO, strongly influences the salinity of lakes on San Salvador Island, Bahamas. The potassium records from Clear Pond and North Storrs show good correspondence with an independently-derived record of El Niño strength (Moy et al., 2002; Fig. 7) indicating that it should faithfully record times of strong El Niño events when more dust is blown from Africa and deposited in the Bahamas (Prospero and Lamb, 2003; Evan et al., 2006). The resolution of our records of past conductivity is not fine enough to capture individual ENSO cycles as each 1 cm stratigraphic interval of our past conductivity records is capable of capturing multi-decadal variation. Thus, these past conductivity records capture times of frequently reoccurring strong El Niño events. Times of strong El Niño events correspond to times of increased conductivity in Clear Pond and North Storrs and times of decreased El Niño events correspond to times of decreased conductivity (Figs. 6, 7).

4.6 Limits of quantitative paleoenvironmental reconstruction

Paleoenvironmental reconstruction through the use of transfer functions must be accomplished with care since transfer functions can overstate the precision and confidence of models, especially if the reconstructed variable is not ecologically important, other variables have important effects, or the environment is spatially structured (Telford and Birks 2005; 2009; Belyea 2007; Juggins 2013; Salonen et al. 2013; Medeiros et al. 2015; Trachsel and Telford 2016). The ecological dynamics of lacustrine ostracodes on San Salvador, however, are particularly amenable for the creation of a conductivity transfer function. Conductivity drives species sorting metacommunity dynamics across a landscape that has minimal spatial structure,

resulting in a predictable relationship between assemblages and conductivity that is ecologically robust (Michelson et al., 2016). The low spatial autocorrelation of high-conductivity lakes, clustered on the island's eastern shore, does not seem to influence ecological dynamics as halophilic species reach high abundance in these lakes and any spatial factors that influence assemblages appear to be related to species sorting by conductivity rather than ecological factors like dispersal or range expansion that could produce spatial clustering (Michelson et al., 2016). Additionally, MFSO avoids overfitting the relationship between ostracode assemblages and the measured environmental variables, since after a variable has entered the model, only the residuals are used to fit the model. In this way, the correlation of environmental variables themselves will not bias the ordination results.

5. Conclusions

A transfer function for conductivity with reasonable predictive ability was developed using ostracodes on San Salvador Island, Bahamas, further demonstrating their ability to produce records of past environments. This model would be improved by further sampling of lakes and estimation of seasonal variation in conductivity in all lakes.

Changes in the conductivity of lakes on San Salvador were broadly synchronous and related to climate change, with times of increased conductivity corresponding to times of strong El Niño events when there are fewer hurricanes providing freshwater input to these lakes. Thus, variation in the strength of El Niño events exerts a strong influence on the aridity of the climate of the Bahamas.

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8. Figure Captions

Figure 1- San Salvador Island, Bahamas. Each pie chart indicates a lake sampled for ostracode assemblages and environmental variables, pie charts represent electrical conductivity, scaled according to the highest conductivity sample, Salt Pond (electrical conductivity: 124.7 mS/cm). Lakes labeled in **bold** were also cored for sedimentary archives.

Figure 2. Ordinations. A: Results of multivariate fuzzy set ordination (MFSO). Effect sizes of correlation between environmental factors and ostracode assemblages are plotted as a bar chart with *p*-values above. Conductivity, dissolved oxygen (DO) and alkalinity were the only environmental factors out of 19 measured that significantly correlate with ostracode assemblages. The y-axis is the incremental increase in Pearson's correlation (*r*) between the Bray-Curtis dissimilarity matrix of species assemblages and the indicated environmental factor resulting from its addition to a forward selection model. The final, 3-variable model correlates strongly ($r = 0.83$, $p = 0.001$, $n = 32$) to changes in species assemblages. B: 2-dimensional non-metric multidimensional scaling plot of all 32 ostracode assemblages and all 11 species collected on the Bray-Curtis dissimilarity matrix. Stress is 13.5%. Numbers represent assemblages ranked from 1-32 according to the measured conductivity in the lake which they were sampled from. Low ranks correspond to low-ranked conductivity. Two-letter combinations represent species. Keys to species abbreviations are listed in Table 1. Keys to lakes from which assemblages were sampled are listed in Electronic Supplementary Table 2. The correlations of both axes to those environmental factors that influence community assembly as revealed by multiple fuzzy set

ordination (MFSO) with forward selection of variables, Conductivity (marked “Cond.”), dissolved oxygen (marked “DO”), and alkalinity (marked “Alk.”) are overlain arrows.

Figure 3- A: Relationship between measured and inferred conductivity using a two-component weighted averaging partial least squares (WA-PLS) regression and calibration model. Line displays 1:1 relationship. B: Residuals against measured conductivity. Line represents 1:1 relationship between measured and inferred conductivity.

Figure 4- Age-depth model for Clear Pond (A) and North Storrs (B). Age models were developed using BACON (Blaauw and Christen, 2011).

Figure 5- Changing abundances of ostracode species through time and paleoconductivity inferred from those assemblages in Clear Pond (A) and North Storrs (B) plotted according to BACON age models derived for each core. Gaps in the North Storrs core represent depths at which no adult ostracode valves were recovered. The total number of adult valves sampled at each stratigraphic layer is plotted to the right of the conductivity records. In the North Storrs core (5B), from 4,520 to 4,331 cal yr B.P., the total adult valves exceed the horizontal scale, varying between 62 valves at 4,520 and reaching a maximum of 169 valves at 4,412 cal yr B.P. The Bray-Curtis distance of each subfossil assemblage to its nearest analogue assemblage in the calibration dataset is plotted to the right of total adult valves. The 95th (dashed line) and 90th (dashed and dotted line) percentiles of Bray-Curtis distance from each modern assemblage to its most similar

modern assemblage is plotted. Subfossil assemblages with a lower distance than the 95th percentile have good modern analogues, while subfossil assemblages with a higher distance than the 90th percentile lack a good modern analogue.

Figure 6- Results of ostracode-based transfer function for conductivity as applied to Clear Pond (A) and North Storrs (B) cores. Also plotted for each core are percent organic matter and percent carbonate content by weight and percent sand by volume. Gaps in the North Storrs core represent depths at which no adult ostracode valves were recovered. Grey bars highlight anti-phase relationship between conductivity and % sand; when peaks in sand due to hurricane strikes correspond to times of lowered conductivity.

Figure 7- Conductivity records, potassium deposition, and an independently-derived record of ENSO from Moy et al. (2002) in Clear Pond (A) and North Storrs (B) cores plotted according to the age models derived for each core. Gaps in the record represent depths at which no ostracode or no adult ostracode valves were recovered. Grey bars represent times elevated conductivity and potassium deposition coincident with time of stronger El Niño events. Strong ENSO activity inhibits hurricane formation in the Atlantic basin and results in greater dust deposition in the Bahamas.

Figure 1

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Figure 2

A

B

Figure 3

Figure 4

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A Clear Pond

B North Storrs

Figure 5

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A Clear Pond

B North Storrs

Figure 6

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A Clear Pond

B North Storrs

Figure 7

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Table 1. Species list of the ostracodes from this study. Species abbreviations used in Figure 2 are shown in parenthesis following each species name. The number of lakes that contained each species is shown (occurrences).

Podocopida		
Podocopina		
Bairdiidae		<u>Occurrences</u>
<i>Paranesidea harpago</i> Kornicker, 1961 (PH)		5
Candonidae		
<i>Paracypria inopinata</i> Klie, 1939 (PI)		18
Cyprididae		
<i>Physocypria denticulata</i> Daday, 1905 (PD)		2
Cytherellidae		
<i>Cytherella arostrata</i> Kornicker, 1963 (CyA)		4
Cytherideidae		
<i>Cyprideis americana</i> Sharpe, 1909 (CA)		31
<i>Peratocytheridea setipunctata</i> (Brady, 1867-1872) Hazel, 1983 (PS)		20
<i>Perissocytheridea bicelliforma</i> Swain, 1955 (PB)		23
Hemicytheridae		
<i>Aurila floridana</i> Benson and Coleman, 1963 (AF)		7
Loxoconchida		
<i>Loxoconcha pursubrhomboidea</i> Edwards, 1944 (LP)		10
Trachyleberididae		
<i>Climacoidea (Reticulocythereis) multicarinata</i> (Swain, 1955) Hazel & Cronin, 1988 (CM)		13
Xestoleberideidae		
<i>Xestoleberis curassavica</i> Klie, 1939 (XC)		14

Taxonomy based on Brandão (2014).

Table 2. Conductivity optima and tolerances for all species.

Species	Optimum (mS/cm)	Tolerance (mS/cm)
<i>Physocypria denticulata</i>	17.64	2.7
<i>Peratocytheridea setipunctata</i>	39.53	46
<i>Cytherella arostrata</i>	52.5	0.11
<i>Paracypria inopinata</i>	54.09	13.79
<i>Paranesidea harpago</i>	55.21	2.68
<i>Climacoidea (Reticulocythereis) multicarinata</i>	55.47	10.1
<i>Perissocytheridea bicelliforma</i>	55.38	59
<i>Xestoleberis curassavica</i>	56.49	9.97
<i>Loxoconcha pursubrhomboidea</i>	57.69	9.46
<i>Cyprideis americana</i>	58.26	189.2
<i>Aurila floridana</i>	62.68	6.81

Niche modeling determined by Gaussian logistic regression according to ter Braak and Looman (1986).

Table 3. Performance of apparent and cross-validated statistics of the conductivity transfer function.

Model type	WA-PLS
No. of PLS components	2
Apparent	
r^2_{apparent}	0.76
RMSE (mS/cm)	12.24
Ave. bias (mS/cm)	-0.0007
Max. bias (mS/cm)	25.25
Cross-validation jack-knifing	
$r^2_{\text{jack-knifed}}$	0.68
RMSEP (mS/cm)	14.47
Ave. bias (mS/cm)	-0.06
Max. bias (mS/cm)	28.11

“WA-PLS” indicates weighted averaging partial least squares regression, while “RMSE(P)” indicates root mean square error (of prediction).

97 Table 4. Results of radiocarbon dating for both cores.

Core	Depth (cm)	Uncalibrated BP $\pm 2\sigma$	$\delta^{13}\text{C}$	Lab code	Source
Clear Pond	20	1250 $\pm$ 40	-26.0	Beta 262899	Park (2012)
	49.5	1850 $\pm$ 40	N.A.	Beta 262900	Park (2012)
	61.3	2640 $\pm$ 120		Livermore N104011	This study
	79	3350 $\pm$ 40	-17.7	Beta 262901	Park (2012)
	83.8	3590 $\pm$ 150		Livermore N104007	This study
	92.2	3330 $\pm$ 70		Livermore N104008	This study
North Storrs	14.4	460 $\pm$ 180		Livermore N104016	This study
	22.5	430 $\pm$ 100		Livermore N104018	This study
	116.3	2950 $\pm$ 120		Livermore N104022	This study
	120	3780 $\pm$ 40	-26.1	Beta 221314	This study
	139.7	4030 $\pm$ 90		Livermore N104023	This study
	147.7	4270 $\pm$ 190		Livermore N104019	This study

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99 All dates reported are uncalibrated. BACON (Blaauw and Christen, 2011) was used to calibrate
100 the radiocarbon dates and construct age models. $\delta^{13}\text{C}$ for dates from Park (2012) are indicated;
101 these samples were tested at Beta Analytical. All other dates were analyzed with an assumed
102 $\delta^{13}\text{C}$ of -25 according to Stuiver and Polach (1977) at Lawrence Livermore National Laboratory.
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105 Electronic Supplementary Table 1- Geographical, limnological, and ostracode data from all
 106 lakes.

Lake	Latitude (°N)	Longitude (°W)	Lake Area (m ²)	Depth (cm)	Dissolved Oxygen (mg/L)
Bamboo Pond	24.045948	74.53048	38654.166	62	1.9
Blue Hole Five	23.96387	74.54559	1048.195	162	10.7
Central Storrs Lake	24.03918	74.44985	684959.67	26	8.2
Clear Pond	23.97319	74.54771	117468.26	62	5.8
Columbus Landing Blue Hole	23.95953	74.54795	668.641	160	8.5
Crescent Pond	24.11323	74.45668	33824.696	66	5.2
Flamingo Pond	24.06982	74.51022	1010170.2	150	7.23
French Pond	23.95360	74.53937	51446.581	2	6.5
Granny Lake	24.043638	74.48653	3184901.9	70	6.88
Great Lake	24.041552	74.51141	13722846	136	4.2
Little Lake	24.04959	74.51705	1841919	102	8.8
Little Salt Pond	24.02062	74.45216	14623.536	5.08	7.77
Long Lake	24.04650	74.49813	4574281.9	88	5.6
Mermaid Pond	23.96502	74.51473	147394.72	97.536	5.3
Moon Rock Pond	24.11035	74.45875	14283.091	64	5.9
Nasty Pond	23.97434	74.49898	15387.39	2	12.8
New Blue Hole	23.959888	74.53728	176.313	98	5.8
No Name Pond	24.01164	74.46019	6800.179	2	12.6
North Storrs Lake	24.05496	74.45245	2568598.7	26	9.5
Osprey Lake	24.11082	74.46432	89936.72	68	4.8
Oyster Pond	24.10925	74.46239	78825.952	96	5.6
Pain Pond	24.11190	74.45680	5728.046	72	6.7
Peel Pond	23.97742	74.49899	9971.38	34	6.7
Plantation Pond	24.03353	74.45786	20758.71	82	6.8
Reckley Hill Pond	24.11469	74.45934	104959.47	78	6.5
Salt Pond	24.02339	74.45161	43155.125	24	2.45
Six Pack Pond	24.052494	74.48767	837466.27	100	3.11
South Storrs Lake	24.02962	74.45013	171239.92	22	6.5
Stouts Lake	23.985504	74.49688	2212710.1	74	6.4
Triangle Pond	24.10415	74.51638	265312.84	24	12.8
Watlings Blue Hole	23.95381	74.55013	3692.672	20	12
Wild Dilly Pond	24.10980	74.46056	7977.104	60	5.7

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Lake	Conductivity (mS/cm)	Water Temperature (°C)	Alkalinity (mg/L)	Total Fe (mg/L)	Mn (mg/L)
Bamboo Pond	4.94	30.1	373	0.006	0.08
Blue Hole Five	30.7	33.5	233.2	0.006	0.019
Central Storrs Lake	75.6	28.7	190	0.160	0.010
Clear Pond	50.2	34.8	274.4	0.054	0.020
Columbus Landing Blue Hole	32.1	32.4	240	0.032	0.007
Crescent Pond	49.6	27.5	166	0.055	0.041
Flamingo Pond	62	32.2	150	0.006	0.000
French Pond	75	36	56	0.234	0.037
Granny Lake	59.9	31.86	132	0.006	0.000
Great Lake	58.9	31.8	105	0.006	0.000
Little Lake	54.7	31.1	192	0.124	0.018
Little Salt Pond	118.6	26	172	0.006	0.030
Long Lake	61.1	28.6	115	0.006	0.000
Mermaid Pond	46.6	23.1	208	0.006	0.000
Moon Rock Pond	52.8	30.1	160	0.119	0.019
Nasty Pond	55.1	35.3	260	0.253	0.079
New Blue Hole	30.8	31	298.4	0.006	0.000
No Name Pond	118.3	35	300	0.484	0.162
North Storrs Lake	77	32.9	170	0.193	0.038
Osprey Lake	73.2	32	140	0.207	0.022
Oyster Pond	53.7	31.8	160	0.101	0.004
Pain Pond	52.2	29.2	166	0.121	0.013
Peel Pond	25.8	32.3	123	0.650	0.060
Plantation Pond	53.1	35.1	220	0.058	0.020
Reckley Hill Pond	67	30.4	148	0.177	0.027
Salt Pond	124.7	28.7	180	0.644	0.116
Six Pack Pond	43.9	30.86	120	0.006	0.000
South Storrs Lake	152.2	29.8	196	0.354	0.074
Stouts Lake	55.4	33.5	144	0.006	0.000
Triangle Pond	90	35.8	184	0.267	0.048
Watlings Blue Hole	34.5	32.6	290	0.060	0.006
Wild Dilly Pond	52.2	29.5	188	0.037	0.020

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Lake	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Sr (mg/L)
Bamboo Pond	11080	432	381.5	1029.0	13.6
Blue Hole Five	5881	305.8	252.1	697.2	14.6
Central Storrs Lake	14590	696.3	537.5	1930.0	22.4
Clear Pond	10290	505.6	365.7	1261.0	14.3
Columbus Landing Blue Hole	6422	320.7	239.2	747.8	12.6
Crescent Pond	10800	508.7	275.8	1326.0	17.3
Flamingo Pond	22700	721.0	898.5	2761.0	28.3
French Pond	15110	744.3	667.8	1872.0	58.2
Granny Lake	19170	625.0	596.8	1709.0	41.9
Great Lake	20780	772.0	603.3	2051.0	20.0
Little Lake	10130	532	389.3	1392.0	16.5
Little Salt Pond	83250	4093	1068.0	5261.0	60.4
Long Lake	17250	571	630.1	2104.0	20.8
Mermaid Pond	10760	317	381.6	1225.0	13.1
Moon Rock Pond	10560	509	368.4	1319.0	15.8
Nasty Pond	11250	528.5	480.3	1414.0	21.2
New Blue Hole	7465	200.0	230.7	577.3	8.1
No Name Pond	31370	1057	1017	3909.0	36.7
North Storrs Lake	15150	742.8	616.2	2048.0	24.4
Osprey Lake	14890	733.2	536.0	1989.0	19.1
Oyster Pond	11030	522.3	383.7	1373.0	16.4
Pain Pond	14840	732.6	559.7	1965.0	18.6
Peel Pond	90360	3911.0	1536.0	4682.0	50.9
Plantation Pond	10830	549.6	410.0	1358.0	14.7
Reckley Hill Pond	13690	656.5	479.7	1756.0	19.7
Salt Pond	24960	1174	1978	3835.0	53.2
Six Pack Pond	15970	471	381.2	1128.0	17.5
South Storrs Lake	39200	1350	2184.0	4925.0	51.5
Stouts Lake	35570	1506	432	1424.0	12.2
Triangle Pond	18660	883.1	601.2	2690.0	17.0
Watlings Blue Hole	6311	333.8	251.2	782.0	11.7
Wild Dilly Pond	10510	504.8	381.8	1316.0	17.6

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Lake	Cl (mg/L)	SO ₄ (mg/L)	Mean Grain Size (µm)
Bamboo Pond	17060	2430	25.622136
Blue Hole Five	9010	1302	189.23477
Central Storrs Lake	27140	3737	149.48356
Clear Pond	17660	2470	141.62195
Columbus Landing Blue Hole	11070	1419	179.17626
Crescent Pond	17400	2555	38.792055
Flamingo Pond	38260	4680	103.13339
French Pond	28730	3259	40.278019
Granny Lake	32510	4270	102.5714
Great Lake	35640	4430	230.5701
Little Lake	17980	2773	180.97129
Little Salt Pond	175690	14930	37.579387
Long Lake	29970	4020	129.96871
Mermaid Pond	16860	2290	107.5088
Moon Rock Pond	17240	2586	28.965886
Nasty Pond	18970	2742	90.485074
New Blue Hole	11400	1710	125.35573
No Name Pond	53910	6590	56.055472
North Storrs Lake	28900	3997	142.47506
Osprey Lake	28390	3912	197.89986
Oyster Pond	18580	2767	199.99145
Pain Pond	27730	3852	87.727795
Peel Pond	180020	17450	38.312305
Plantation Pond	18710	2730	93.721647
Reckley Hill Pond	24220	3481	124.71989
Salt Pond	58100	7780	178.81881
Six Pack Pond	25210	3350	189.90664
South Storrs Lake	72325	10000	75.632343
Stouts Lake	65020	7600	111.86344
Triangle Pond	37760	5162	90.79782
Watlings Blue Hole	4270	1497	57.229201
Wild Dilly Pond	17840	2476	176.71285

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Lake	<i>Cyprideis</i> <i>9enticula</i> (percent abundance)	<i>Perissocytheridea</i> <i>bicelliforma</i> (percent abundance)	<i>Peratocytheridea</i> <i>setipunctata</i> (percent abundance)	<i>Paracypria</i> <i>inopinata</i> (percent abundance)
Bamboo Pond	0.07100592	0.21893491	0	0
Blue Hole Five	0.44303797	0.00843882	0.48101266	0.06751055
Central Storrs Lake	1	0	0	0
Clear Pond	0.38526912	0.04249292	0.38243626	0.12181303
Columbus Landing Blue Hole	0.07492795	0	0.92507205	0
Crescent Pond	0.52173913	0	0	0.47826087
Flamingo Pond	0.87346939	0	0	0.11836735
French Pond	0.67553191	0.32446809	0	0
Granny Lake	0.46	0	0.03	0.13
Great Lake	0.13091922	0.01671309	0.14763231	0.32311978
Little Lake	0.07344633	0.02542373	0.24858757	0.34463277
Little Salt Pond	0.02845528	0.97154472	0	0
Long Lake	0.14095745	0.0106383	0.38031915	0.12765957
Mermaid Pond	0.13937282	0.00696864	0.38327526	0.07317073
Moon Rock Pond	0	0	0.26862745	0
Nasty Pond	0.86891386	0.13108614	0	0
New Blue Hole	0.56716418	0.04776119	0.3761194	0
No Name Pond	0.33596838	0.65612648	0.00790514	0
North Storrs Lake	0.9893617	0.0106383	0	0
Osprey Lake	0.16666667	0.00888889	0.31777778	0.09777778
Oyster Pond	0.03429355	0.00274348	0.8079561	0.04389575
Pain Pond	0.34013605	0.10204082	0.3537415	0.07482993
Peel Pond	0.74056604	0.25943396	0	0
Plantation Pond	0.58333333	0.17777778	0.23333333	0.00555556
Reckley Hill Pond	0.73333333	0.04888889	0.16888889	0.04888889
Salt Pond	0.08906883	0.91093117	0	0
Six Pack Pond	0.27884615	0.04487179	0.21474359	0.1025641
South Storrs Lake	1	0	0	0
Stouts Lake	0.04233871	0	0.27016129	0.08064516
Triangle Pond	0.90977444	0.09022556	0	0
Watlings Blue Hole	0.16395664	0.00271003	0.83197832	0.00135501
Wild Dilly Pond	0.17256637	0	0.19911504	0.07079646

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Lake	<i>Climacoidea</i> (<i>Reticulocythereis</i>) <i>multicarinata</i> (percent abundance)	<i>Cytherella</i> <i>arostrata</i> (percent abundance)	<i>Loxoconcha</i> <i>pursubrhomboidea</i> (percent abundance)	<i>Xestoleberis</i> <i>curassavica</i> (percent abundance)
Bamboo Pond	0	0	0	0
Blue Hole Five	0	0	0	0
Central Storrs Lake	0	0	0	0
Clear Pond	0.05949008	0	0	0.00849858
Columbus Landing Blue Hole	0	0	0	0
Crescent Pond	0	0	0	0
Flamingo Pond	0	0	0	0.00816327
French Pond	0	0	0	0
Granny Lake	0.035	0	0	0.305
Great Lake	0.00835655	0	0.01114206	0.33147632
Little Lake	0.02259887	0	0.01694915	0.23446328
Little Salt Pond	0	0	0	0
Long Lake	0.0212766	0	0.01595745	0.2393617
Mermaid Pond	0.05226481	0	0.10452962	0.24041812
Moon Rock Pond	0.0372549	0.01960784	0.02745098	0.11176471
Nasty Pond	0	0	0	0
New Blue Hole	0	0	0	0
No Name Pond	0	0	0	0
North Storrs Lake	0	0	0	0
Osprey Lake	0.07555556	0	0.03333333	0.23777778
Oyster Pond	0.01097394	0.00274348	0.06858711	0.01097394
Pain Pond	0.06802721	0.01360544	0.03401361	0.01360544
Peel Pond	0	0	0	0
Plantation Pond	0	0	0	0
Reckley Hill Pond	0	0	0	0
Salt Pond	0	0	0	0
Six Pack Pond	0.07692308	0	0	0.28205128
South Storrs Lake	0	0	0	0
Stouts Lake	0.03024194	0	0.3891129	0.14717742
Triangle Pond	0	0	0	0
Watlings Blue Hole	0	0	0	0
Wild Dilly Pond	0.1460177	0.01327434	0.38053097	0.00884956

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Lake	<i>Aurila floridana</i> (percent abundance)	<i>Paranesidea harpago</i> (percent abundance)	<i>Physocypria lenticulate</i> (percent abundance)
Bamboo Pond	0	0	0.71005917
Blue Hole Five	0	0	0
Central Storrs Lake	0	0	0
Clear Pond	0	0	0
Columbus Landing Blue Hole	0	0	0
Crescent Pond	0	0	0
Flamingo Pond	0	0	0
French Pond	0	0	0
Granny Lake	0.04	0	0
Great Lake	0.01949861	0.01114206	0
Little Lake	0.02824859	0.00564972	0
Little Salt Pond	0	0	0
Long Lake	0.06382979	0	0
Mermaid Pond	0	0	0
Moon Rock Pond	0.51960784	0.01176471	0
Nasty Pond	0	0	0
New Blue Hole	0	0	0.00895522
No Name Pond	0	0	0
North Storrs Lake	0	0	0
Osprey Lake	0.06222222	0	0
Oyster Pond	0	0.01783265	0
Pain Pond	0	0	0
Peel Pond	0	0	0
Plantation Pond	0	0	0
Reckley Hill Pond	0	0	0
Salt Pond	0	0	0
Six Pack Pond	0	0	0
South Storrs Lake	0	0	0
Stouts Lake	0.04032258	0	0
Triangle Pond	0	0	0
Watlings Blue Hole	0	0	0
Wild Dilly Pond	0	0.00884956	0

140 Electronic Supplementary Table 2- Key to assemblage labels in Figure 2.

Lake	Conductivity (mS/cm)	Label in Fig. 2
Bamboo Pond	4.94	1
Blue Hole #5	30.7	2
New Blue Hole	30.8	3
Columbus Landing Blue Hole	32.1	4
Watlings Blue Hole	34.5	5
Peel	42.8	6
Six Pack	43.9	7
Mermaid Pond	46.6	8
Crescent Pond	49.6	9
Clear Pond	50.2	10
Pain Pond	52.2	11
Wild Dilly Pond	52.2	12
Moon Rock Pond	52.8	13
Plantation Pond	53.1	14
Oyster Pond	53.7	15
Little Lake	54.7	16
Nasty Pond	55.1	17
Stouts	55.4	18
Great Lake	58.9	19
Granny	59.9	20
South Storr's	60.4	21
Long Lake	61.1	22
Flamingo	62	23
Reckley Hill Pond	67	24
Osprey Lake	73.2	25
French Pond	75	26
Central Storr's	75.6	27
North Storr's	77	28
Triangle Pond	90	29
No Name	118.3	30
Little Salt Pond	118.6	31
Salt Pond	124.7	32

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