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Cover photo: *Diploria strigosa*, the common brain coral, preserved in growth position at the Cockburn Town fossil coral reef site (Sangamon age) on San Salvador Island. Photo by Al Curran.

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HOLOCENE ENVIRONMENTAL CHANGES IN THE INTERIOR KARST REGION OF SAN SALVADOR, BAHAMAS: THE GRANNY LAKE POLLEN RECORD

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ABSTRACT

Preliminary palynological investigation of sediments from Granny Lake provide evidence for reconstructing Holocene environment and climate for the interior karst region of San Salvador Island, Bahamas. These investigations affirm that palynological research can be successfully conducted in hypersaline interior Bahamian lakes with calcareous sediments. Although the pollen concentration is generally low, enough pollen is preserved to allow limited interpretations of paleoenvironments based on absolute pollen frequencies.

Palynological and sedimentological data support a Holocene sequence of relative environmental stability for the interior karst regions of San Salvador. Despite the overall pattern of stability, some minor environmental fluctuations have occurred. The most severe of these episodes, radiocarbon dated to 4,950 ± 360 yrs. B.P., indicates a period when the water level of the lake was much lower than at present. This drying episode corresponds to the widespread mid-Holocene warming period, dated between 7,500 and 4,000 yrs. B.P. in other parts of North America. The upper unit of the stratigraphic column indicates an episode of mass wasting, most likely associated with deforestation caused by the introduction of European methods of agriculture to San Salvador. A low frequency of *Pinus* pollen grains in the sediments provides an interesting puzzle, since no pine trees now grow or ever have been documented to grow on San Salvador. The conservative explanation for these grains is long distance wind transport. Mahogany tree pollen grains were not observed. This negative evidence, combined with other data, suggests that the interior karst region has been dominated by a coppice-thicket plant community throughout the Holocene. The mahogany forests documented for San Salvador were probably only a coastal phenomenon.

INTRODUCTION

Palynological methods have not been previously applied to the interior lakes of San Salvador. These lakes range from brackish to hypersaline with abundant bacterial activity and calcareous sediments. Pollen analysts generally avoid investigating samples from calcareous sediments because of low pollen concentrations (Dimbleby, 1985). Fieldwork conducted in July, 1984 attempted to assess the feasibility of applying standard palynological techniques to sediments from an interior San Salvador lake. The following paper presents results of the analysis of two matching cores obtained from Granny Lake. Our interest in San Salvador was sparked by Mylroie's (1983) intriguing suggestion that the major environmental influence during the Holocene has been the activities of humans, especially during the last 500 years. He further argued that European agricultural practices may be responsible for the inland scrub brush cover and the mass wasting of topsoil into the interior lakes. Palynological methods are well-suited to addressing such a hypothesis.

FIELD AND LABORATORY METHODS

Field Setting

Granny Lake, located in the east central portion of San Salvador (see Index Map 2), was chosen for this research for two reasons. First, it meets the requirements necessary for obtaining pollen cores, and second, it is ideally located to sample the plant communities of the interior karst region. This region includes land that was part of earlier loyalist plantations and is currently used for slash and burn agricul-

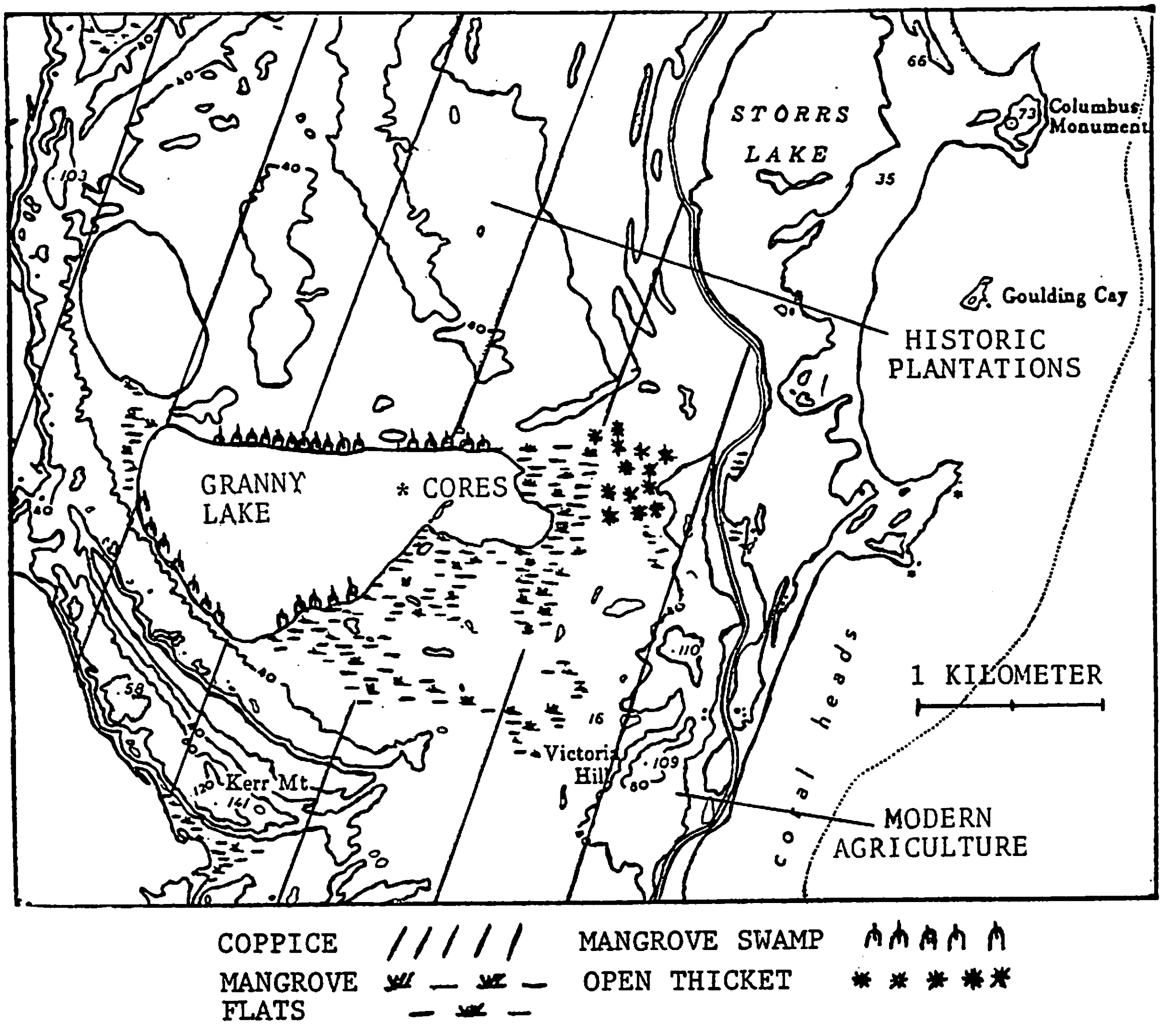

Fig. 1. Grany Lake Basin and surrounding plant communities, San Salvador, Bahamas.

ture. The depositional history, lithology, and geomorphology of the Granny Lake basin has been extensively described elsewhere (Dakoski and Bain, 1984; Florentino and Bain, 1984; Foradas and Pacheco, 1985; Teeter, 1986; Teeter and Thalman, 1984; Thalman, 1983; Thalman and Teeter, 1983 a,b; and Titus, 1984). Modern vegetational communities surrounding Granny Lake have also been described by Smith (1982).

Granny Lake occupies a basin bordered by arcuate and irregular ridges to the north, west, and east (Fig. 1). These ridges are dominated by the blacklands coppice plant community. Maximum water depth is 2.5 meters. To the south is a broad flat area which is affected by annual lake level fluctuations. This area is occupied by a mangrove flat plant community with a wide variety of salt-tolerant grasses and sedges. An open thicket is located on the gently rising land to the east of the lake. Around the edges of the hypersaline lake is a thriving mangrove swamp with a variety of ferns and epiphytes growing among the mangroves. Historic and modern agriculture has been practiced to the northeast and southeast of the lake.

Coring Procedures

A matching pair of 5 centimeter-wide pollen cores were obtained with a modified Livingston piston corer suspended between two rubber rafts. Cores were taken to bedrock (or sufficiently lithified material to prevent further penetration) with a 10 pound slip hammer. The cores were corked in their aluminum casings immediately after extraction, and the 5 centimeters of basal overflow were sealed in sample bags. The cores were taken about 150 meters from the south central side of the lake, maximizing the potential pollen rain from all local plant communities (see Fig. 1).

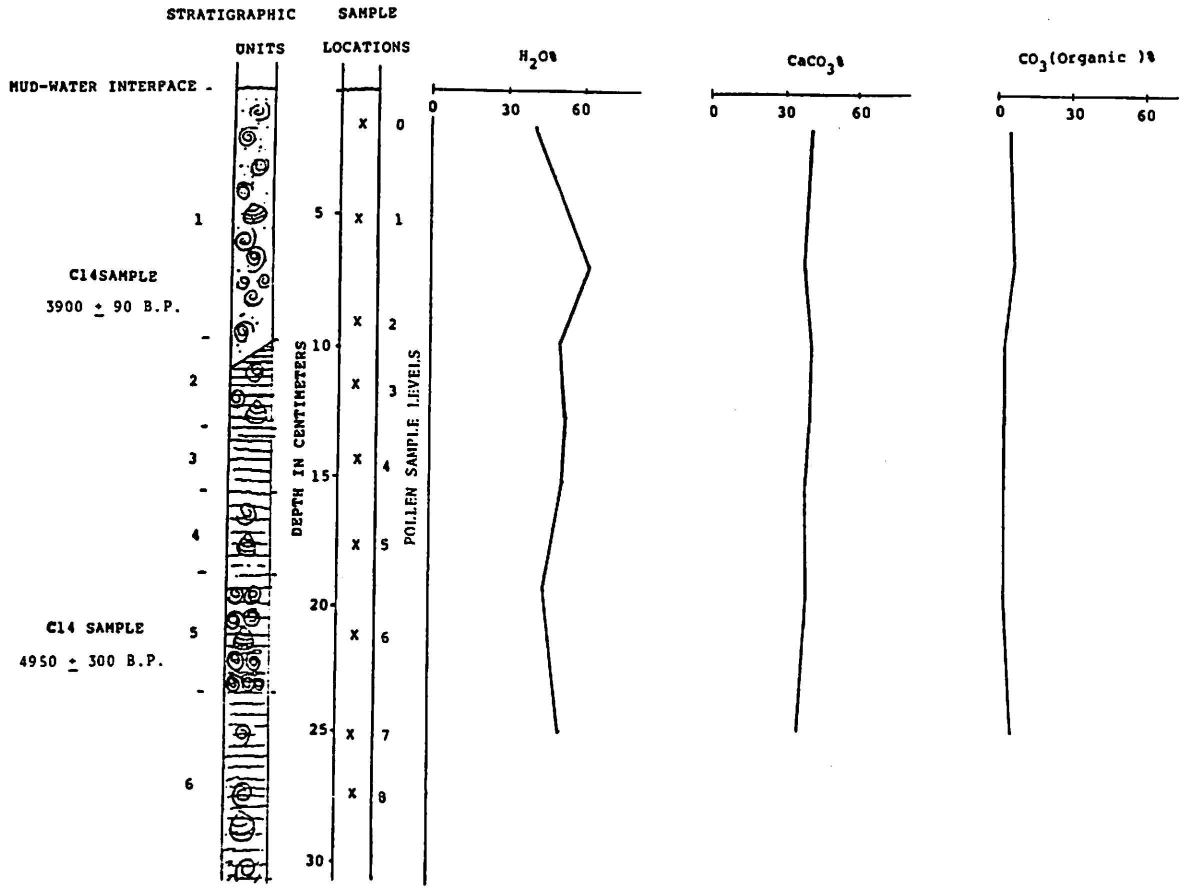

Fig. 2. Stratigraphic sequence and loss-on-ignition results, Core 4, Granny Lake, San Salvador, Bahamas.

Laboratory Procedures

Once in the laboratory, the Granny Lake cores were subjected to four types of analysis: X-ray photogrametry; stratigraphic analysis; loss-on-ignition analysis; and pollen analysis. After X-ray analysis, Core 4 was chosen to be opened, while Core 3 was left sealed for stratigraphic control. Core 4 stratigraphy was described in congruence with the X-ray photographs. Molluscan macrofossils were identified with the aid of the field guide by Morris (1973). Designated stratigraphic units determined the location of pollen and loss-on-ignition samples. Nine samples of 0.5 cc for pollen and seven samples of 1 cc for loss-on-ignition analysis were taken from the locations noted in Figure 2. Loss-on-ignition analysis was performed with the use of a muffle furnace. Pollen samples were processed using standard methods (Faegri and Iverson, 1964), including a spike of exotic *Lycopodium* grains. Fossil pollen grains were identified to various taxonomic levels with the aid of the pollen library and comparative collection of Dr. Paul A. Colinvaux (Department of Zoology, The Ohio State University). The pollen diagram was compiled using the Fortran Universal Pollen Calculation and Plot Program run with Ohio State's IRCC Computer System. Zonation of the pollen diagram followed procedures outlined in Birks and Birks (1980). Further description of methodology is presented in Foradas and Pacheco (1985).

RESULTS AND INTERPRETATIONS

X-Ray and Stratigraphic Analyses

X-ray photogrametry revealed abundant macrofossils and several distinct strata in the 31 centimeters (including basal overflow) of Core 4. Compaction of the core samples has most likely reduced the actual depth of sediment marker layers by some unknown factor. Six units were designated based on

STRATA	DEPTH	COLOR	SEDIMENTS	% MACROFOSSILS
Unit 1	0-10cm	light brownish gray	med.to coarse calcareous muds	(30%) Batillaria m. & pelecypod frags.
Unit 2	10-13	white to light gray	med.soft calc. muds	(25%) Batillaria m. & pelecypod frags.
Unit 3	13-16	white to light gray	fine to med. soft calc. muds	(0%) none observed
Unit 4	16-19	white to light gray	med.soft calc. muds	(25%) Batillaria m. & pelecypod frags.
Unit 5	19-23	light gray	med.to coarse fossiliferous muds	(85%) Batillaria m. few pelecypods
Unit 6	23-31	white to light gray	fine to med. soft calc. muds.	(25%) pelecpod frags. & few Batillaria m.

Table 1. Stratigraphic units designated for Core 4, Granny Lake.

texture, composition, and abundance of molluscan macrofossils. A description of these units is located in Table 1 and they are graphically displayed in Figure 2.

Unit 1 is interpreted as an episode of mass wasting, most likely associated with the introduction of European methods of agriculture to San Salvador. This upper unit is separated from Unit 2 by an erosional or scouring surface, which appeared as a clear parting on the X-rays. Shell material near the parting of Units 1 and 2 was radiocarbon dated to 3,900 ± 90 yrs. B.P. Although this date does not agree with the interpretation of Unit 1, it can be explained by the mass wasting episode carrying older material into the lake, which was subsequently dated. Units 2-4 are basically similar, but are separated by the frequencies of macrofossils in each unit. No macrofossils were observed in Unit 3, suggesting a depositional environment of relatively stable, deeper water. Unit 5 is a shell-rich layer, which based on behavioral observations of the gastropod, *Batillaria minima*, represents a drying episode of some magnitude. A radiocarbon date of 4,950 ± 360 yrs. B.P. was obtained for Unit 5 on shell material given extended counting time to reduce error. The date of this episode corresponds to the mid-Holocene warming period documented for other parts of North America (Knox, 1983). Unit 6 includes the basal overflow from the core and is similar to Unit 4.

Loss-On-Ignition-Analysis

This procedure estimates the percentage by weight of water, organic material, and calcium carbonate in a given volume of sediment. The results of this analysis for seven samples of Core 4 sediments were very consistent from sample to sample. A graph of the percentages observed for each of these contents is also found in Figure 2. All of the sampling levels contained between 40% and 62% water, with a mean percentage of 51%. Solid carbon percentage was very low, ranging between 37% and 40%. Lack of clear differences prevents substantial interpretation of these results, but does demonstrate a consistency in the depositional environment of Granny Lake throughout the Holocene.

Pollen Analysis

The pollen concentration in the samples prepared from Core 4 is generally low, although enough pollen was preserved to make a pollen diagram based on absolute pollen frequencies. At each of the nine pollen levels the 0.5 cc samples provided between three to five slides. All standardized transects were counted on all slides from each level. Statistically valid samples were achieved for all levels except the two from Units 3 and 4. The ratio of *Lycopodium* to fossil pollen in the first pollen level counted was 1 to 17, causing an abandonment of a pollen influx calculation. Without pollen influx data there is no idea of the quantity of pollen making up the local pollen rain. Likewise, the effects of plants with a large or small production of pollen cannot be adjusted. However, since all possible transects were exhausted, there is some idea of pollen concentration per 0.5 cc of sediment. The mean for grains per 0.5 cc is 286, of which about 70% are identifiable at least to family.

Pollen taxa. Granny Lake fossil pollen grains could be identified to various taxonomic levels depending upon several factors such as adequate comparative specimens and uniqueness of grain morphology. The pollen diagram (Fig. 3) is constructed primarily at the family level. Percentage changes in certain taxa over time can be considered indications of environmental and climatic conditions. The pollen diagram is dominated by a few such taxa,

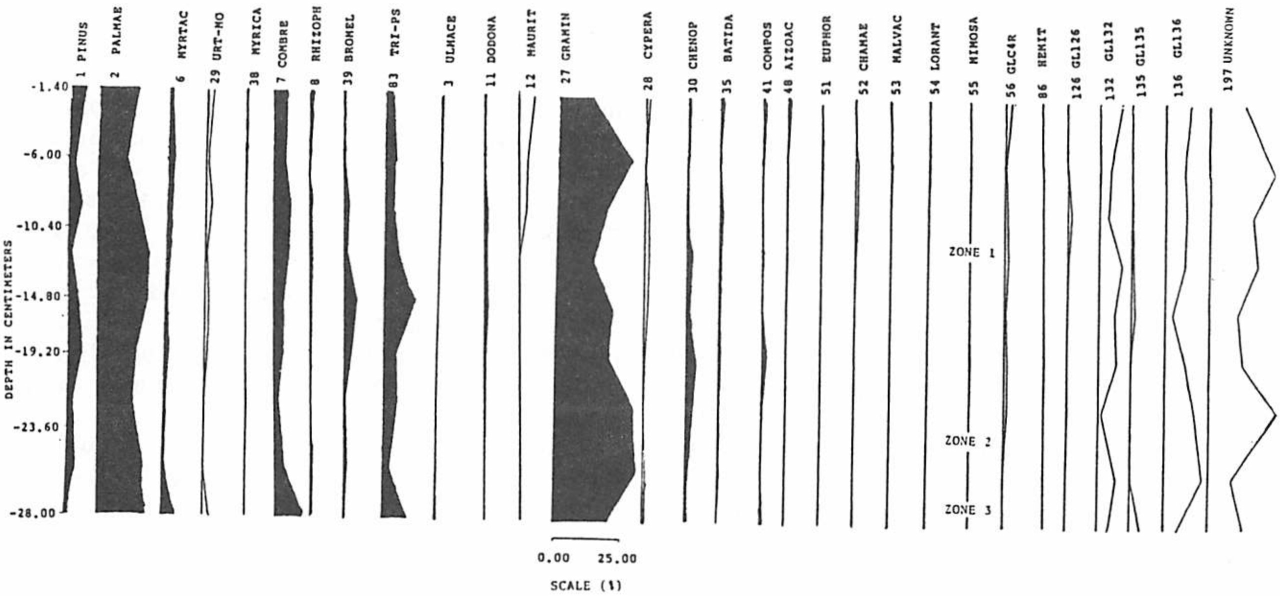

Fig. 3. Pollen diagram for Core 4, Granny Lake, San Salvador, Bahamas.

FIG. 3 CODE		Taxonomic ID	Common Name	Environment
1	Pinus	P. caribaea v. bahamensis	pine	sandy substrates
2	Palmae	Thrinax sp.	thatch palm	coppice & thicket
6	Myrtac	Myrtaceae	myrtle family	coppice & thicket
11	Dodona	Dodonaea	dogwood	coppice & thicket
7	Combre	Conocarpus erectus L.	buttonwood	mangrove swamp
8	Rhizoph	Rhizophora mangle L.	red mangrove	mangrove flats
39	Bromel	Tilandsia sp.	air plants	mangroves & coppi
83	Tri-Ps	Acrostichum aureum L.	giant fern	edge of mangroves
27	Gramin	Graminae	grass family	pioneer, open are
30	Chenop	Salicornia sp.	glasswort	alkaline flats
35	Batid	Batida maritima L.	saltwort	lake margin
41	Compos	Compositae	sunflowers	open areas

Table 2. List of indicator taxa from pollen diagram, Granny Lake.

and these are the focus of interpretations. Table 2 lists indicator taxa, identified taxonomic level, and environmental conditions.

Mahogany pollen was not observed at any level. This unexpected negative result questions the extent of mahogany forests on San Salvador during the Holocene. The fossil pollen spectra indicates that the mangrove and coppice-thicket plant communities presently surrounding Granny Lake have been established throughout the Holocene. The canopy effect of a mahogany forest would have produced a pollen spectra much different than what was observed, indicating that the lack of mahogany pollen was not a preservation bias. Since mahogany trees definitely existed on San Salvador during the recent past, one possible conclusion is that they were a coastal phenomenon, occupying an econiche similar to the introduced australian pines near Cockburn Town. The limb material from Reckley's Hill Pond (Kwolek, 1984) and the massive rhizocretions of Hale (this volume) both come from near coastal environments, supporting a coastal econiche for mahogany.

Tree pollen that does appear in the Granny Lake pollen record is that of pine. No pine trees now grow or ever have been recorded to grow on San Salvador. Authorities on Bahamian flora, Corell and Correll (1982), have noted that the peculiar distribution of native Bahamian pines is a most baffling problem. Pines flourish on Abaco, Andros, Grand Bahama, and New Providence, but then are totally absent on all other islands except the far southern Caicos. No explanation exists for this peculiar pattern, and it is unlikely that the pine pollen from Granny Lake sediments provides an answer. Pine is a notorious long distance traveller (Birks and Birks, 1980), each grain being equipped with dual air sacs that can carry the grain for hundreds of kilometers when launched into the wind. The low and consistent frequency of pine grains in the pollen samples suggests long distance wind transport, which is a more parsimonious explanation than a San Salvador pine forest. Pine was not observed in Unit 6, providing a possible minimum date for the colonization of pine in the Bahamas of about 5,000 years. Palynological data from south-central Florida (Watts, 1975; 1980) indicates that pine does not become a prominent part of the pollen spectra in Florida until after 5,000 yrs. B.P., correlating with the Granny Lake data.

Pollen zones. The pollen diagram can be subdivided into three zones, or environmental and climatic periods (Fig. 3). Zone 1 corresponds to pollen levels taken from Units 1-4 and dates from sometime after 5,000 yrs. B.P. to present. This zone is characterized by fluctuations in the percentages of indicator taxa. Another characteristic of this zone, which is not reflected in the pollen diagram, is a high frequency of immature clusters of grass grains of the family Graminae. These clusters are pieces of anthers that have fallen off the plants as compact units. This phenomenon is interpreted as evidence for annual lake level fluctuations and seasonal violent storms. The flat area south of the lake is easily inundated by rising lake levels. Grass anthers that have not matured would be drowned and included in the pollen assemblage.

The data supports the establishment of modern conditions sometime after 5,000 yrs. B.P., correlating to the stabilization of rising sea levels (Mylroie, 1983). Fluctuations in the percentages of wet and dry taxa represent the seasonality effects of several successive wet or dry years. The plant communities surrounding the lake are generally resilient to these moisture changes. In wet years, the lake level is high and the southern flats are inundated. These periods have less grass and more mangrove community plants. In opposition, dry years show an increase in grass pollen because the flats are open to colonization. Thatch palms of the coppice and thicket mirror these changes in climatic conditions, with increased moisture increasing the percentage of palms.

Zone 1 covers the period of human impact to the environment from agriculture and lumbering. No important effects of this impact are evident in the pollen record. The mangrove and coppice thicket plant communities were not seriously impacted by human activities, possibly because activity in the interior was minimal. Clear-cutting, documented by the mass wasting episode of stratigraphic Unit 1, must not have included all parts of the interior, leaving enough of the mangrove and coppice plants to easily recolonize agricultural areas. Since the plantation period was not long-lived, the pollen record from Granny Lake was not altered.

Zone 2 corresponds to Unit 5, which was dated to 5,000 yrs. B.P. The pollen record supports the interpretations of this unit as a drying episode with low lake levels. Grass pollen is at the highest frequency during this period and mangrove community plants are at the lowest frequencies. Immature clusters of grass do not occur during this period, suggesting that the flats were exposed and dry. The modern seasonal rainfall pattern was either not established or did not produce enough moisture to inundate the flats. Independent climatic evidence indicates that the modern meridonal circulation patterns were not in place until after 6,000 yrs. B.P. (Knox, 1983). As mentioned earlier, this period is interpreted as representing the mid-Holocene warming period.

Zone 3 is similar to Zone 1, except that immature grass clusters and pine grains do not occur. Pollen from plants of the myrtle family is at its highest frequency during this zone, perhaps reflecting a change in the species composition of the coppice-thicket community through time. The climate during this period was moist and the lake level was probably fairly stable. A low frequency of grass pollen supports this conclusion.

SUMMARY

Palynological methods have been applied to sediments obtained from Granny Lake, an interior hypersaline lake of San Salvador. Pollen concentration was too low to calculate pollen influx, but adequate to construct a pollen diagram based on absolute pollen frequencies. These research efforts affirm that palynological methods can be applied to interior Bahamian lakes.

An overall picture of relative environmental stability during the Holocene emerges for the Granny Lake basin and the interior karst region of San Salvador. Despite overall stability, stratigraphic and pollen evidence was able to distinguish three climatic zones. Zone 1 represents modern conditions characterized by a seasonal rainfall pattern, and punctuated by violent storms. Human activity during this period was found to have a minimal effect on the mangrove and coppice-thicket plant communities surrounding Granny Lake. Modern plant communities are good analogs for earlier Holocene communities, and the present is not anomalous with respect to the past. Zone 2 is interpreted as a dry period, corresponding to the mid-Holocene warming period in other parts of North America. Shell material from this period was dated to 4,950 ± 360 yrs. B.P., providing a base line date for all three zones. Zone 3 represents a moister period prior to the drying episode, but before modern conditions had become established.

Pine grains within the pollen samples are considered to result from long distance wind transport. A lack of pine in Zone 3 perhaps dates the time of increase of pine in the Bahamas Islands. The lack of mahogany tree pollen suggests that mahogany forests did not occupy the interior karst region during the Holocene. One possible solution to the mahogany problem is the suggestion that mahogany forests were a coastal phenomenon.

The pollen record from Granny Lake is the first record ever for San Salvador, but solid climatic interpretations can never be based on a single record. Further palynological investigations should use Granny Lake as a test case, providing a foundation for future research.

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