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Edited by
James L. Carew

Production Editors
Daniel R. Suchy
Nicole G. Suchy

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Front Cover: View to the SSE on White Cay in Grahams Harbour off the north coast of San Salvador, Bahamas. At this spectacularly scenic site one can see that marine erosion has removed the entire windward portion of these early Holocene eolianites (North Point Member, with an alochem age of ~5000 radiocarbon years B.P.) that were deposited when sea level was at least 2 meters below its present position.

Back Cover: Stephen Jay Gould, keynote speaker for this symposium, holds a *Cerion rodregoi* at the Chicago Herald Tribune's 1891 monument to the landfall of Christopher Colombus, which is located on the windward coast of Crab Cay on the eastern side of San Salvador Island, Bahamas. The monument consists of an obelisk constructed from local limestone which houses a carved rock sphere depicting the globe with the continents. The inscription carved in a marble slab, reads: "On this spot, Christopher Columbus first set foot upon the soil of the New World."

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ANALYSIS OF THE RELATIONSHIP BETWEEN KARST FEATURES AND VEGETATION TYPE ON SAN SALVADOR ISLAND, BAHAMAS

Marna K. Lehnert, John E. Mylroie, and David L. Arnold
Department of Geosciences
Mississippi State University
Mississippi State, MS 39762

ABSTRACT

This study examined the relationship between karst landforms and vegetation type on San Salvador Island, Bahamas. Two island areas were chosen: Line Hole area in the north (recently cultivated) and Hard Bargain area in the center (uncultivated for 50 years). Each area has lowland plains; the Hard Bargain area also has eolianite ridges. Banana holes on the lowland plains and pit caves on the ridges are the dominant karst features. In both areas, quadrats of 100 m^2 were defined, in which both vegetation and karst features were surveyed.

Samples of 72 species were collected from 7 quadrats. Chi-square tests of independence suggest that variation in vegetation between Line Hole and Hard Bargain is a result of succession stage. In addition, in Hard Bargain, vegetation may be dependent on terrain type and presence of karst features, but the results are inconclusive. Analysis by t-test suggests that karst features do not control the size (diameter and height) of the species present.

INTRODUCTION

Scattered observations of biological influences upon weathering and landform development in karst areas have appeared in the literature (Viles, 1988; Folk et al., 1973; Neumann, 1968). Recent work on banana holes (Pace and others, 1993; Harris and others, 1995; Lehnert, 1996) suggest that the role of vegetation is over-stated, however specific studies have confirmed the role of vegetation and biogenic carbon dioxide in increased dissolution rates (Viles, 1988; Smart and Whitaker, 1989).

Vegetation may also be affected by the presence of karst features. For example, deep depressions known as the Sandy Point Pits on San Salvador Island collect water during rain showers. The larger vegetation in the area have roots that extend deep into the pits to obtain fresh water either directly, or as a more efficient means of getting to the water table. This study focused on whether or not karst features have affected the vegetation growth in two study areas on San Salvador Island, Bahamas (Figure 1). Initial studies of

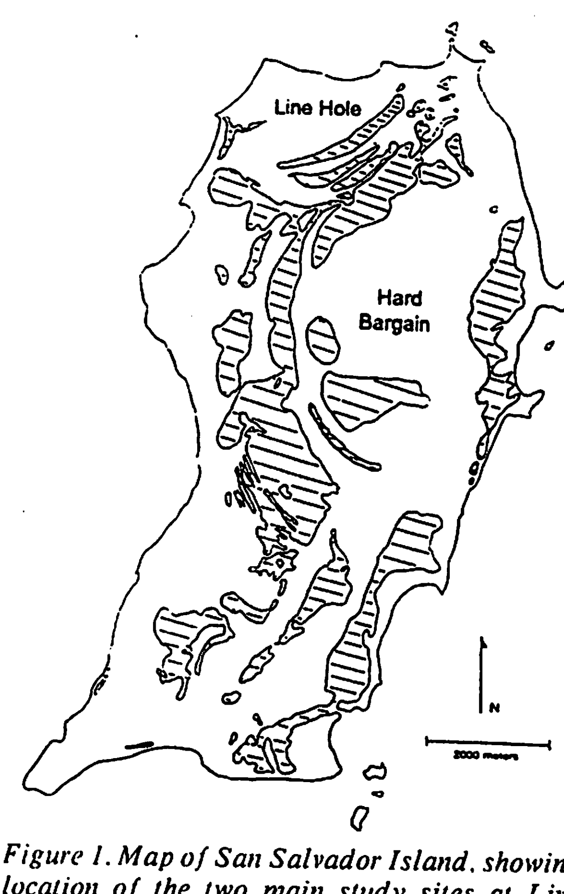

Figure 1. Map of San Salvador Island, showing location of the two main study sites at Line Hole and Hard Bargain.

vegetation began on San Salvador Island early this century (Coker, 1905), and recent research has been accomplished (Correll, 1979; Correll and Correll, 1982; Smith, 1993). This paper is an outgrowth of a MSc thesis written by one of the co-authors (Lehnert, 1996). The reader is referred to Lehnert (1996) for an in-depth analysis of the procedures and results presented herein.

GEOLOGIC SETTING

San Salvador Island is part of the Bahamas. The Bahama Islands are a 1400 km long portion of a NW-SE trending archipelago that extends from Little Bahama Bank off the coast of Florida to Great Inagua Island, just off the coast of Cuba. The exposed rocks of the Bahamas are all Late Quaternary carbonates (<500,000 years in age), dominated by Pleistocene subtidal facies at low elevations, and eolianites at elevations above 6 meters. Paleosols occur at all elevations. The glacio-eustatic sea-level changes of the Quaternary have alternately flooded and exposed the Bahamian platforms, subjecting them to cycles of carbonate deposition and dissolution, respectively (Carew and Mylroie 1995a). The Bahamas are tectonically stable (Carew and Mylroie, 1995b), and the sea-level changes recorded imxBahamian rocks reflect only glacial eustasy and slow isostatic platform subsidence.

The Bahama Islands have landscapes that are dominated by original depositional features, and are only slightly modified by subsequent dissolutional (karst) processes. The high porosity of the limestones that form the islands results in rapid infiltration of meteoric water and the absence of surface streams and related erosional features such as valleys and channels. Surface karst landforms such as sinking streams, blind valleys, and tower karst are absent. The karst features of the Bahamas fall into four main categories: karren, depressions, caves, and blue holes (Mylroie and Carew, 1995). The caves are the karst features of central importance to this study.

The topography of San Salvador Island (Figure 1) has been classified into five main types by Wilson and others (1995): Beach (2.5%), Holocene Rocks (4.5%), Eolianite Dunes (21%), Lakes and Tidal Creeks (22%), and Sangamon Terrace (49%). The Eolianite Dune terrain consists of lithified carbonate sand dunes formed during the late Quaternary. These dunes can reach elevations of up to 40 meters on San Salvador Island. The Sangamon Terrace is a broad lowland plain at +2 to +7 meters elevation made up primarily of subtidal, intertidal and supratidal deposits laid down during the last interglacial sea-level highstand (the Sangamon interglacial of North America) circa 125,000 years ago. This interglacial sea-level highstand reached +6 meters above current sea level.

CAVES

There are three accessible types of dissolution caves in the Bahamas above current sea level: pit caves, flank margin caves, and banana holes (Mylroie and Carew, 1995). The relationships between pit caves, flank margin caves, and banana holes is shown in Figure 2. The fresh-water lens floats on underlying marine ground water, and the fresh-water lens elevation is controlled by sea level position. Flank margin caves and banana holes develop within this lens and are indicators of past sea level position.

Pit caves are formed as a result of dissolution by descending meteoric water collected in the epikarst (Pace et al., 1993; Mylroie and Carew, 1995; Mylroie et al., 1995). Pit caves are vertical shafts that often descend in a stair-step fashion, with occasional small chambers, but they are rarely open all the way to the fresh-water lens. Pit caves have a width to depth ratio less than one. Pit caves are located preferentially on Pleistocene eolianite dunes, and are not found on Holocene rocks.

Flank margin caves are formed in the distal margin of a fresh-water lens located under the flank of an eolianite ridge. At that location fresh water and sea water mix to produce dissolutionally-aggressive brackish water. Flank margin caves are found primarily in pre-Grotto Beach age rocks (Schwabe et al., 1993), and are absent from Holocene rocks. These caves are not present in the study areas on San Salvador.

Banana holes are isolated globular chambers that formed by dissolution at the top of a past fresh-water lens. Those with thin roofs often collapse to produce small depressions that collect soil and provide excellent conditions for growing specialty

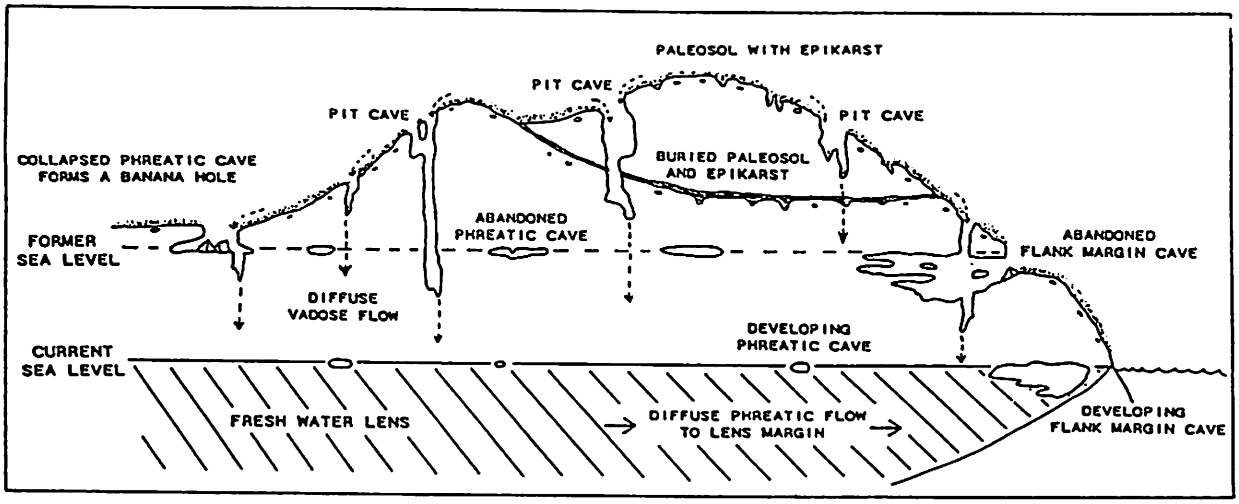

Figure 2. Cross-section of a typical Bahamian island, showing relationship between the land surface, karst features, and sea level.

crops such as bananas, hence the name banana hole, given to them by Bahamians. Banana holes have a width to depth ratio greater than one, and are found primarily on the Sangamon Terrace terrain at elevations of 2-7 m, in a variety of Pleistocene facies such as eolianites and lagoonal deposits. For a more thorough discussion of banana hole development see Harris et al. (1995).

STUDY AREAS

Two studwareas were chosen: Hard Bargain area in the east central portion of San Salvador Island, and Line Hole area in the north (Figure 1). The Hard Bargain area is located within both the Sangamon Terrace and the Eolianite Dune terrains. Banana holes are the predominant karst features within the Sangamon Terrace terrain (hereafter called the terrace terrain), while pit caves are common in the eolianite dune terrain (hereafter called the dune terrain). The Hard Bargain area has not been cultivated at least within the past 50 years. The vegetation in this area has been classified within the Blackland Community, and more specifically the Blacklands (coppice) subcommunity (Smith, 1993).

The Line Hole area is located within terrace terrain and contains banana holes. This area contains no dune terrain. The Line Hole area has undergone slash and burn type cultivation within the last 20 years. The vegetation in this area has been classified within the Blackland Community, and within the Sinkhole, Blacklands (coppice), and Agricultural subcommunities (Smith, 1993).

Five 100 m^2 quadrats were chosen for study in the Hard Bargain area, and two quadrats for the Line Hole area following procedures established by Causton (1988) and Kershaw and Looney (1985). Maps showing all karst features and all vegetation with a trunk diameter of greater than 3 cm were drawn from detailed surveys of the sites. Examples of each type of vegetation were collected and photographed, and descriptions were recorded. Where possible, identification was made in the field; where not, identifications were made in the laboratory. Figures 3 and 4 illustrate how the data were spatially recorded. Table 1 is a summary of the data collected from these seven quadrats, showing collection of 72 different plant species.

The sites were selected to provide a variety of characteristics. Hard Bargain (HB) Site One was selected to represent the terrace terrain without obvious large karst features. HB Sites Two and Three were selected to represent terrace terrain with abundant large karst features, primarily banana holes. HB Site Four was selected to represent dune terrain with large karst features, primarily pit caves. HB Site Five was selected to represent dune terrain without obvious large karst features. Line Hole (LH) Site One was selected to represent terrace terrain with large karst

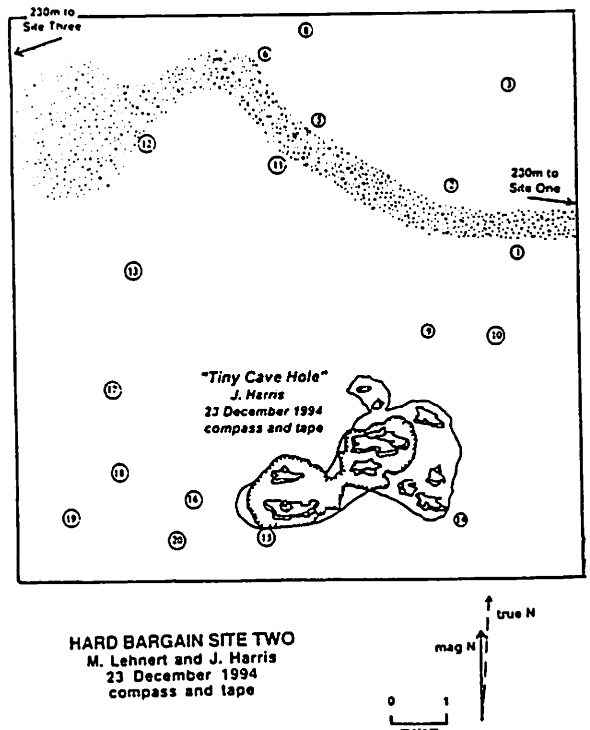

Figure 3. Map of sample location numbers from Hard Bargain Site 2. Each number (in circles) represents a separate plant. Dotted region is the main trail through the area.

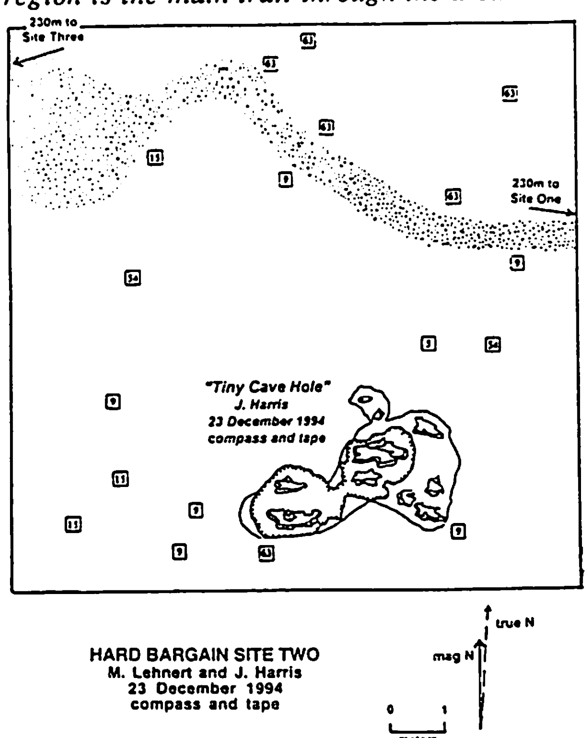

Figure 4. Map of species identification numbers from Hard Bargain Site 2. Each number (in squares) identifies which species is present in what location. Dotted region is the main trail through the area.

features, primarily banana holes. LH Site Two was selected to represent terrace terrain without obvious large karst features.

Hard Bargain Area

Two standard statistical tests were applied to the data collected in the Hard Bargain area: the t-test and the chi-square test of independence. Only two species - Erithalis fruticosa and Metopium toxiferum - were sufficiently abundant in both the non-karst and karst subareas for the t-test (Table 2). The t-test compared the size (heights and diameters) differences of these two species in karst and non-karst subareas. The results indicate that the null hypothesis (i.e. there is no significant difference in vegetation size in areas with karst features versus areas without karst features) cannot be rejected. Thus, it appears that karst features are not an influential factor in the size of these two particular species. It has been suggested (Smart and Whitaker, 1989) that karst features offer access to the water table, in addition to collecting abundant nutrients that would be beneficial to the growth (diameter and height) of vegetation. These results appear to contradict that idea. On the other hand, it is possible that *Erithalis fruticosa* and *Metopium toxiferum* do not require larger amounts of water and nutrients, and thus may not need karst features to aid in collecting nutrients and water necessary for optimal growth.

Three chi-square tests of independence were performed on the data from the HB area, based first on topography, second on karst, and finally a control chi-square test was run. The topography test compared a non-karst subarea in terrace terrain to a non-karst subarea in dune terrain (HB Site 1 versus HB Site 5). The results suggest that for this sample, the distribution of the specified species may be dependent upon terrain type (Table 3). The terrace terrain is at a lower elevation (one to seven meters) than the dune terrain (greater than seven meters), therefore one might expect that the terrace terrain is more likely to have an increased soil moisture and nutrient content than the dune terrain. Moreover, soil erosion is not commonly characteristic of terrace terrain (HB Site 1), but it is common in dune terrain (HB Site 5).

Species ID#	Species Identification	Hard Bergain Site One (Sangamon)	Hard Bergain Site Two (banana hole)	Hard Bergain Site Three (banana hole)	Hard Bergain Site Four (pit cave)	Hard Bergain Site Five (Dune Ridge)	Line Hole Site One (banana hole)	Line Hole Site Two (Sangamon)
1	Cyrilaceae family	0	0	0	1	0	0	0
2	Acacia sp.	5	5	0	3	5	3	0
3	Lauraceae family	0	0	6	0	0	0	0
4	Amyris elemifera	8	11	10	12	15	11	26
5	Rhamnaceae family	0	1	0	0	2	5	16
6	Piscidia sp.	0	0	0	0	0	1	0
7	Lasiacis divaricata	0	2	0	1	1	0	0
8	Drypetes diversifolia	0	0	0	0	0	2	0
9	Erithalis fruticosa	33	30	0	6	6	2	0
10	Psychotria ligustrifolia	96	20	8	3	26	0	0
11	Citharexylum sp.	0	0	0	0	0	0	4
12	Pithecellobium sp.	0	0	0	7	0	0	0
13	Pithecellobium unguis-cati	2	0	0	0	0	0	0
14	Sapotaceae family	0	0	0	0	5	1	3
15	Coccoloba diversifolia	2	12	4	2	11	7	4
16	Psychotria nervosa	0	23	6	3	0	5	4
17	Savia bahamensis	0	0	0	1	0	0	0
18	Lysiloma latisiliquum	0	0	8	0	0	0	0
19	Trichilia sp.	0	0	0	1	0	0	0
20	Eugenia sp.	0	0	27	0	0	0	0
21	Ficus sp.	0	0	2	0	0	0	0
22	Colubrina sp.	0	0	0	0	8	0	5
23	Krugiodendron sp.	0	0	1	0	0	0	0
24	Coccoloba sp.	0	0	0	0	0	7	0
25	Euphorbia lucida	0	10	0	8	0	0	2
26	Byrsonima sp.	0	8	0	1	1	1	8
27	Tabebuia bahamensis	8	1	0	7	0	2	6
28	Picramnia pentandra	0	0	0	0	0	0	35
29	Torrubia sp.	0	3	0	1	0	0	0
30	Eugenia confusa	0	0	0	17	16	0	11
31	Bursera simaruba	9	2	0	2	4	1	1
32	Myrtaceae family	0	0	0	0	0	0	15
33	Phyllanthus epiphyllanthus	0	9	0	0	0	17	0
35	Mimosa bahamensis	0	5	0	0	0	0	0
36	Capparis sp.	0	0	0	0	0	0	6
37	Exostema sp.	7	0	0	0	0	0	0
38	Ficus sp.	0	0	14	0	0	0	0
39	Guettarda sp.	0	0	0	1	0	0	0
40	Maytenus sp.	1	0	0	0	0	0	0
41	Acacia sp.	0	0	18	16	0	0	0
42	Calyptranthes pallens	13	4	0	66	4	42	39
43	Erithalis sp.	0	0	0	0	6	0	0
44	Byrsonima lucida	0	0	0	0	0	0	16
45	Guettarda sp.	0	0	0	1	0	0	0
46	Maytenus sp.	7	0	4	10	0	0	0
47	Exothea sp.	0	10	0	0	5	0	0
48	Guaiacum sanctum	0	13	16	5	0	0	0
49	Anamomis sp.	0	0	0	6	0	0	0
50	Croton sp.	33	0	0	0	0	0	0
51	Myrsinaceae family	0	0	8	0	0	0	0
52	Cordia sebestena	4	3	0	5	4	8	3
53	Hippomane mancinella	0	0	0	0	0	1	0
54	Myrsine floridana	1	15	0	12	10	9	14
55	Lantana sp.	9	0	0	0	0	0	0
56	Gymnathes sp.	0	0	0	0	4	0	0
57	Drypetes sp.	0	0	1	0	0	0	0
58	Nectandra sp.	0	0	0	2	0	0	0
59	Diospyros sp.	0	1	0	0	0	0	0
60	Flacourtiaceae family	1	3	0	2	0	0	2
61	Opalonia sp.	13	15	13	63	32	24	21
62	Annona glabra	1	1	0	5	1	7	8
63	Metopium toxiferum	2	6	6	2	6	5	7
64	Opuntia stricta	1	0	0	0	0	0	0
65	Diospyros sp.	0	0	0	0	0	11	23
66	Bourreria ovata	0	0	0	0	0	8	0
67	Thrinax morrisii	2	7	19	18	17	0	1
68	Jacquinia keyensis	0	0	0	0	28	2	0
69	Schoepfia schreberi	0	0	0	0	0	10	0
70	Ficus citrifolia	0	0	0	0	4	4	0
71	Trichilia sp.	0	0	0	0	0	4	0
72	Sapotaceae family	0	0	0	0	0	1	0
73	Calyptranthes sp.	0	0	0	0	3	0	0
	Totals:	248	220	171	279	224	201	280

Table 1. List of the frequencies of species found in all seven sites and their totals.

Hard Bargain Sites One and Five (non-karst subareas)

	Erithalis fruticosa (ID# 9)	*Metopium toxiferum (ID# 63)*
Number of Observations	10	8
Degrees of Freedom	9	7
Mean Diameters (cm)	5.29	10.188
Standard Deviation	0.597	4.078
Sample Variance	0.357	16.627
Mean Heights (m)	5.2	6.313
Standard Deviation	0.775	0.718
Sample Variance	0.6	0.516

Hard Bargain Sites Two, Three and Four (karst subareas)

	Erithalis fruticosa (ID# 9)	*Metopium toxiferum (ID# 63)*
Number of Observations	12	13
Degrees of Freedom	11	12
Mean Diameters (cm)	5.558	9.954
Standard Deviation	1.516	4.359
Sample Variance	2.297	18.999
Mean Heights (m)	5.025	5.154
Standard Deviation	2.23	1.784
Sample Variance	4.971	3.113

"t" values for comparison of ***diameters:***

Erithalis fruticosa	*Metopium toxiferum*
Observed = 0.542	Observed = 0.121
Critical $_{\alpha=0.05}$ = 2.086	Critical $_{\alpha=0.05}$ = 2.086

"t" values for comparison of ***heights:***

Erithalis fruticosa	*Metopium toxiferum*
Observed = 0.243	Observed = 2.012
Critical $_{\alpha=0.05}$ = 2.086	Critical $_{\alpha=0.05}$ = 2.086

Table 2. Results of the t-test for the Hard Bargain area using the heights and diameters of the two species, Erithalis fruticosa (ID#9) and Metopium toxiferum (ID#63).

The chi-square test of independence of karst for the frequencies of vegetation in the HB non-karst subareas (HB Sites 1 and 5) versus the HB karst subareas (HB Sites 2, 3, and 4) (Table 4). The chi-square values suggest that the distribution of species types may be dependent upon the subarea (karst versus non-karst) in which they are found. This indicates that karst features may be important to the area in which certain species are found. The results of this test differ from the t-test results in that only the frequencies of vegetation were examined, and not their individual characteristics (diameters and heights). Karst features may not contribute to the size of particular species, but they may influence the spatial distribution of species establishment within an area. That is, the amount of water and nutrients that collect in and near karst features may not be sufficient to drastically change the appearance of an already established species, but it may be enough to support the initial stages of development, at least more so than in an area that does not contain these karst features.

The control test compared the only two sites that were within the HB area and terrace and karst subareas (HB Sites 2 and 3) (Table 5). The results suggest that for our sample, the distribution of the species specified may be dependent upon the areas in which they were found. In other words, the two sites should be very similar in regard to the distribution of species because they are both located within the HB area, and terrace and karst subareas, but the results do not appear to support this. As the HB Site 2 versus the HB Site 3 test was designed as a control, and it shows these two karst sites to be different, the data used as a basis for statistics performed to test topographic differences, and karst versus non-karst differences, may not be reliable. In other words, all the plots appear different from each other, and it cannot be said conclusively that those differences are due to topography or karst development. This variation could be the result of having the size of the sample sites (100 m^2) too small to adequately represent the population being tested, or other unknown factors.

Line Hole Area

Only the chi - square test of

Species ID#	Species Identification	Observed Frequencies		Expected Frequencies		Chi-square Statistics	
		Sangamon	Dune Ridge	Sangamon	Dune Ridge	Sangamon	Dune Ridge
2	Acacia sp.	5	5	6.448	3.552	0.32512	0.59017
4	Amyris elemifera	8	15	14.830	8.170	3.14566	5.71005
9	Erithalis fruticosa	33	6	25.147	13.853	2.45257	4.45194
10	Psychotria ligustrifolia	86	26	72.216	39.784	2.63069	4.77563
31	Bursera simaruba	9	4	8.382	4.618	0.04553	0.08264
42	Calyptranthes pallens	13	4	10.961	6.039	0.37914	0.68823
61	Opalonia sp.	13	32	29.015	15.985	8.83993	16.04639
	TOTALS	167	92	167	92	17.81883	32.34506

Degrees of Freedom	6
Chi-square (observed)	50.164
Chi-square (critical)	12.592

Table 3. Results of the chi-square test of independence comparing topography of HB Site 1 (Sangamon terrace terrain) to HB Site 5 (dune ridge terrain).

Non-Karst Subareas (Sites One & Five) vs. Karst Subareas (Sites Two, Three, & Four)

Species ID#	Species Identification	Observed Frequencies: Non-Karst Subareas	Observed Frequencies: Karst Subareas	Expected Frequencies: Non-Karst Subareas	Expected Frequencies: Karst Subareas	Chi-square Statistics: Non-Karst Subareas	Chi-square Statistics: Karst Subareas
2	Acacia sp.	10	8	8.188	9.812	0.401	0.335
4	Amyris elemifera	23	33	25.474	30.526	0.240	0.201
9	Erithalis fruticosa	39	36	34.117	40.883	0.699	0.583
10	Psychotria ligustrifolia	112	31	65.050	77.950	33.886	28.278
15	Coccoloba diversifolia	13	18	14.102	16.898	0.086	0.072
27	Tabebuia bahamensis	7	8	6.823	8.177	0.005	0.004
30	Eugenia confusa	16	17	15.012	17.988	0.065	0.054
31	Bursera simaruba	13	4	7.733	9.267	3.587	2.993
42	Calyptranthes pallens	17	70	39.576	47.424	12.878	10.747
46	Maytenus sp.	7	14	9.553	11.447	0.682	0.569
47	Exothea sp.	5	10	6.823	8.177	0.487	0.407
52	Cordia sebestena	8	8	7.278	8.722	0.072	0.060
54	Myrsine floridana	11	27	17.286	20.714	2.286	1.908
61	Opalonia sp.	45	81	57.317	68.683	2.647	2.209
63	Metopium toxiferum	8	14	10.008	11.992	0.403	0.336
67	Thrinax morrissii	19	44	28.659	34.341	3.255	2.716
	TOTALS	353	423	353	423	61.679	51.472

Degrees of Freedom	15
Chi-square (observed)	113.150
Chi-square (critical)	18.307

Sangamon Terrace Terrain Non-Karst Subarea (Site One) vs. Sangamon Karst (Banana Hole) Subareas (Sites Two & Three)

Species ID#	Species Identification	Observed Frequencies: Non-Karst Subareas	Observed Frequencies: Karst Subareas	Expected Frequencies: Non-Karst Subareas	Expected Frequencies: Karst Subareas	Chi-square Statistics: Non-Karst Subareas	Chi-square Statistics: Karst Subareas
2	Acacia sp.	5	5	5.766	4.234	0.102	0.139
4	Amyris elemifera	8	21	16.723	12.277	4.550	6.197
9	Erithalis fruticosa	33	30	36.328	26.672	0.305	0.415
10	Psychotria ligustrifolia	86	28	65.737	48.263	6.246	8.507
42	Calyptranthes pallens	13	4	9.803	7.197	1.043	1.420
61	Opalonia sp.	13	28	23.642	17.358	4.791	6.525
	TOTALS	158	116	158	116	17.036	23.204

Degrees of Freedom	5
Chi-square (observed)	40.239
Chi-square (critical)	11.07

Eolianite Dune Terrain Non-Karst Subarea (Site Five) vs. Eolianite Karst (Pit Cave) Subarea (Site Four)

Species ID#	Species Identification	Observed Frequencies: Non-Karst Subareas	Observed Frequencies: Karst Subareas	Expected Frequencies: Non-Karst Subareas	Expected Frequencies: Karst Subareas	Chi-square Statistics: Non-Karst Subareas	Chi-square Statistics: Karst Subareas
4	Amyris elemifera	15	12	10.869	16.131	1.570	1.058
9	Erithalis fruticosa	6	6	4.831	7.169	0.283	0.191
10	Psychotria ligustrifolia	26	3	11.674	17.326	17.580	11.845
30	Eugenia confusa	16	17	13.284	19.716	0.555	0.374
42	Calyptranthes pallens	4	66	28.179	41.821	20.747	13.979
54	Myrsine floridana	10	12	8.856	13.144	0.148	0.100
61	Opalonia sp.	32	53	34.217	50.783	0.144	0.097
67	Thrinax morrissii	17	18	14.089	20.911	0.601	0.405
	TOTALS	126	187	126	187	41.628	28.049

Degrees of Freedom	7
Chi-square (observed)	69.676
Chi-square (critical)	14.067

Table 4. Results of the chi-square test of independence comparing non-karst and karst subareas for the Hard Bargain area.

Species ID#	Species Identification	Observed Frequencies		Expected Frequencies		Chi-square Statistics	
		HB Site Two	HB Site Three	HB Site Two	HB Site Three	HB Site Two	HB Site Three
4	Amyris elemifera	11	10	11.532	9.468	0.02452	0.02987
10	Psychotria ligustrifolia	20	8	15.376	12.624	1.39076	1.69387
16	Psychotria nervosa	23	6	15.925	13.075	3.14337	3.82846
46	Gualacum sanctum	13	16	15.925	13.075	0.53720	0.65428
61	Opalonia sp.	15	13	15.376	12.624	0.00916	0.01116
63	Metopium toxiferum	6	6	6.590	5.410	0.05275	0.06425
67	Thrinax morrisii	7	19	14.277	11.723	3.70944	4.51791
	TOTALS	95	78	95	78	8.86722	10.79982

Degrees of Freedom	6
Chi-square (observed)	19.667
Chi-square (critical)	12.592

Table 5. Results of the control chi-square test of independence comparing HB Site 2 to HB Site 3 (both contain karst features and are located within Sangamon Terrace).

independence was applied to the data from the Line Hole area. The t-test was not applicable due to the lack of sufficient abundance of species in the comparative sites. The results (Table 6) suggest that for our samples, the vegetation in the Line Hole area may be independent of the subarea in which it is found (karst versus non-karst). It appears that within the Line Hole area, karst features are probably not important in determining the area in which certain species are found. Based on cultivation history, succession is probably in an earlier stage in this area than in the Hard Bargain area, and it is possible that the vegetation in the Line Hole area is still dependent upon its seed bank (Glenn-Lewin et al., 1992), and the competition for spatial establishment has not yet begun. Under these conditions, the presence or absence of karst features in the area would not have a great influence on the distribution of particular species in that area.

Hard Bargain Versus Line Hole

A chi-square test of independence was performed to compare the frequencies of species found in the Hard Bargain area to those found in the Line Hole area (Table 7). Three tests were performed to compare the frequencies. For all three tests, the results suggest that the distribution of species types may be dependent upon the area (HB versus LH) in which they are found. The HB area has had >50 years to recover from slash and burn-type cultivation, and is most likely in a more advanced stage of secondary plant succession (Glenn-Lewin et al., 1992) than the Line Hole area. The vegetation found in each area is a function of, and thus dependent upon, its particular stage of secondary succession.

General Comparison

Almost all of the sites have >50% co-occurringspecies (Table 8), the exceptions being those associated with HB Site 3. This is interesting considering that 40 of the 72 species are found exclusively in single sites (Table 9). As previously mentioned, this could be due to the small sample area of the populations being tested. Each site has a relatively small number of species that are abundant (Table 10), although Line Hole Site 2 has the greatest number, and more than either of the two non-karst sites in the Hard Bargain area, which may relate to the difference in the stage of succession of each area. The number of species that are common in each site is at least double and up to 12 times the number of abundant species in that site.

DISCUSSION

The analysis of the vegetation data by chi-square tests of independence indicate that differentiation of the seven quadrats based on the presence or absence of karst features cannot be reliably done. While differences exist between karst and non-karst areas, they also exist between areas that have similar karst development in the Hard Bargain area. Conversely, in the Line Hole area, karst and non-karst areas are not significantly different in vegetation type. The most plausible explanation for the contrast between the Hard

Species ID#	Species Identification	Observed Frequencies		Expected Frequencies		Chi-square Statistics	
		Non-Karst Subareas	Karst Subareas	Non-Karst Subareas	Karst Subareas	Non-Karst Subareas	Karst Subareas
4	Amyris elemifera	20	11	20.655	10.345	1.363	1.748
5	Rhamnaceae family	16	5	11.723	9.277	1.561	1.972
42	Calyptranthes pallens	39	42	45.217	35.783	0.855	1.080
54	Myrsine floridana	14	9	12.839	10.161	0.105	0.133
61	Opalonia sp.	21	24	25.120	19.880	0.676	0.854
62	Annona glabra	8	7	8.373	6.627	0.017	0.021
63	Metopium toxiferum	7	5	6.699	5.301	0.014	0.017
65	Diospyros sp.	8	7	8.373	6.627	0.017	0.021
	TOTALS	139	110	139	110	4.620	5.846

Degrees of Freedom	7
Chi-square (observed)	10.472
Chi-square (critical)	14.067

Table 6. Results of the chi-square test of independence comparing non-karst and karst subareas for the Line Hole area.

(Vegetation in HB Sites One & Two vs LH Sites One & Two)

Species ID#	Species Identification	Observed Frequencies		Expected Frequencies		Chi-square Statistics	
		Hard Bargain	Line Hole	Hard Bargain	Line Hole	Hard Bargain	Line Hole
4	Amyris elemifera	19	27	15.588	30.412	0.74682	0.38279
15	Coccoloba diversifolia	14	11	8.472	16.528	3.60745	1.84904
42	Calyptranthes pallens	17	81	33.209	64.791	7.91168	4.05523
54	Myrsine floridana	16	23	13.216	25.784	0.58648	0.30061
61	Opalonia sp.	28	45	24.738	48.262	0.43026	0.22054
63	Metopium toxiferum	8	12	6.777	13.223	0.22055	0.11304
	TOTALS	102	199	102	199	13.50324	6.92126

Degrees of Freedom	5
Chi-square (observed)	20.425
Chi-square (critical)	11.07

(Vegetation in HB Sites Four & Five vs LH Sites One & Two)

Species ID#	Species Identification	Observed Frequencies		Expected Frequencies		Chi-square Statistics	
		Hard Bargain	Line Hole	Hard Bargain	Line Hole	Hard Bargain	Line Hole
4	Amyris elemifera	27	27	29.769	24.231	0.25760	0.31648
15	Coccoloba diversifolia	13	11	13.231	10.769	0.00403	0.00495
30	Eugenia confusa	33	11	24.256	19.744	3.15176	3.87216
42	Calyptranthes pallens	70	81	83.244	67.756	2.10698	2.58858
54	Myrsine floridana	22	23	24.808	20.192	0.31777	0.39040
61	Opalonia sp.	85	45	71.667	58.333	2.48062	3.04762
63	Metopium toxiferum	8	12	11.026	8.974	0.83029	1.02007
	TOTALS	258	210	258	210	9.14905	11.24026

Degrees of Freedom	6
Chi-square (observed)	20.389
Chi-square (critical)	12.592

(Vegetation in HB Sites One & Three vs LH Sites One & Two)

Species ID#	Species Identification	Observed Frequencies		Expected Frequencies		Chi-square Statistics	
		Hard Bargain	Line Hole	Hard Bargain	Line Hole	Hard Bargain	Line Hole
4	Amyris elemifera	18	27	12.935	32.065	1.98311	0.80000
15	Coccoloba diversifolia	6	11	4.887	12.113	0.25367	0.10233
42	Calyptranthes pallens	13	81	27.020	66.980	7.27481	2.93473
61	Opalonia sp.	26	45	20.409	50.591	1.53170	0.61790
63	Metopium toxiferum	8	12	5.749	14.251	0.88138	0.35556
	TOTALS	71	176	71	176	11.92467	4.81052

Degrees of Freedom	4
Chi-square (observed)	16.735
Chi-square (critical)	9.488

Table 7. Results of the chi-square test of independence for the comparison of vegetation in the Hard Bargain area versus the Line Hole area.

	HB-1	HB-2	HB-3	HB-4	HB-5	LH-1	LH-2
HB-1	22						
HB-2	15	26					
HB-3	7	8	18				
HB-4	16	21	10	32			
HB-5	13	17	6	16	25		
LH-1	12	16	5	14	16	28	
LH-2	12	16	6	16	16	16	25

Table 8. Matrix table comparing the numbers of species found in each site to all other sites.

Only 1 Site	2 Sites	3 Sites	4 Sites	5 Sites	6 Sites	All 7 Sites
40	8	6	2	6	6	3

Table 9. Table showing the number of species found in single sites, two sites, three sites; up to all seven sites. Data were derived from Table 1.

	Hard Bargain Site One (Sangamon)	Hard Bargain Site Two (banana hole)	Hard Bargain Site Three (banana hole)	Hard Bargain Site Four (pit cave)	Hard Bargain Site Five (Dune Ridge)	Line Hole Site One (banana hole)	Line Hole Site Two (Sangamon)
NE	50	46	54	40	47	44	47
R	10	10	5	16	10	13	9
C	9	14	12	14	12	13	11
A	3	2	1	2	3	2	5

NE = non-existent = 0
R = rare = 1 - 4
C = common = 5 - 20
A = abundant = > 20

Table 10. Table showing species abundance from all seven sites. Data were derived from Table 1.

Bargain area and the Line Hole area is that the cultivation history has influenced plant succession. In the Line Hole area, cultivation has been recent, and native vegetation is just beginning to re-establish itself. These species may be more opportunistic colonizers and exploiters of disturbed land, and less sensitive to variations in karst development and topography. The Hard Bargain area has not been cultivated for more than 50 years; therefore, plant succession is more advanced than in other areas, and for this reason terrain differences may have begun to exert an influence on species frequency.

The t-test for *Erithalis fruticosa* and *Metopium toxiferum* showed no differences in plant height or diameter between karst and non-karst quadrats within the Hard Bargain area. These data contrast with the chi-square differences noted for species frequency, which showed differences between all the quadrat types. The data suggest that while local terrain differences might influence which plants become established, these differences do not seem to influence the success of some of those plants once they are established.

The quadrat size and the number of quadrats may have been too small to accurately delineate the interaction of vegetation and landforms. Small scale variations in microclimate within the various sites, including soil temperature and moisture, air temperature and humidity, small scale wind currents, and sunlight may also be important, but undocumented, factors.

Another factor that may influence the vegetation growth patterns s the degree to which karst features are actually expressed on San Salvador Island. Within the Sangamon Terrace terrain, quadrats were selected based on the presence or absence of banana holes. As noted earlier, banana holes are often used by Bahamians to grow specialty crops, as they often contain moist, thick soils, whereas the surrounding land is often bare or thinly-mantled rock. Therefore this study was designed to see whether quadrats containing banana holes, in the wild state, exhibited different or more robust vegetation. The vegetation is not more robust in banana hole quadrats, and differences in vegetation exist even between banana hole quadrats (i.e., HB Sites 2 and 3). The problem may be that banana holes represent the surface expression of collapsed shallow-phreatic voids. Harris and others (1995) demonstrated that many banana hole voids exist which have not collapsed. Therefore quadrats that were classified in this study as free of banana holes, in both the Hard Bargain and Line Hole areas, may have numerous uncollapsed and therefore unseen banana hole voids in the subsurface that influenced plants on the surface above. The major influence could be in providing a void that allowed roots to traverse directly to the water table, despite the bare appearance of the rock in which they rooted.

A final factor to consider is that San Salvador Island has undergone one and perhaps two deforestation events. The first is believed to have occurred shortly after contact with the islands by Europeans in the late 15th century, when an initial high-canopy forest was logged for its wood. The second may have occurred during the Loyalist area, when plantations were established in late 18th century by British loyalists thrown out of the newly-established United States. The true original vegetation has been lost, and major changes to the ecosystem can be assumed to have occurred. San Salvador Island today is covered by a mixture of introduced and native plants, growing on a substrate much altered by plantation and slash and burn agriculture for two centuries. The system may be so disturbed that the original relationship between karst features and vegetation may have been forever altered.

This study was the first of its kind to be conducted on a carbonate island of Quaternary age. One of the desired outcomes was to see if karst features influenced vegetation. If so, would that influence be strong enough to allow detection by remote means, as in satellite or aerial photographs? If the influence of karst on vegetation can indeed be seen in satellite photos, then the method of studying these environments will change. Unfortunately, it does not appear that such goals can be reached. The initial work has provided some base-line data regarding which plants are present in which terrains. The study has also indicated that understanding plant succession may be critical in interpreting vegetation and land use in carbonate islands.

SUMMARY AND CONCLUSIONS

Seven quadrats (700 m^2) from two geographic locations (Hard Bargain and Line Hole areas) encompassing four subareas of topography (dune and terrace; karst and non-karst) produced 72 species of macro-scale vegetation. With the exception of the two Line Hole sites (LH Site 1 and LH Site 2), the data herein suggest that for these samples, all plots appear to differ from each other in terms of species distribution. A number of factors could play a role in the differences and similarities found in this study: 1) quadrat size, and/or number of quadrats too small to accurately represent the population; 2) microclimate within the various sites, including soil temperature and moisture, air temperature and humidity, small scale wind currents, and sunlight; 3) uncollapsed karst features may be present, undetected but influencing the nature of plant growth on the surface; and 4) the island has been greatly disturbed during the last 500 years by human agriculture and land use, which may have introduced disturbances that prevent a proper karst/vegetation relationship from developing.

The large number of species found in single sites is consistent with the work of Correll (1979) and Smith (1993), in that a large number of species are found within the Blackland Community and there are a select number of common species found within this community. Moreover, the common species found in this study are similar to those found by Coker (1905), Correll (1979), and Smith (1993).

Based on the samples in this study, there does appear to be a relationship between karst features and vegetation type in the Hard Bargain and Line Hole areas. However, position in the succession regime may be important. In addition, other factors may have contributed to the relationships observed in this study (e.g., quadrat number and size, micro-climate). However, because numerous speculations could be made based on the data collected, further investigations taking into consideration the number and size of the sample quadrats, the micro-climate in the area, the presence of cryptic karst features, and the human history of the island, may definitely resolve the question of whether or not there is a relationship between karst features and vegetation type in the Bahamas.

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