



Paleoenvironmental evidence for first human colonization of the eastern Caribbean



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ABSTRACT

Identifying and dating first human colonization of new places is challenging, especially when group sizes were small and material traces of their occupations were ephemeral. Generating reliable reconstructions of human colonization patterns from intact archaeological sites may be difficult to impossible given post-depositional taphonomic processes and in cases of island and coastal locations the inundation of landscapes resulting from post-Pleistocene sea-level rise. Paleoenvironmental reconstruction is proving to be a more reliable method of identifying small-scale human colonization events than archaeological data alone. We demonstrate the method through a sediment-coring project across the Lesser Antilles and southern Caribbean. Paleoenvironmental data were collected informing on the timing of multiple island-colonization events and land-use histories spanning the full range of human occupations in the Caribbean, from the initial forays into the islands through the arrival and eventual domination of the landscapes and indigenous people by Europeans. In some areas, our data complement archaeological, paleoecological, and historical findings from the Lesser Antilles and in others amplify understanding of colonization history. Here, we highlight data relating to the timing and process of *initial* colonization in the eastern Caribbean. In particular, paleoenvironmental data from Trinidad, Grenada, Martinique, and Marie-Galante (Guadeloupe) provide a basis for revisiting initial colonization models of the Caribbean. We conclude that archaeological programs addressing human occupations dating to the early to mid-Holocene, especially in dynamic coastal settings, should systematically incorporate paleoenvironmental investigations.

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1. Introduction

1.1. Issues in colonization of the Caribbean

Irving Rouse (1986, 1992) proposed long ago that early ceramic-age (or Neolithic) colonists to the Caribbean (Saladoid archaeological cultures) introduced to the Antillean archipelago agriculture, the use of pottery, and established lifeways and belief systems

from their greater Amazonian homeland. He developed a stepping-stone colonization model, whereby settlers first targeted specific islands closer to mainland South America before moving onto other islands further up the archipelago. Recent investigations are increasingly showing that earlier groups of people (Archaic populations) occupying the islands may have introduced cultigens and produced pottery and some researchers argue that first and later settlers made direct voyages from northern South America to the northern Lesser Antilles or the Greater Antilles, thus bypassing nearly 70% of the island arc (Callaghan, 2010; Fitzpatrick, 2013; Fitzpatrick et al., 2010; Keegan, 2010; Pagán-Jiménez, 2013; Pagán-Jiménez et al., 2015; Rodríguez Ramos et al., 2008).

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Archaeological traces of the earlier Archaic residents are considerably different than the later and, apparently, more densely settled Saladoid and post-Saladoid groups. Owing to a variety of taphonomic and sampling issues the earliest colonists to the Caribbean dating to the early/mid-Holocene in particular are difficult to identify using traditional methods of archaeological surveying, testing, and excavation. Additional lines of evidence from paleoecology are required to provide data on small-scale scouting or colonization events and habitat modifications by early as well as later occupants (Athens et al., 2014; Burney, 1997a, 1997b; Foley et al., 2014).

We conducted an extensive paleoenvironmental investigation across nine islands of the Lesser Antilles and southern Caribbean (Fig. 1). Microfossils of pollen and phytoliths, charcoal particulates, sediment chemistry, and a program of high-precision radiocarbon dating provide new evidence that first colonizers to the islands arrived earlier than previously thought. These first colonizers were modifying and perhaps managing landscapes that had implications for subsequent colonizing groups, including the larger Neolithic communities from greater Amazonia. Archaeological remains of these earliest colonists may be deeply buried under alluvial, colluvial, or volcanic deposits and in cases of coastally oriented people may be underwater due to rising sea level. Clearly, archaeological programs addressing early to mid-Holocene human occupations and land-use histories, especially in dynamic coastal settings, should systematically incorporate paleoenvironmental investigations.

Data from the current project inform on the full span of human history in the eastern Caribbean, from first colonization of the islands through the arrival of Europeans. In some areas, our data complement archaeological, paleoenvironmental, and historical

Table 1

Locations of the cores discussed in the text.

Island, location	Core number	Northing ^a	Westing ^a
Trinidad, Nariva Swamp	NV08-1	1031.035	6102.603
Grenada, Meadow Beach	MB08-1	1209.728	6136.403
Grenada, Lake Antoine	12-VII-08	1211.011	6136.393
Martinique, Baie de Fort-de-France	KC08-1	1433.802	6059.677
Martinique, Pointe Figuier	PF08-1	1427.680	6054.558
Marie Galante, Vieux Fort	VF08-1	1558.697	6117.637

^a Coordinates are in degrees, minutes, and seconds. Example: N1209.728 = N12°, 09 min, 72.8 s.

findings from the Lesser Antilles and in others amplify understanding of colonization history. Results presented in this paper relate specifically to initial colonization history of the eastern Caribbean. In particular, data from Trinidad, Grenada, Martinique, and Marie-Galante (Guadeloupe) provide a basis for revisiting initial colonization models of the Caribbean (Fig. 1; Table 1).

1.2. Methodological challenges and debates in identifying the earliest traces of human activities in the Caribbean

Models of prehistoric island colonization are generally based on data collected from archaeological sites (Alcover, 2008; Rouse, 1986; Siegel, 1991). While archaeological excavations are important it is increasingly apparent that many human activities leave only subtle traces, for which traditional methods of archaeological surveying, testing, and excavation may not be adequate for identification and assessment (Jones, 1994; Neff et al., 2006; Pohl et al., 1996; Pope et al., 2001). Paleoenvironmental investigations in the Caribbean are revealing the importance of systematically collecting

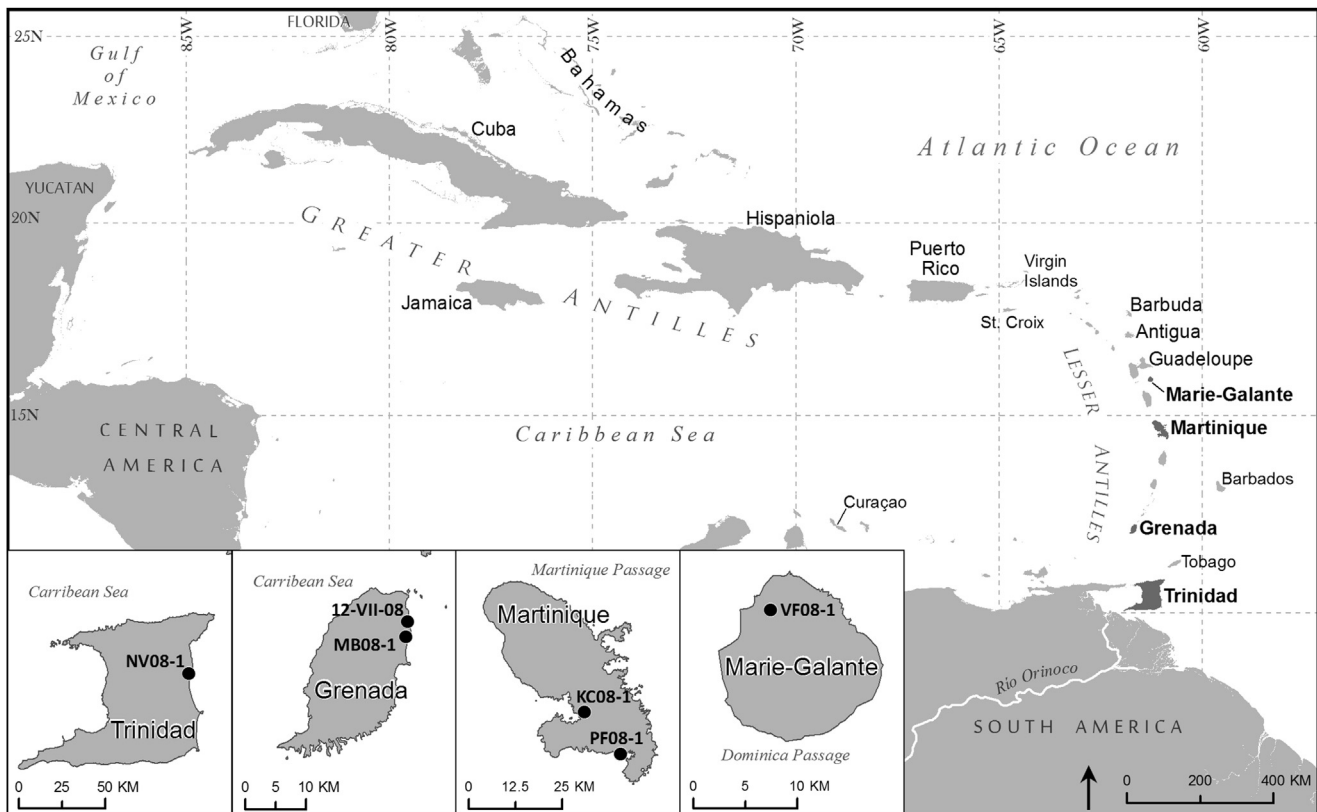


Fig. 1. Map of the Caribbean basin. Environmental cores were collected from Trinidad, Grenada, Curaçao, Barbados, Martinique, Marie-Galante, Antigua, Barbuda, and St. Croix. Cores discussed in this paper came from Trinidad, Grenada, Martinique, and Marie-Galante (inset).

microfossils from sedimentary deposits to identify past human activities that are not well represented in the archaeological record (Brenner and Binford, 1988; Burney, 1997a; Burney et al., 1994; Higuera-Gundy et al., 1999; Siegel et al., 2005).

Standard models of initial human colonization of the Caribbean indicate two independent entry routes: the Yucatán Peninsula to the Greater Antilles (c. 5900 cal yr BP) and the Orinoco Valley to Trinidad (c. 8000 cal yr BP) (Boomert, 2013; Rouse, 1992; Wilson, 2007; Wilson et al., 1998). Early to Middle Archaic (early to mid-Holocene) archaeological sites are well represented in the Greater and northern Lesser Antilles (Davis, 2000; Kozłowski, 1974; Lundberg, 1989; Rodríguez Ramos et al., 2008; Veloz Maggiolo and Ortega, 1983). However, there is a dearth of documented Archaic sites between Tobago and Antigua, a distance accounting for most of the Lesser Antillean chain (from the South American continental margin to the Guadeloupe Passage).

Investigators have argued that Archaic groups did not occupy the southern Lesser Antilles and that these same islands were bypassed by the later first ceramic-age settlers to the Caribbean, who presumably traveled directly from the South American mainland to the northern Lesser Antilles, Virgin Islands, and Puerto Rico (Callaghan, 2003, 2010; Fitzpatrick, 2013). Before drawing conclusions concerning colonization strategies based on negative evidence it is important to consider issues of archaeological site-discovery techniques, taphonomic processes, volcanism, land-use histories, and sea-level changes. Early Holocene landscapes with archaeological sites may be buried beneath volcanic deposits presenting unique challenges in identifying them (Armstrong, 1980). Lacking systematic surveys, poor representation of these sites is likely the product of sampling bias and issues of visibility. We know from other tropical regions that sites dating to the early Holocene are often underrepresented compared to later, more visible Neolithic occupations. Yet paleoenvironmental records reveal the presence of active early Holocene occupations in those same regions (Jones, 1994; Neff et al., 2006; Burney, 1997a). Another factor potentially obscuring early Holocene Caribbean landscapes is the massive erosion resulting from colonial plantation practices that have scoured upland areas and buried old, lowland surfaces under meters of colluvial and alluvial deposits on many islands, thus obliterating or sealing archaeological sites within contexts difficult to detect or access. Finally, sea-level changes have resulted in the drowning of former shoreline or near-shoreline terrestrial landscapes (Murray-Wallace and Woodroffe, 2014) potentially containing sites dating to the early to mid-Holocene. Inundation of coastlines and low-lying landforms no doubt will be exacerbated as global warming continues. Postglacial relative sea-level (RSL) predictions based on glacial isostatic adjustment modeling in the Caribbean reveal RSL values of approximately -2 m MSL (4000 cal yr BP), -4 m MSL (5000 cal yr BP), -8 m MSL (7000 cal yr BP), and -13 m MSL (8000 cal yr BP) (Peltier and Fairbanks, 2006; Toscano et al., 2011). Depending on seafloor topography and age there is the potential for submerged early Holocene landscapes and archaeological sites associated with the islands (Armstrong, 1980; Cooper and Boothroyd, 2011). Addressing the archaeological implications of submerged landscapes will require the analysis of bathymetric maps and sea-level curves in connection with specific islands and conducting underwater surveys.

2. Disentangling natural from cultural impacts in Caribbean paleoenvironmental records

Modifications to Caribbean landscapes have been well-documented following arrival of Europeans, most notably in eyewitness accounts, archival sources, historical maps, and oral histories (Sauer, 1966; Sheridan, 1973; Watts, 1987). Richardson

(2004) observed that fires have been used by humans for millennia in modifying physical environments, especially after the arrival of Europeans. This account was based on archival research, literature reviews, and oral histories with a focus primarily on the British West Indies between the mid/late-nineteenth to early-twentieth century. Recent paleoenvironmental investigations have extended this perspective of landscape modification to the earliest human occupations of the Caribbean islands using sedimentological data. Studies addressing prehistoric landscape modifications in the Caribbean have been limited and small in scale (Brenner and Binford, 1988; Burney et al., 1994; Kjellmark, 1996; Lane et al., 2008a, 2008b, 2009, 2014; Peros et al., 2006; Siegel et al., 2005).

Dated sequences of microfossils from particularly productive cores combined with regional paleoenvironmental/climatic reconstructions are presented here to build on previous models of island colonization history. A number of regional studies provide a paleoclimate/environmental history context for interpreting the microfossil, sedimentary, and landscape records obtained in the current project (Banner et al., 1996; Beets et al., 2006; Bertran et al., 2004; Caffrey, 2011; Caffrey and Horn, 2015; Caffrey et al., 2015; Curtis et al., 2001; Haug et al., 2001; Hodell et al., 1991; Higuera-Gundy et al., 1999; Kjellmark, 1996; Malaizé et al., 2011; Mangini et al., 2007).

It is increasingly clear that relying exclusively on the archaeological record may be misleading when accounting for past human events, especially during times of low population densities early in the Holocene of the New World or earlier in the Old World. Human-derived disturbance indicators recovered from sedimentary records may be more reliable in identifying first colonizers to new places. In landscape ecology, a disturbance or perturbation is defined as any event that results in a disruption to an ecosystem (White and Pickett, 1985). With some modification this is the sense in which we have been using the term “disturbance” when investigating Caribbean paleoanthropogenic landscapes.

As archaeologists, paleoethnobiologists, and geographers we are concerned specifically with distinguishing between disturbances or disruptions in ecosystem structure caused by natural vs. human agents. For example, fire as a disturbance factor may occur as a relatively short discrete event or repeated events during an interval of time ranging from decades to hundreds of years. The discrete firing event may be the result of nature, such as a lightning strike. Greater frequencies of discrete firing events may also be associated with climate change (increased aridity and combustible ground-cover). Alternatively, the continuous presence of fire may be the result of active landscape management, especially during wetter periods of climate history (Burney et al., 1994; Pyne, 1998). These scenarios will produce alternative signatures in the paleoenvironmental record: (1) a discrete firing event represented by a spike in charcoal concentration value with little to no sustained presence or (2) longer phase of fire presence represented by elevated and sustained charcoal concentration values. It is important to consider too the context of documented disturbances, including climate conditions (wet vs. dry), relative percentages or presence/absence of economically useful plant taxa, changes in mix of species composition, and relative density of vegetation coverage. Climate reconstructions provide a framework within which disturbance indicators are evaluated. Specifically, evaporation/precipitation ratios over time represent one line of evidence to be viewed along with dated sequences of microfossils, sediment chemistries, and landscape histories.

2.1. Quaternary climate change in the Caribbean

Quaternary climate change and concomitant sea-level variation

are critical to an understanding of Trinidad's land bridge connections to South America, the Caribbean islands evolving shorelines and estuaries, and earliest signs of human activities on the islands. Climate change at the Pleistocene/Holocene transition drove the adaptive changes evident in the resources used by the inhabitants of the South American lowland tropics who became increasingly dependent on estuaries and mangrove environments (Boomert, 2000; Piperno and Pearsall, 1998). It is difficult to determine local sea-level rise; even a relatively small basin such as the Caribbean Sea does not follow a homogenous sea-level curve due to local variations in isostatic response, local tectonics, and changes in the earth's rotational state (Rull et al., 1999; Toscano et al., 2011). In general terms, it is agreed that eustatic sea level was, on average, 121 ± 5 m lower than present at the height of the last glacial maximum, 18,000 cal yrs BP, and that temperatures in the low latitudes were c. 5–8 °C lower than present (Burnham and Graham, 1999; Curtis et al., 2001; Fairbanks, 1989; Geophysics Study Committee, 1990; Guilderson et al., 1994; Leyden, 1985; Webb et al., 1997). Holocene data from the wider Caribbean indicate that sea level reached its present height c. 2000 years ago (Gischler, 2006; Rull, 2000; Scheffers et al., 2009; Toscano and Mcintyre, 2003, 2006).

Evidence points to late Pleistocene aridity associated with lower temperatures due to the feedback loop between atmospheric moisture and greenhouse effect (Brenner, 1994; Curtis et al., 2001; Haug et al., 2001; Holmes et al., 1995; Leyden, 1985). Late Pleistocene and early Holocene intervals of cooler, drier climate supported an array of moist forests, dry forests, and savannas (Burnham and Graham, 1999). The timing for the onset of mesic Holocene conditions was regionally variable (Beets et al., 2006; Bertran et al., 2004; Brenner et al., 2000; Caffrey, 2011; Curtis, 1997; Curtis et al., 2001; Haug et al., 2001; Higuera-Gundy et al., 1999; Hodell et al., 1991, 2005; Leyden, 1985; Mangini et al., 2007; Mayle and Power, 2008). Reconstructions from Lakes Valencia, Venezuela and Miragoane, Haiti reveal dry conditions persisting until c. 7000–8000 cal yr BP (Curtis et al., 2001; Leyden, 1985). Mesic conditions in Panama were present by 10,500 BP and in Jamaica xeric conditions dominated until c. 9500 BP (Bush et al., 1992; Curtis et al., 2001; Street-Perrott et al., 1993). The effect of rising sea level in the early Holocene was to cause a trend away from savanna in favor of mangrove-dominated environment in coastal regions in the Caribbean (Van der Hammen, 1988) and the cores from this project support this view. Moist conditions prevailed during the early/mid-Holocene (7000–3000 BP) for much of the Caribbean and evidence points to drying during the late Holocene (3000 BP to present) although the timing of the drying episode is not consistent across the region (Deevey et al., 1983; Islebe et al., 1996; Piperno et al., 1990). Data from Guadeloupe suggest a stormy dry period from c. 1150–950 BP (Beets et al., 2006). Lakes on the Yucatán peninsula also indicate a series of droughts in the late Holocene (Curtis et al., 1996; Whitmore et al., 1996). The Lake Valencia data revealed an increase in salinity after c. 3000 BP, but oxygen isotope evidence was lacking (Curtis et al., 2001). A core from eastern Venezuela produced a peat layer at 9.2 m, which dated to c. 7000 BP suggesting an average sea-level rise of 13.2 cm/100 years since that time (Rull et al., 1999). Studies of marine cores from the Cariaco Basin on the north coast of Venezuela also indicate late Holocene aridity (Haug et al., 2001).

One important sequence of Caribbean climate history over the past 10,500 years comes from the investigations of ^{18}O -isotope values of ostracods (carbonate shells) in the sediments of Lake Miragoane, Haiti (Brenner and Binford, 1988; Curtis et al., 2001; Higuera-Gundy, 1991; Higuera-Gundy et al., 1999; Hodell et al., 1991). The chronological resolution for the Miragoane sediments analyzed by Curtis was 16.8 years per sample (Curtis, 1992, 1997;

Curtis and Hodell, 1993; Hodell et al., 1991). Within a 17-year span there may be unusual dry or wet episodes that are not detectable, especially those related to El Niño events (Giannini et al., 2001). Mangini et al. (2007) analyzed ^{18}O -isotope values of a c. 7000-year-old stalagmite collected from a cave on Barbados. Although Mangini et al. (2007) generally documented elevated rainfall between 6700 and 3000 BP (consistent with the Miragoane study), they observed that lower precipitation values in Barbados were coterminous with higher values recorded in the Miragoane sediments. Oxygen-isotope values in stalagmites reflect summer precipitation, while isotope values in ostracods record average annual precipitation thereby leveling out seasonal variation (Mangini et al., 2007). The degree of resolution may be finer in the stalagmite data, allowing for assessments in seasonal variability that cannot be tracked in ostracod records. In addition, mean latitudinal changes in the Atlantic Intertropical Convergence Zone through time may affect rainfall patterns in the region of the equator (Black et al., 2004; Brenner et al., 2000; Haug et al., 2001; Hodell et al., 2005; Mangini et al., 2007; Rosenmeier et al., 2002). The Cariaco Basin sediment records over the past c. 6000 years compare to other tropical Atlantic locations, ranging from West Africa to northern South America and the circum-Caribbean region (Curtis et al., 2001; Goni et al., 2009; Haug et al., 2001; Hodell et al., 2005). Complicating climate reconstructions in the Caribbean are regional variations due to island topography and strong seasonal variations resulting from interactions of the tropical Atlantic and Pacific oceans, particularly sea surface temperature anomalies associated with ENSO and North Atlantic Oscillation effects (Enfield and Alfaro, 1999; Giannini et al., 2000; Jury et al., 2007).

2.2. Reconstructing anthropogenic landscapes in the Caribbean

In his sediment-coring work on Puerto Rico, Burney (1997a; Burney et al., 1994) documented human colonization by c. 5300 cal yr BP, approximately two millennia prior to what the archaeological record indicated at the time. His assessment was based exclusively on substantial increases in charcoal-particulate frequencies. Identifications of anthropogenic inputs in paleoecological records are strengthened when evaluating independent lines of evidence that when integrated are unlikely to have been a product of nature in the absence of humans (Caffrey and Horn, 2015). Burney (1997a) was most successful in this regard on Madagascar. First colonizers to new places do not leave identical ecological signatures wherever they go. Ethnobotanically useful taxa present in the pre-human landscape may be considerably diminished or extirpated due to overexploitation. Alternatively, some native plant taxa may be selectively spared and nurtured in a form of active landscape management. Variable trajectories of landscape modifications are measurable through the identification of the baseline pre-human landscape.

In the current investigation of Caribbean paleoenvironments, measurable lines of evidence included pollen, phytolith, and charcoal-microparticulate distributions; sediment chemistries; landscape characterizations; and archaeological and paleoclimate records. Data collected from sediment cores were linked to the calendrical time scale through a program of radiocarbon dating. Not all lines of evidence were available for all cores or periods of time owing to issues of context-specific depositional regimes and differential preservation.

Further reconstructing anthropogenic landscapes, we distinguish between “modified” vs. “managed” terrains. Conservation biologists frequently use the terms modified and managed landscapes interchangeably (Koh and Gardner, 2010; Tabarelli et al., 2012). However, in the case of pre-industrial communities, especially first colonists to new places, distinguishing between and

attempting to identify modified and managed landscapes informs on the intent and kinds of activities conducted. We define a modified terrain as one that has been altered incidentally due to human activities. For example, in constructing shelters trees and underbrush may be removed thus altering the composition of the local biotic community and perhaps underlying edaphic conditions. Paleoenvironmental proxies of clearing activities may include fossil indicators of such quick-growing, gap-colonizing plants as trumpet trees (*Cecropia*), mulberry shrubs (Moraceae), myrtle trees (Myrtaceae), sedges (Cyperaceae), grasses (Poaceae), asters (Asteraceae), *Chenopodium* and *Amaranthus* (cheno-ams), wild plantain (*Heliconia*), and cattails (*Typha*). New settlers to an area may modify landscapes for their needs and with time gradually or quickly introduce exotic or nurture native economically useful plant taxa resulting in an actively managed landscape. The distinction between modified and managed landscapes is one of gradation and implies a degree of intentionality. A modified landscape may be the byproduct of human activities whereas a managed landscape is the primary goal. It is our expectation that managed landscapes were an outgrowth of modified landscapes. Depending on sedimentation or depositional rates it may be difficult to impossible to discern the trajectory from modified to managed landscapes in the paleoenvironmental record.

3. Materials and methods

The foundation of this investigation was the collection of multiple independent proxies of environmental conditions and anthropogenic landscapes spanning and ideally predating the range of human occupations in the southern and eastern Caribbean. Proxies included plant microfossils (pollen, phytoliths, charcoal particulates) and sediment chemistry. These data were evaluated within the frameworks of available archaeological and paleoclimate records. Sediment cores were taken in places where the potential was good for the preservation of proxies.

In general, coring locations were selected in wetlands or lakes in proximity to known archaeological sites, allowing us to assess human impacts on, and adjustments to, local, supra-local, and regional environmental settings. Except for some volcanic islands, natural lakes are absent in the Lesser Antilles. On most islands we targeted wetlands, typically coastal mangrove swamps with good potential for preserved plant microfossils. In some cases, intact wetlands suitable for microfossil preservation had been drained for modern agriculture or development projects. This was most extreme on Barbados, where remnants of only a single wetland remain on the island (Ramcharan, 2005). The predominant mode of phytolith deposition is fluvial, thus we attempted to core on the landward side of depressions, where sedimentation from inflowing streams was presumed to be greatest. Continuously saturated sediments were targeted to increase the likelihood of preserved pollen. Reconnaissance surveys were conducted in the watersheds that potentially contributed sediment to each coring location. Watersheds were determined by analysis of topographic maps and field observations. Within each watershed observations were made of current soil state (e.g., degree of anthropogenic degradation), current land use, and evidence of past land use. These data combined with soil surveys, current and historical records of land use, and archaeological inventories provided background information in assessing possible landscape dynamics over time. Disturbances to landscapes potentially impacting stratigraphic relations were assessed through radiocarbon chronologies.

3.1. Coring technology and collecting methods

Cores were recovered using a modified Livingstone rod-piston

corer built by Jason Curtis (Colinvaux, 2007; Wright, 1967). This device was used to collect successive one-meter drives into soft sediments of wetlands in 5.7-cm outside diameter polycarbonate core tubes. Two cores were collected from the deepest part of Lake Antoine on Grenada using two attached anchored inflatable boats as a platform. The uppermost unconsolidated lake sediments were collected using a 7.6-cm mud–water interface (MWI) sediment corer, specifically designed to retrieve those flocculate layers of sediment without disturbance. Next, the section of sediment from 50 to 150 cm was collected without casing pipe. Then casing pipe (10-cm PVC drain pipe) was lowered into the sediment and pushed in approximately 1 m to hold position and sediments from 1.5 to 8.5 m were collected through the casing. A backup parallel core was collected from the mud surface to 8.03 m. Lake sediments were transported in their plastic collecting tubes to the University of Florida Department of Geological Sciences for sampling and analysis of carbonate microfossils suitable for oxygen isotope analysis. Unfortunately, adequate microfossils for isotope analysis were discontinuously preserved precluding their use for climate reconstruction.

All wetland cores were extruded, split, described, and subsampled in the field. Physical descriptions included color (Munsell), other visible attributes (e.g., large pieces of organic debris, charcoal, shells), and finger tests of texture. Sampling for physical/chemical analysis was conducted by natural strata. Phytolith samples were taken every 5 cm and pollen every 2 cm, thus embedding two pollen samples within each phytolith sample. Testing of sediment subsamples was carried out in the laboratories of the Department of Geography, University of Cincinnati; Spectrum Analytic Inc., Washington Courthouse, Ohio; Department of Geography, University of Minnesota, Duluth; Department of Geological Sciences, University of Florida, Gainesville; Department of Anthropology, Washington State University, Pullman; and Department of Anthropology, University of Missouri, Columbia.

3.2. Physical and chemical analyses of sediments

After air-drying, percentages of organic matter (OM) and organic carbon (OC) were determined by loss on ignition (Dean, 1974). The Bouyoucos hydrometer method was used to determine particle-size percentages of remaining inorganic material (Bouyoucos, 1936). Laboratory analyses by the hydrometer method were used to confirm field finger tests of texture, which can be misleading in highly organic sediments because organic material may “feel” like clay to the finger. Particle size is important to measure, especially in sediments from dynamic coastal settings to identify processes of sandbar aggradation or degradation linked to shifts in relative sea level and brackish to freshwater ratios.

Chemical analyses provide additional information about the depositional environment. P, Ca, Mg, Na, and S were measured using the Mehlich-3 ICP method (Mehlich, 1984). Na and Ca levels reflect changes in salinity, from brackish environments open to marine flow to closed freshwater lagoons. Elevated P values may indicate human activities within the watershed contributing to the depositional setting (Holliday and Gartner, 2007; Lippi, 1988; Sjöberg, 1976).

3.3. Pollen methods

Pollen samples were quantified (1–2 cc) using European *Lycopodium* spp. spores as exotic tracers, unlikely to be found in Caribbean fossil pollen assemblages (Stockmarr, 1971). Tracer spores allow fossil pollen concentration values to be calculated and to minimize processing error. Following the addition of the tracer spores, samples were washed with 10% HCl. This step removed

carbonates and dissolved the bonding agent in the tracer spore tablets. Samples were then rinsed in distilled water, sieved through 150- μm mesh screens, and swirled to remove the heavier inorganic particles. Next, samples were consolidated and 50% hydrofluoric acid was added to the residues to remove unwanted silicates. This step deflocculated the residues, effectively removing all colloidal material smaller than two microns. Samples were then washed in 1% KOH to remove any remaining humates, dehydrated in glacial acetic acid, and subjected to an acetolysis treatment (Erdtman, 1960) consisting of 9 parts acetic anhydride to 1 part concentrated sulfuric acid. During this process, the samples were placed in a heating block for a period not exceeding 8 min. This step removed most unwanted organic materials, including cellulose, hemicellulose, lipids and proteins, and converted these materials to water-soluble humates. The samples were then rinsed in distilled water until a neutral pH was achieved.

Samples were next subjected to a heavy density separation using zinc chloride or sodium polytungstate (2.00 specific gravity). After the lighter organic fraction was isolated from the heavier minerals the lighter pollen and charcoal remains were collected. Residues were then dehydrated in absolute alcohol and transferred to a glycerine medium for curation in glass vials. Permanent slides were prepared using glycerine as a mounting medium, and pollen and charcoal identifications and counts were made using a Nikon compound stereomicroscope at 400 \times magnification. Identifications were confirmed by comparison with the Washington State University Palynology Laboratory's pollen reference collection. With adequate preservation, minimum 200-grain counts were made for each sample (Barkeley, 1934; Bryant and Hall, 1993, p. 280).

Pollen and charcoal concentration values were calculated for all samples. Pollen concentration values below 2500 grains/ml of sediment may not reflect past conditions and usually record a differentially preserved assemblage (Bryant and Hall, 1993; Hall, 1981). Counts with low concentration values should be viewed with caution. Pollen results were graphed as percentages of the total sum in Tiliagraph, a computer program designed for the presentation of plant microfossil data (Grimm, 1988). Charcoal and total pollen concentrations were also graphed. Zonation of the pollen sequences were calculated by a constrained sum of squares analysis (CONISS), although in all cases zones were empirically obvious. Following standard palynological conventions, interpretations of each sequence were made from the base of the core upwards and were based on appearance/disappearance of key indicator plants, shifts in relative abundances of taxa, and patterning and magnitude of charcoal concentrations.

3.4. Phytolith methods

After samples were received in the lab, an initial set (typically 8 samples to correspond to equipment capacities) was selected from each core. These samples were distributed across the major lithostratigraphic units identified in the core. If the core proved to be of interest based on dating, identified plant taxa, or nature of the sediments and phytoliths were well represented then additional samples were processed to fill in the stratigraphy. Approximately 24 samples were processed from productive cores.

Samples were processed following the standard University of Missouri (MU) phytolith processing procedure (Pearsall, 2015). Dried phytolith extracts were mounted in Canada balsam and slides examined until a 200-count of diagnostic phytoliths was reached or the entire slide was scanned. Identifications were made using the MU phytolith comparative collection (<http://phytolith.missouri.edu> for the diagnostic database and counting form templates). Diatoms and sponge spicules were tallied outside the 200-count. Two Tilia

graphs were produced for each core, a resolved diagram of all taxa and a composite diagram of grouped data.

Phytolith recovery was variable among cores, most likely a result of low phytolith influx in some locations or time periods. Nature and density of vegetation, size of watershed, and sedimentation rates are likely to be important factors determining phytolith influx, although these conditions remain to be systematically field tested. In no core did all samples achieve a 200-count of diagnostic phytoliths. Rather than calculate proportions of phytoliths based on counts of less than 200 per slide we presented all data as raw counts. For samples exceeding 200 diagnostic phytoliths counting stopped at 200; the relative numbers of kinds of phytoliths can be compared for these samples. Counts below 200 represent all diagnostics on a single slide and these data are treated as presence/absence.

When presenting pollen and phytolith results, especially in comparing settings across islands, it is important to display the full range of taxonomic identifications and not only those proxies of anthropogenic inputs. In so doing, we gain insight into the natural biodiversity of paleohabitats settled by first colonists and how that biodiversity may have been modified or managed through human interventions over the ensuing decades, centuries, or millennia. Comparing the structure and composition of floristic communities across potential routes of colonization, we are also afforded opportunities to address relative degrees of familiarity versus strangeness of newly settled landscapes.

4. Paleoenvironmental data related to initial colonization of the eastern Caribbean

A variety of economically useful plant taxa and disturbance indicators were identified in sediment cores collected in the current investigation of island paleoenvironments. Although the cores from Trinidad, Curaçao, Barbados, Antigua, Barbuda, and St. Croix produced rich bodies of paleoecological data following colonization, they do not unambiguously pre-date the earliest archaeologically documented occupations for those islands (Boomert, 2000; Davis, 2000; Drewett, 2006; Hardy, 2009; Havisser, 1987; Watters et al., 1992). Except by way of comparison with one of the cores from Trinidad, these other datasets will not be discussed here.

One of the cores from Nariva Swamp along the east coast of Trinidad penetrated dated sediments that approached the earliest documented human occupations on the island and pre-dated the oldest anthropogenic contexts from the Lesser Antilles. Trinidad is a likely origin for some or all of the earliest colonists to the Lesser Antilles, thus representing a place where survival strategies were developed and knowledge and experiences were culturally archived by people prior to venturing into and exploring new landscapes. Insight into how humans interacted with homeland landscapes provides a framework for understanding the anthropogenic signatures of their first forays into new places.

4.1. Nariva Swamp, Trinidad

A core extracted from a red and black mangrove estuary within Nariva Swamp contained two zones of unusually high organic carbon content and high sand percentages. A sample of preserved wood from 250 cm was dated to c. 7060 cal yr BP (AA82681, Table 2). Pollen preservation was good with moderate phytolith deposition and abundant particulate charcoal representation (Fig. 2 and Fig. S1). From the base of the core to approximately 180 cm a combination of ethnobotanically significant and disturbance-indicator taxa are represented (Table S1).

The core did not penetrate sediments deeper than 320 cm (beneath the basal charcoal spike), thus we did not obtain an

Table 2

AMS radiometric dates from cores discussed in the text.

Core location	Lab sample number	Core/sample depth/material	¹⁴ C age (BP) ^a	δ ¹³ C (‰)	2σ cal date range ^b (BP)	Cal median date (BP)
Nariva Swamp, Trinidad	Beta-379162	NV08-1, 100–105 cm, PP ^c	1750 ± 30	−26.5	1710–1560	1640
Nariva Swamp, Trinidad	Beta-378825	NV08-1, 100–105 cm, OS ^c	3220 ± 30	−27.4	3550–3370	3430
Nariva Swamp, Trinidad	Beta-382069	NV08-1, 100–105 cm, OS, alkali insoluble	3260 ± 30	−27.2	3570–3400	3490
Nariva Swamp, Trinidad	Beta-343380	NV08-1, 208–210 cm, PW ^c	5900 ± 30	−25.0	6790–6660	6720
Nariva Swamp, Trinidad	AA-82681	NV08-1, 250–251 cm, PW	6160 ± 70	−30.4	7250–6890	7060
Meadow Beach, Gren	AA84798	MB08-1, 215–217 cm, Peat	2880 ± 39	−27.0	3160–2880	3010
Meadow Beach, Gren	AA84799	MB08-1, 330–332 cm, Peat	4420 ± 40	−30.4	5280–4870	5010
Meadow Beach, Gren	AA82678	MB08-1, 492 cm, PW	5270 ± 50	−31.1	6180–5930	6060
Lake Antoine, Gren	Beta-377885	Antoine 12-VII-08-1, 146 cm, PP	1290 ± 30	−23.2	1290–1180	1240
Lake Antoine, Gren	AA91729	Antoine 12-VII-08-3, 311–313 cm, LS ^c	2030 ± 40	−34.2	2110–1890	1980
Lake Antoine, Gren	AA91728	Antoine 12-VII-08-6, 611–613 cm, LS	4860 ± 45	−29.2	5710–5470	5600
Lake Antoine, Gren	Beta-377883	Antoine 12-VII-08-7, 700 cm, PP	7340 ± 40	−28.4	8300–8020	8140
Lake Antoine, Gren	AA91730	Antoine 12-VII-08-7, 736–738 cm, LS	8050 ± 50	−28.6	9090–8730	8930
Baie de Fort-de-France, Martinique	AA92562	KC08-1, 229–230 cm, OS	1710 ± 30	−27.7	1700–1550	1610
Baie de Fort-de-France, Martinique	Beta-341060	KC08-1, 575 cm, PP	4420 ± 30	−25.4	5270–4870	5000
Baie de Fort-de-France, Martinique	AA82676	KC08-1, 674–676 cm, OS	5000 ± 50	−27.3	5890–5620	5740
Pointe Figuier, Martinique	AA92561	PF08-1, 128 cm, PW	330 ± 35	−27.8	480–310	390
Pointe Figuier, Martinique	AA82677	PF08-1, 222–223 cm, OS	2600 ± 50	−29.1	2840–2490	2740
Vieux Fort, MG	Beta-379163	VF08-1, 60–65 cm, PP	230 ± 30	−25.3	420–1 ^d	260
Vieux Fort, MG	Beta-383083	VF08-1, 60–65 cm, OS, alkali insoluble	660 ± 30	−27.2	670–560	610
Vieux Fort, MG	Beta-378827	VF08-1, 60–65 cm, OS	630 ± 30	−27.0	660–550	600
Vieux Fort, MG	AA84800	VF08-1, 205–207 cm, Peat	1980 ± 35	−26.3	2000–1830	1930
Vieux Fort, MG	AA84883	VF08-1, 255–257 cm, OS	2960 ± 30	−31.2	3210–3010	3120
Vieux Fort, MG	AA84884	VF08-1, 414.5 cm, CW ^c	4380 ± 60	−26.7	5280–4840	4960
Vieux Fort, MG	AA82675	VF08-1, 655–657 cm, Peat	5730 ± 70	−27.4	6710–6320	6530

^a 1σ range.^b IntCal13 of CALIB ver. 7.0 was used to calibrate the dates and to compute the cal median values (Reimer et al., 2013).^c PW: preserved wood, LS: lake sediment, OS: organic sediment, PP: preserved plant matter, CW: carbonized wood.^d The most recent 7 percent of the range is suspect due to impingement on the end of the calibration data set.

unambiguous pre-anthropogenic landscape. The relatively high charcoal concentration at the core base underlies the deepest dated context, followed by sustained but somewhat lower charcoal concentrations, with two additional higher values at 160 cm and 80 cm. The charcoal particulate concentration values between 280 cm and 195 cm ranged from 250 to 500 fragments per cm³, higher than the sustained charcoal concentrations in the other cores for the same time periods discussed below (Fig. 2). In addition to frequency and magnitude of burning events, a number of other factors influence charcoal concentration values, including sedimentation rates, fuel types, fire temperature, and secondary transport mechanisms. This makes comparisons across coring locations difficult. The Nariva sequence is noteworthy, nonetheless, for the strength of the charcoal signature.

The stratigraphically lower two elevated charcoal concentrations (core base and 160 cm), separated by sustained charcoal presence, date to the mid-Holocene period of wet conditions discussed earlier in the paleoclimate section (Banner et al., 1996; Higuera-Gundy et al., 1999; Mangini et al., 2007). Some have argued that sustained levels of charcoal values do not necessarily indicate human-induced burning, but may represent background charcoal influx between fire events. It has been further proposed that wet climate conditions may lead to greater abundance of vegetative fuel, increasing the likelihood of fire events (Caffrey and Horn, 2015; Higuera et al., 2009, 2010). We suggest that sustained charcoal during the mesic conditions of the mid-Holocene combined with somewhat elevated percentages of Poaceae and higher values of *Cecropia* and Moraceae below 195 cm indicate that local clearings were being maintained (Athens et al., 2014; Burney, 1997a, 1997b; Burney et al., 1994; Pyne, 1998). The initial high value of *Cecropia* is associated with the basal spike in charcoal. Elevated percentages of Moraceae and *Cecropia* persist above 195 cm, along with high charcoal values suggesting that this portion of Nariva Swamp was continuously occupied and managed by humans for millennia (Fig. 2). Ethnobotanically useful taxa

associated with the period below 195 cm (prior to c. 6720 cal BP) include Fabaceae, Anacardiaceae, *Spondias*, *Coccoloba*, and Sapotaceae (Table S1).

Sediment, phytolith, pollen, and charcoal data support a gradual shift in depositional environments and vegetation, and a strong transition by c. 6720 cal yr BP (Beta-343380). Prior to this date, there was a notable absence of sand in the profile, representing a time when sea level was still slowly rising and the coring location was not yet estuarine. Phytolith and pollen evidence reveal open, mixed habitats with arboreal, understory, and open-habitat plants, including Poaceae, *Cecropia*, and Moraceae. Habitats may have been managed and maintained through sustained burning. Subsequently, Asteraceae was absent, grass phytoliths decreased, and the location received sediments carried from the Central Range uplands including microfossils of savanna vegetation. As sea level encroached and the estuary was formed, storms on the windward coast contributed sand to the sediment profile. Phytolith evidence in the upper portion of the core, subsequent to c. 6720 cal yr BP, reflects a vegetation shift to freshwater swamp forest, with palm and sedges, and finally to reduced palm and increased woody dicots, probably representing mangrove and a shift to brackish conditions (Fig. S1). Likewise, pollen data show a marked shift by c. 6720 cal yr BP, with decreasing arboreal types (including Anacardiaceae, *Coccoloba*, *Psidium*-type, Sapindaceae, *Chrysophyllum*, Sapotaceae, and *Cecropia*) and increased and sustained *Rhizophora* (Fig. 2).

Four Archaic archaeological sites are known for the Nariva Swamp area dating no earlier than c. 2890 cal yr BP (Boomert, 2000) (Table S2). Given taphonomic factors especially those related to sea-level increases and lacking systematic surveys it is likely that more Archaic sites were present and of greater antiquity than current archaeological evidence indicates. Microfossil data from the Nariva Swamp core support such a scenario.

Recently, starch-grain evidence has been identified for cultivars and other ethnobotanically useful taxa processed by the occupants

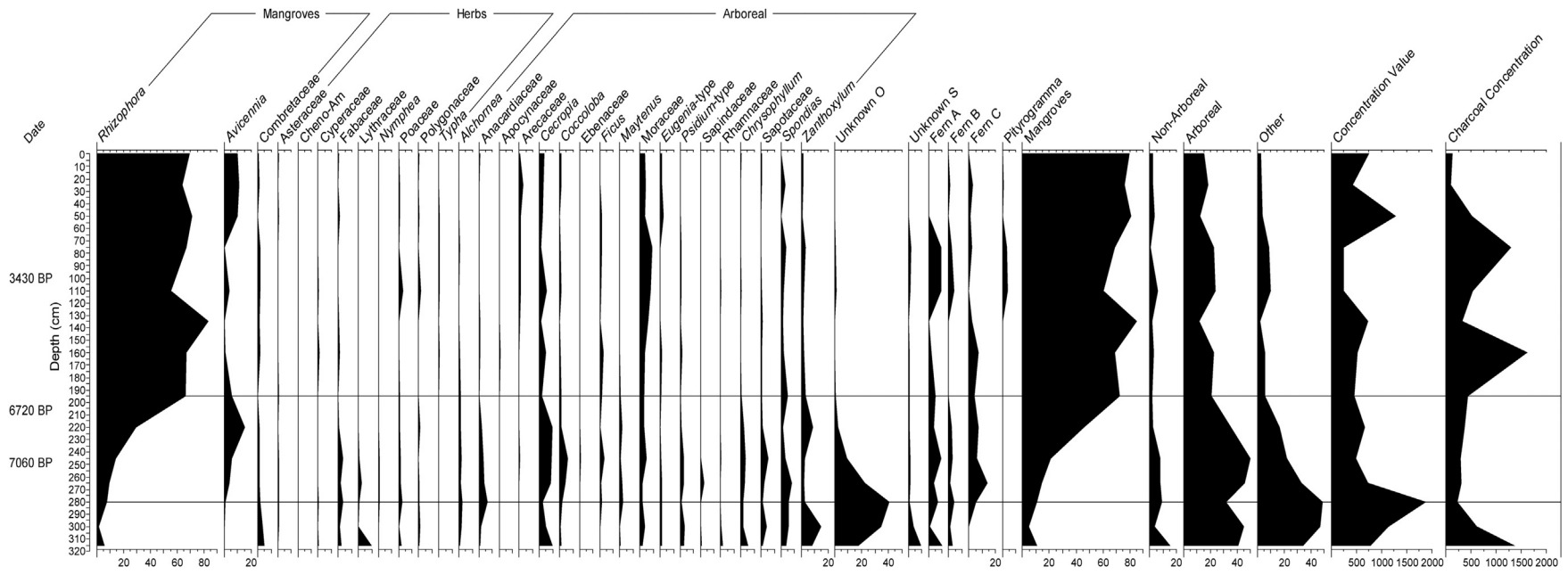


Fig. 2. Nariva Swamp, Trinidad core pollen-percentage diagram. Pollen and charcoal concentrations are expressed as grains and fragments, respectively, per cm³ of sediment. Anthropogenic inputs from the core base include disturbance indicators of Poaceae, Cecropia, Moraceae, and charcoal microparticulates. Ethnobotanically useful taxa include Fabaceae, Anacardiaceae, Spondias, Coccoloba, Marantaceae, and Sapotaceae.

of St. John, an early Archaic site located near the west coast of Trinidad (Pagán-Jiménez et al., 2015). Starch grains collected from ground stone artifacts include *Ipomoea batatas*, *Zamia* sp., *Canna* spp., Marantaceae, Dioscoreaceae, *Zea mays*, Fabaceae, and *Capsicum* spp. Radiocarbon dates associated with the artifacts range between c. 6980 and 5080 cal yr BP (Pagán-Jiménez et al., 2015; Table S2). These findings provide additional evidence that the earliest-known occupants of Trinidad were modifying, creating, and managing landscapes, including the introduction of some plant domesticates.

The composition and structure of the paleobiotic communities and the nature of anthropogenic indicators vary by degree between Nariva Swamp, Trinidad and the Lesser Antillean contexts. A number of plant taxa were represented in all cores across the islands (Tables S1 and S3). Percentages of some taxa and concentration values of charcoal particulates co-varied with time, which may relate to issues of biogeography, climate change, human colonization of new places, or some combination. Similarities in anthropogenic patterns reflect already-developed adaptive strategies from mainland South America or Trinidad, or both, which were applied to new places reflecting a form of dynamic landscape learning as first colonizers dispersed rapidly through the island chain.

4.2. Grenada

Grenada is the southernmost island in the Lesser Antilles Volcanic Island Arc and is composed of conjoined andesite and basalt cones and lava domes with the last known activity dating to the early Holocene (Fig. 1). Despite the island's size of 344 km², only 14 prehistoric sites are documented for the island, all dating to ceramic-age occupations (post c. 2200 cal yr BP) (Boomert, 2000; Bullen, 1964).

Two cores provide evidence for earlier human occupations than what is presently known archaeologically for Grenada (Fig. 1). No Archaic sites have been documented on the island. A sample from the base of the Meadow Beach core produced a date of c. 6060 cal yr BP (AA82678) and is associated with a swamp-forest ecosystem. Between c. 6060 and 5010 cal yr BP charcoal concentrations were low (Fig. 3 and Fig. S2). Ethnobotanically useful taxa such as Poaceae, Solanaceae, Arecaceae, Moraceae, Myrtaceae, Sapotaceae, and *Spondias* formed a significant part of the pollen assemblage during this early to mid-Holocene era. However, sedimentation rate was high and pollen concentration values were low during this interval, raising the possibility that these data record a differentially preserved or deposited assemblage (Table S4). In the absence of a clear charcoal signal indicating human activity and with low pollen concentrations, we conclude these taxa were part of the natural vegetative assemblage.

Sustained and elevated charcoal concentration values consistent with anthropogenic burning activity are bracketed by dates of c. 5010 and 3010 cal yr BP (Fig. 3; Table 2). Sedimentation rate for this c. 2000-year date range is quite low (Table S4) and this is a period documented to be among the wettest in Caribbean climate history, thus it unlikely that the associated high charcoal concentrations were the result of widespread natural fires (see also Burney et al., 1994; Siegel et al., 2005). Arecaceae phytolith concentrations declined significantly above 300 cm, shortly after the onset of large-scale burning, which may be either a secondary byproduct of landscape modifications or intentional and intensive harvesting of palms by newly arrived human colonists, or some combination of both factors. Restructuring of the local plant community is apparent by c. 5010 cal yr BP (Fig. 3 and Fig. S2). In the Amazon and Central America, increased charcoal concentrations have been attributed to human-induced burning rather than natural fire events (Clement

and Horn, 2001; Horn et al., 2000; Kennedy et al., 2006; Mayle and Power, 2008; Piperno and Pearsall, 1998). Low charcoal frequencies combined with sparse disturbance indicators have been interpreted to reflect the absence of human impacts (McMichael et al., 2012). The 1700 to 2400-year period of human-induced burning and landscape modifications documented in the Meadow Beach core most likely represent the impacts of the first colonizers to Grenada.

An 8.4-m core was collected from Lake Antoine. Unlike Meadow Beach, the Lake Antoine sequence is dominated by freshwater taxa. Pollen concentration values were variable but relatively high throughout the core. Four biozones were identified. Lake sediment from 737 cm produced an end date of c. 8930 cal yr BP (AA91730) for the lowest biozone. At that depth total phosphorus value was extraordinarily high (1000 mg/kg), Moraceae pollen dominated, and there was a relatively high abundance of herbs and cultigens. At 700 cm there was a substantial spike in charcoal, major increase in Arecaceae (palm family with edible fruit), and elevated herb totals (disturbance indicators) (Fig. 4). This context was dated to c. 8140 cal yr BP (Beta-377883). In the context of regional archaeology, the associated radiocarbon dates are too old for these patterns to present early human occupations. We regard the early Lake Antoine assemblages to be linked to natural disturbances associated with dry conditions in the early to mid-Holocene. As discussed earlier, paleoclimate records indicate a period of dry conditions between approximately 10,000 and 7200 cal yr BP (Curtis et al., 2001). The charcoal-particulate spike and disturbance indicators documented in the lowest sections of the core may reflect natural fire events associated with this xeric period (Banner et al., 1996; Curtis, 1997; Curtis and Hodell, 1993; Hodell et al., 1991; Leyden, 1985). Periods of arid conditions in the Pacific have been proposed to account for naturally caused fires and elevated charcoal values documented in paleosediment records in contrast to fires caused by early human activities (Athens et al., 2004; Hunter-Anderson, 2009; Prebble and Wilmshurst, 2009). At this stage of research, evidence is not strong enough to argue for human occupations during the early Holocene on Grenada and pre-dating the oldest-known occupations elsewhere in the Caribbean.

At 600 cm in the Lake Antoine core there is a major increase in charcoal inputs followed by sustained concentration values. Sediment from 612 cm was dated to c. 5600 cal yr BP (AA91728), placing that fire event in the middle to early-late Holocene (Table 2). Associated with this sudden onset and sustained presence of fire were elevated values of pollen from disturbance indicators (*Cecropia*) and pollen and phytoliths of economically useful taxa (Anacardiaceae, *Bursera*, Moraceae, Sapotaceae, and *Spondias*) (Fig. 4 and S3; Table S1). As with the Meadow Beach core, the increased and sustained presence of charcoal coincided with a major decline in Arecaceae (Figs. 3 and 4, Figs. S2 and S3). The Meadow Beach and Lake Antoine data are consistent regarding the timing of human-derived disturbances on Grenada no later than c. 5600–5010 cal yr BP, at least 3000 to 3500 years earlier than what the archaeological record currently indicates for the presence of humans.

4.3. Martinique

Martinique, located midway along the Lesser Antilles chain and part of the volcanic island arc, is made up of several volcanic cones of varying age, one of which, Mt. Pelée, has been active throughout the Holocene (Fig. 1). A 7-m core from a wetland along the Baie de Fort-de-France produced a near-basal date of c. 5740 cal yr BP (AA82676, Table 2) and no proxies for anthropogenic inputs at that time (Fig. 5 and Fig. S4; Table 3). In its entirety, the core sediments were strongly organic, most of which were 45–70% OM by dry

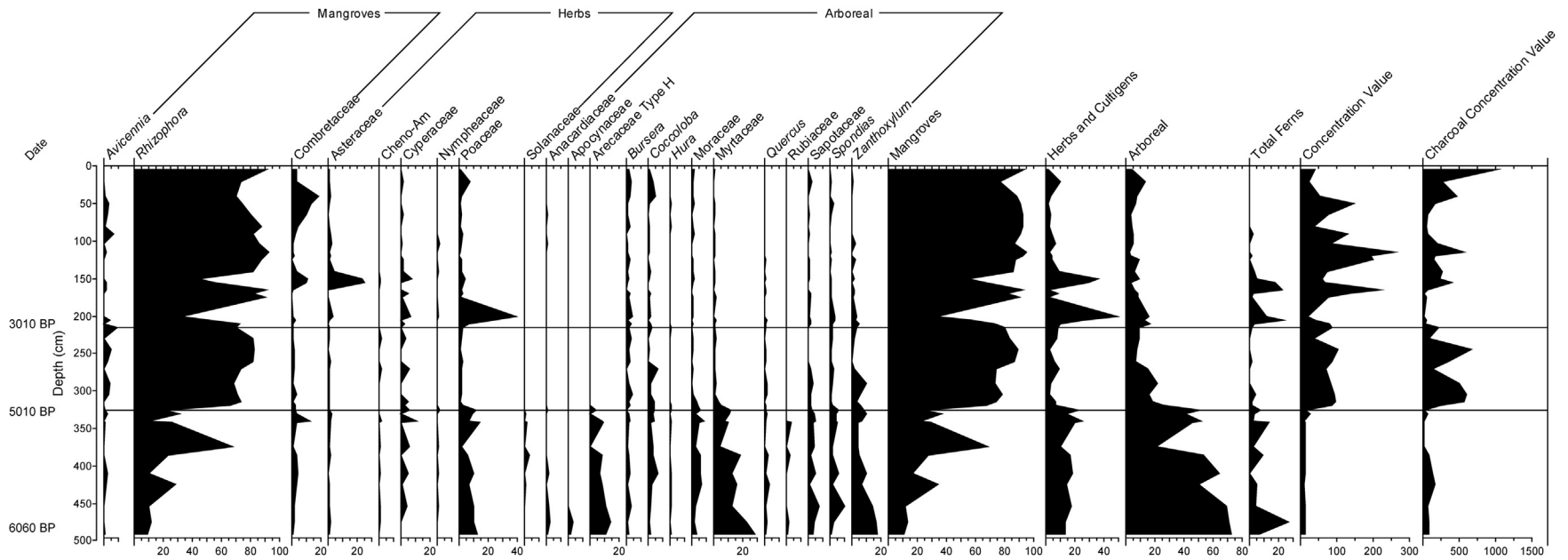


Fig. 3. Meadow Beach, Grenada core pollen-percentage diagram. Pollen and charcoal concentrations are expressed as grains and fragments, respectively, per cm³ of sediment. Charcoal-concentration values spiked and remained elevated between c. 5010 and 3010 median cal yr BP. Prior to this period of large-scale fires ethnobotanically useful taxa were relatively well represented, including Poaceae, Solanaceae, Arecaceae, Moraceae, Myrtaceae, Sapotaceae, and *Spondias*.

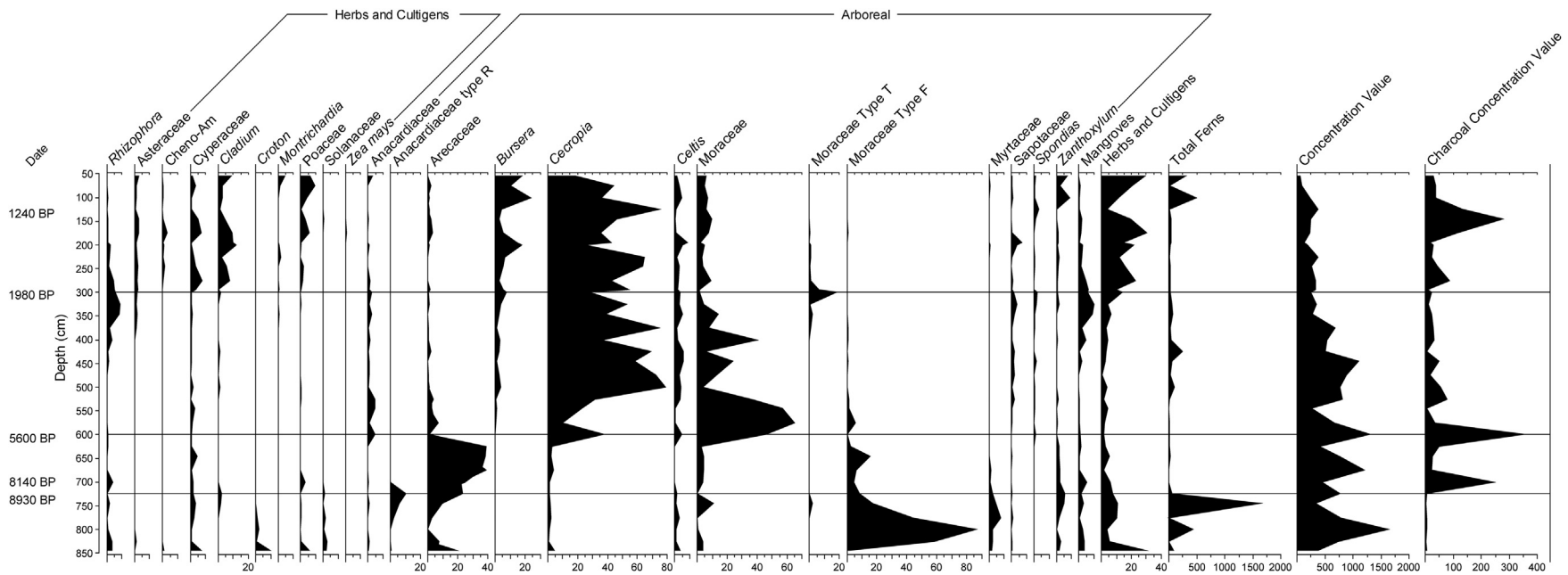


Fig. 4. Lake Antoine, Grenada core pollen-percentage diagram. Pollen and charcoal concentrations are expressed as grains and fragments, respectively, per cm³ of sediment. Anthropogenic inputs from approximately 600 cm include disturbance indicators of *Cecropia* and charcoal microparticulates. Ethnobotanically useful taxa include Anacardiaceae, Arecaceae, Moraceae, Sapotaceae, and *Spondias*. It is possible that the elevated values of charcoal, Arecaceae, and herb totals at 700 cm also reflect early human activities. However at this stage of research, the associated date of median 8140 cal yr BP is too old and lacking other regional archaeological or paleoenvironmental evidence for early human occupations we regard the 700-cm assemblage to be linked to natural disturbances associated with dry conditions in the early to mid-Holocene. Cultigens are represented by a minor amount of *Zea mays* at 175 cm.

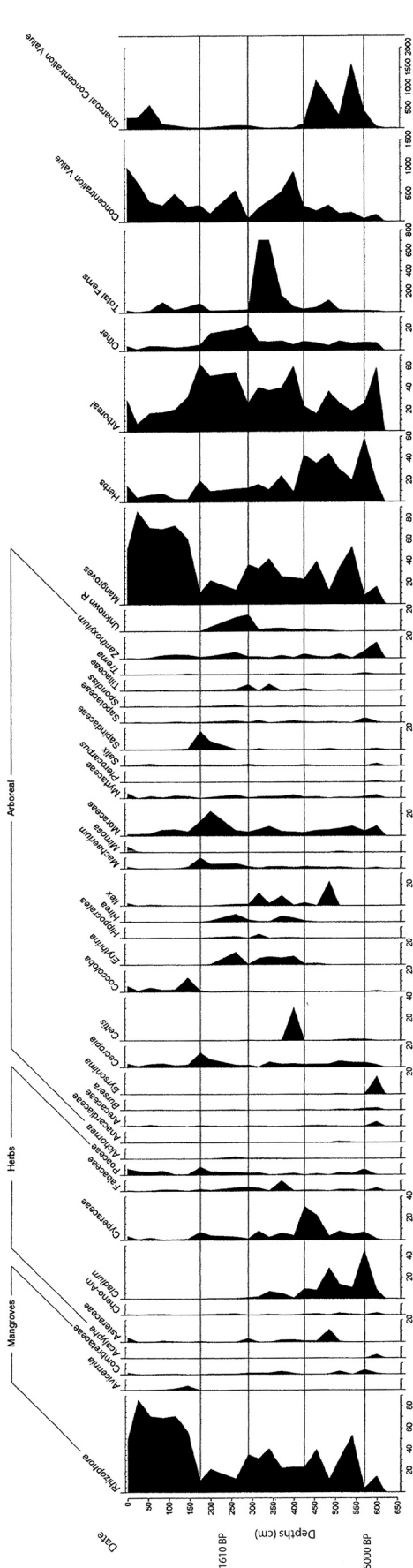


Fig. 5. Baie de Fort-de-France, Martinique core pollen-percentage diagram. Pollen and charcoal concentrations are expressed as grains and fragments, respectively, per cm^3 of sediment. Anthropogenic inputs between 575 and 425 cm include disturbance indicators of *Cladium*, Poaceae, Asteraceae, Cyperaceae, and charcoal microparticulates.

Table 3

Earliest available Archaic single radiocarbon dates per island from the Lesser Antilles/southern Caribbean associated with archaeological deposits or sediments with evidence of human activities in order from oldest to most recent.

Island/location (source of information)	2 σ cal. age range	Cal. median year ^a
Trinidad/Banwari Trace site (Boomert, 2000)	8170–7850 BP	8000 BP
Barbuda/Strombus line (Watters et al., 1992)	6150–5650 BP	5890 BP
Grenada/Lake Antoine (current project)	5710–5470 BP	5600 BP
Tobago/Milford 1 site (Boomert, 2000)	5380–5030 BP	5200 BP
St. Martin/Etang Rouge 3 site (Bonnisent, 2009)	5290–5020 BP	5160 BP
Curaçao/Rooi Rincon site (Haviser, 1987)	5310–4890 BP	5150 BP
Antigua/Birgits site (de Mille, 2011; Nodine, 1990)	5280–4980 BP	5140 BP
Martinique/Baie de F-de-F (current project)	5270–4870 BP	5000 BP
Marie-Galante/Vieux Fort (current project)	5280–4840 BP	4960 BP
Barbados/Heywoods site (Fitzpatrick, 2011)	4690–4410 BP	4540 BP
Anguilla/Whitehead's Bluff site (Crock et al., 1995)	3665–3405 BP	3530 BP
Saba/Plum Piece site (Hofman and Hoogland, 2003)	3585–3410 BP	3510 BP
St. Croix/Coakley Bay (current project)	3160–2950 BP	3030 BP

^a CALIB 7.0 (Reimer et al., 2013) was used to calibrate the dates and compute the cal median values.

weight. The mineral fraction of the core increased notably in the upper two meters, especially near the surface reflecting changing land cover and use patterns in the watershed. Rising sea level is indicated by elevated sediment salinity values and aggradation between 600 and 450 cm, followed by a period of stabilization, then slightly more seawater incursion above 200 cm, possibly a product of instability in the mangrove ecosystem.

The basal zone (625–575 cm) was dominated by *Cladium* (sawgrass), other sedges, *Byrsonima*, Moraceae, and *Zanthoxylum*. Red mangrove pollen was present but reduced compared to later quantities. This assemblage reflects a swamp forest and slightly brackish environment.

The next zone (575–425 cm) represents a similar environment with elevated amounts of mangroves and fewer arboreal elements. *Cladium* and other sedges remain common. Charcoal values began to increase in the upper portion of the basal zone by 600 cm along with increases in pollen concentrations of Poaceae and Cyperaceae, colonizing taxa associated with open, cleared spaces. One pollen sample revealed a spike in Sapotaceae, an edible-fruit-bearing tree. Preserved plant matter from 575 cm was dated to c. 5000 cal yr BP (Beta-341060, Table 2). Increases in Asteraceae and Cyperaceae pollen were documented by approximately 500 cm. These herbaceous families include weedy invaders of cleared, open areas. The pollen and charcoal assemblage from this zone may represent an actively managed anthropogenic landscape. The interpreted signal of human activity from c. 575–425 cm occurred during the mesic conditions of the mid-Holocene. Following the earliest evidence of human intervention in the area, charcoal concentration values declined to negligible levels, suggesting that human activities in the local area were minimal although indicators of clearings remained elevated (*Cladium*, Cyperaceae, *Cecropia*). Adequate organic material was not available at 425 cm to date the decline in charcoal concentration values. There is good archaeological evidence for settlements on the island by c. 2400 BP (Bright, 2011).

A core from the Pointe Figuier wetland along the south coast displayed nearly continuous elevated Cyperaceae, Fabaceae, Moraceae, Myrtaceae, Poaceae, *Brysonima* (base of core), and charcoal concentration values from c. 2740 cal yr BP (AA82677) through historic occupations, indicating again the presence of humans during the Late Archaic (late middle Holocene) and later (Fig. 6 and Fig. S5; Table 2). Coarse sand in the lower part of the core is composed chiefly of pulverized coral and marine shells. Prior to c. 2600 cal yr BP, the coring location was either closer to the shoreline or more open to the ocean, possibly a tidal flat before aggradation.

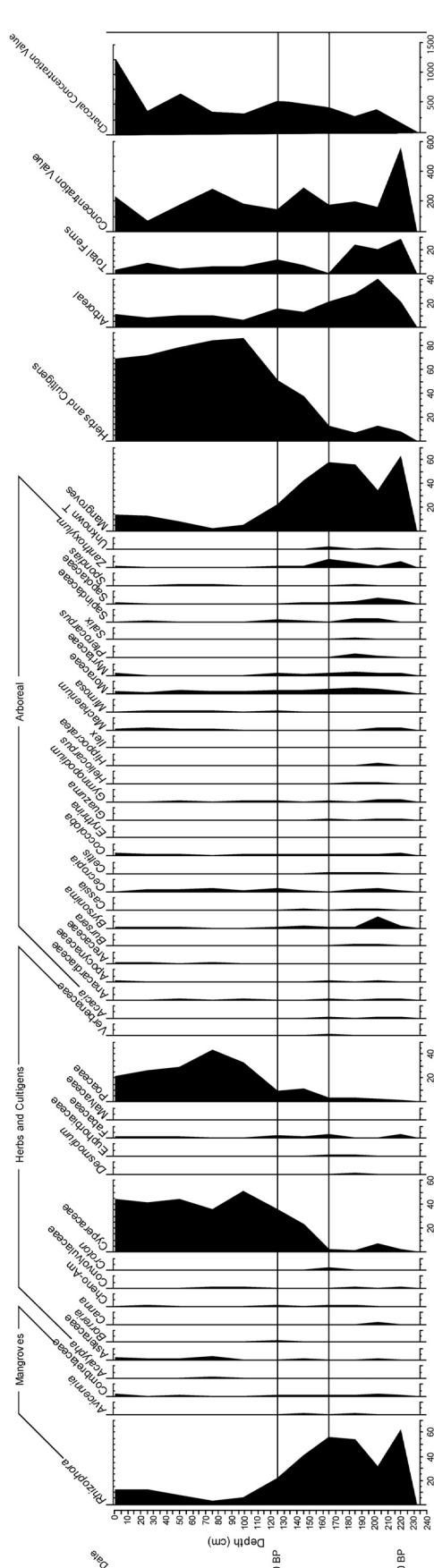


Fig. 6. Pointe Figuier, Martinique core pollen-percentage diagram. Pollen and charcoal concentrations are expressed as grains and fragments, respectively, per cm³ of sediment. Anthropogenic inputs from the core base include *Camra*, *Cyperaceae*, *Fabaceae*, *Moraceae*, *Myrtaceae*, *Poaceae*, *Brysonitria*, and charcoal microparticulates. Elsewhere in the Neotropics, *Camra* has been documented to be a cultivar and propagated for its edible roots (Gade, 1966; Piperno and Pearsall, 1998).

Proximity to the shoreline is reflected in elevated sodium levels in the lower strata. A stratigraphic break at 162 cm most likely reflects a scouring event and truncation of sedimentation. The composition of sediments, including terrestrial gravels and other large clasts above the unconformity suggests that the scouring event was fluvial in nature. The most likely scenario is a major storm and consequent flooding. The position of Anse Figuier in a small embayment on the south coast of Martinique could have made it particularly vulnerable to hurricanes. Storms may have also reconfigured coastal bars and beaches isolating the coring location from the coast as reflected in decreasing sodium levels in the sediments.

Two possible Archaic sites (Boutbois, Godinot) have been identified in northern Martinique (Allaire and Mattioni, 1983). On reexamination these sites may or may not be of Archaic age; they may be special-purpose aceramic sites dating to the ceramic age, although the lithic assemblages from the two sites are similar in character to Archaic sites documented on Trinidad (Bérard, 2006a, 2006b; Boomert, 2000). Charcoal collected from Boutbois produced a date range of 1700–1320 cal yr BP (2σ), clearly postdating the Archaic age (Bérard, 2006b). The best evidence for early human activities on Martinique comes from the Baie de Fort-de-France core, considerably earlier than current archaeological data from the island.

4.4. Marie-Galante (Guadeloupe)

Marie-Galante is situated along the forearc of the Lesser Antilles subduction zone, a mainly submarine ridge of uplifted seafloor; the island is composed of uplifted Pliocene to Holocene-age coral limestone reef structures of generally very low relief (Fig. 1). A nearly 7-m core collected from a wetland along Riviere du Vieux Fort produced a basal date of c. 6530 cal yr BP (AA82675, Table 2). At that time, mean sea level was approximately 2 m lower than today and was slowly rising. High Na and S levels and OM preservation in the basal sediments reflect a stable, brackish, moderately high saline mangrove-forest habitat. Disturbance-indicating vegetation is reduced and particulate charcoal is almost wholly lacking in all samples from this basal zone, representing a non-anthropogenic landscape (Fig. 7; Table 3).

With rising sea levels the red mangrove environment was destabilized reflected by sandy, shell-rich deposits beginning at 464 cm. Superadjacent sediments indicate a nearer-to-shore lagoonal environment with frequent bands of biogenic marls and increased salinity. A high concentration of mollusk shells between 464 and 440 cm is indicative of the die-off of species present in formerly stable mangroves. The marl layers are a product of autochthonous biogenic sediments forming either within algal mats or via pelletization during episodes of Ca supersaturation within stagnant backwater contexts. Clay strata were deposited during still-water episodes. Periods of marl and clay precipitation were interrupted by development of organic strata, reflecting resurgence of mangrove forest in the area. Concentrations of *Neritina* shells with evidence of in situ predation at 396–398 cm also indicate a period of brackish mangrove habitat stabilization.

Beginning at 400 cm, dramatic and sustained increases in particulate charcoal concentrations were documented (Fig. 7; Table 1). This period of elevated charcoal concentrations was bracketed by the dates of c. 4960 and 3120 cal yr BP, which is associated with the mid-Holocene period of wet conditions in the Caribbean (Table 2). Pollen concentration values for invasive weedy and economically useful taxa increased at this time. Disturbance-indicator taxa included *Asteraceae*, *Poaceae*, *Cyperaceae*, and *Cecropia*. With the clearing of local forests plants of economic value were selectively spared and encouraged, resulting in what were previously low pollen concentrations with higher values. Economically useful

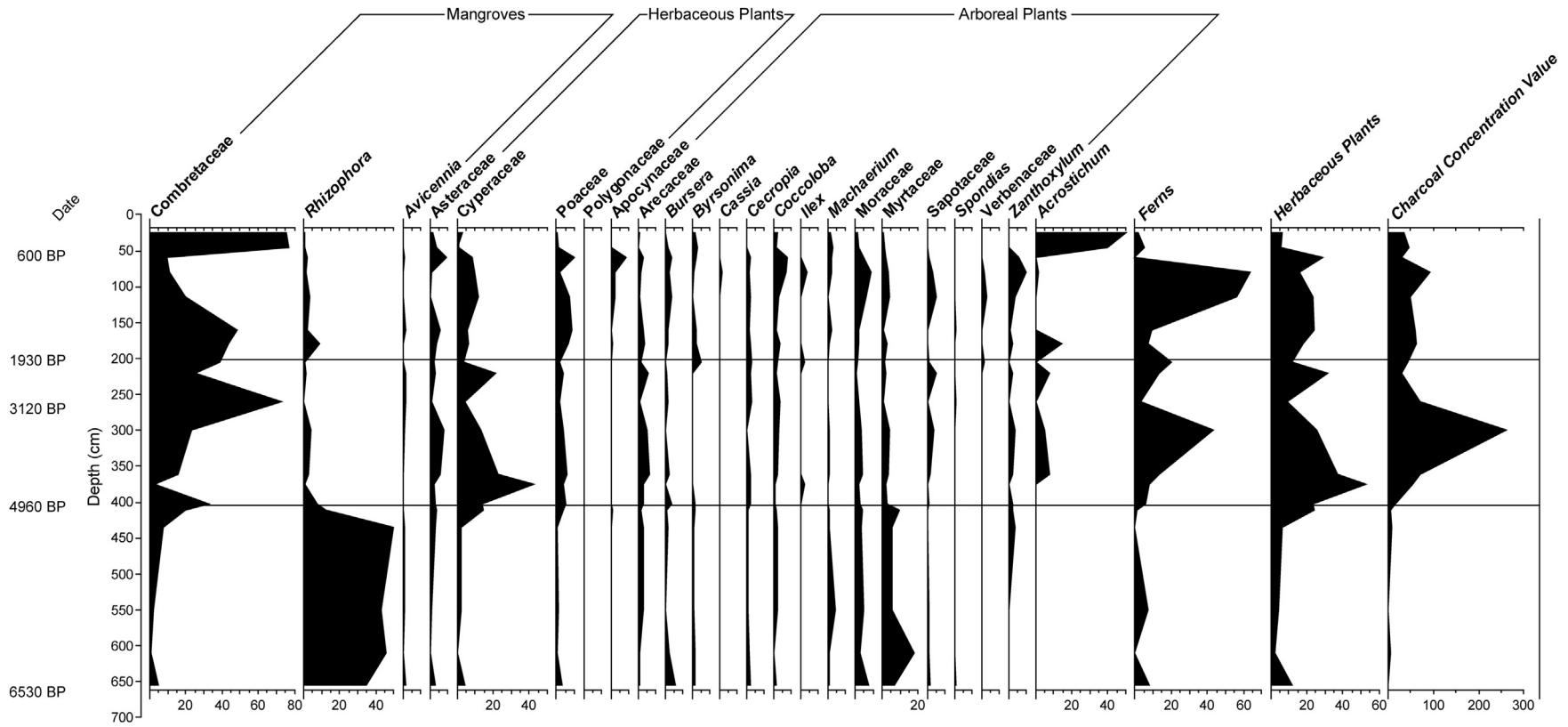


Fig. 7. View Fort, Marie-Galante core pollen-percentage diagram. Pollen and charcoal concentrations are expressed as grains and fragments, respectively, per cm³ of sediment. Landscape transformations are evident from 400 cm, with disturbance indicators including Asteraceae, Cyperaceae, Poaceae, *Cecropia*, and charcoal microparticulates. Ethnobotanically useful taxa include Arecaceae and Sapotaceae. The structure of the mangrove community changed dramatically with the near-disappearance of *Rhizophora* and replaced by *Combreataceae*.

plant taxa included *Arecaceae* (palm family) and *Sapotaceae* (*Sapotaceae* family). It is not clear what accounts for the replacement of the *Rhizophora* (red) by the *Combretaceae* (white) mangrove communities, although evidence of rising sea level by 464 cm may be linked to the reduction in red mangrove at about 410 cm. Major increases in charcoal concentration values beginning at 400 cm may or may not be related to the shift in mangrove communities. Red mangrove has been documented to be a superior fuel wood (Morton, 1965) however its' diminished presence in the Marie-Galante pollen record predates by an unknown number of years the significant increase in probable anthropogenic fires. The charcoal and pollen data reflect a human-modified if not actively managed landscape by c. 5000 cal yr BP, considerably earlier than archaeological evidence for human occupations on Marie-Galante.

4.5. Summary

Paleoenvironmental data collected from a core in Nariva Swamp, Trinidad indicate that humans were modifying and perhaps managing landscapes in that region nearly 2000 cal yr before initial colonization of the Lesser Antilles. Certainly floristic communities in many of the Lesser Antillean islands were recognizable to the first colonists, clearly attested to by the many similarities in plant taxa documented in the pollen and phytolith data (Tables S1 and S3). The landscape-learning curve was not demonstrably steep for pioneering groups entering the islands for the first time.

Data collected from cores on Grenada, Martinique, and Marie-Galante are consistent in the timing of initial human colonization approximately 5000 cal yr BP, although a date from the Lake Antoine, Grenada core suggests human presence as early as c. 5600 cal yr BP. Evidence from this mid-Holocene era consists of considerable and sustained increases in charcoal particulates and shifts in pollen and phytolith spectra related to plants representing disturbances or perturbations to landscapes and increases in economically useful taxa. These data represent initial human occupations of the islands, whereby landscapes were modified and eventually managed.

From the perspective of landscape ecology, human-derived perturbations created greater heterogeneity in ecosystem structure than what was present prior to colonization. Native economically useful plants most likely were nurtured in managed landscapes as first colonists created places recognizable to them as home. In this regard, newly occupied and modified places were manifestations of transported landscapes, not in the sense of physically bringing in new species from elsewhere but in a cognitive and behavioral sense; knowledge of and lifeways practiced in their previous homelands were drawn upon in the colonization and humanization of landscapes (Thomas, 2008).

5. Revised understanding of Caribbean island colonization

A large suite of ^{14}C dates is now available from Trinidad and Tobago, the southern Caribbean, and the Lesser Antilles falling within the range of early to middle Holocene (Archaic) occupations in the Caribbean and which are associated with archaeological deposits or anthropogenic landscapes (Table S2). Contrary to recent suggestions for a minimal to non-existent presence of Archaic occupations in the islands south of the Guadeloupe Passage (Callaghan, 2010) it is clear that humans were well-established in the southern Lesser Antilles during that time. If Archaic inhabitants were coastally oriented and sea level is 2–4 m higher today than 4000 to 5000 years ago it is likely that many of those early sites are now inundated.

The dates associated with Archaic archaeological sites or anthropogenic landscapes are ordered from oldest to most recent

and as a group represent latest possible dates of initial colonization (Table S2). At 2σ , most dates overlap with each of the two adjacent dates. There is a general geographic progression from south to north in the distribution of the oldest dates on each island (Fig. 8; Table 3). Trinidad was the earliest occupied island based on dates from the Banwari Trace and St. Johns sites and anthropogenic contexts in Nariva Swamp. If the remaining dates reflect general colonization rates of the islands then there is a significant temporal gap or occupational pause between Trinidad and Grenada. Geologically and culturally Trinidad and northern South America are connected (Bellizzia and Dengo, 1990; Boomert, 2000). Boomert (2013) suggested that hunters and foragers may have occupied Trinidad by approximately 10,000 BP before sea-level increases created the island, although there is no solid archaeological or paleoecological evidence for a human presence on Trinidad at that time.

It is unlikely coincidental that there is a temporal gap of at least 2500 to 3000 years between the earliest evidence of human activities on Trinidad and Grenada and that the shortest straight-line distance between the two islands is about 140 km, considerably longer than interisland distances amongst any of the Windward Islands except for Barbados (Bright, 2011). It is impossible to say with any certainty what the push or pull factors were that prompted the first individuals by c. 5600 cal yr BP (dates from the Grenada cores) to embark on the 140-km journey from either Trinidad or the north coast of Venezuela. Overcrowding or inadequate food or other resources were unlikely push factors, especially during that era of low population densities based on available site distribution data (Boomert, 2000). Without resorting to notions of aimless drift, accidental voyaging, or random walking perhaps terms other than “push” or “pull” might better characterize some instances of exploration and colonization of new places. People did move into the islands beyond Trinidad and at the moment we do not know why.

By approximately 5600 cal yr BP, Grenada and many if not all of the remaining islands in the Lesser Antilles up to Antigua were being investigated, if not settled. Therefore, following the long pause between Trinidad and Grenada, human dispersal through the eastern Caribbean was rapid. Similar colonization patterns have been documented in the Pacific, whereby Near Oceania (island groups proximate to New Guinea and Australia) was settled first followed by a long pause before the westernmost islands of Remote Oceania were colonized. Of course, distances between islands or island groups of the Caribbean and the Pacific are markedly different; compare 140 km between Trinidad and Grenada to 380 km between Santa Anna of eastern Near Oceania and the Santa Cruz islands of western Remote Oceania and then 800 km between Vanuatu and Fiji within Remote Oceania (Kirch, 2010a). However, the colonization process seems to be the same for the Caribbean and Oceania: pulse between mainland and nearest islands/island groups, pause between islands/island groups separated by great expanses of water, followed by additional pulse(s) and rapid expansion (Terrell, 2011; Wilmschurst et al., 2011).

Alternative explanations may account for high percentages of disturbance indicators in many of our core samples dating to the mid-Holocene. Brief forays or scouting investigations may result in sufficiently modified landscapes to produce shifts in the microfossil spectra. Optionally, some landscapes were visited and prepared for later use without being occupied. The paucity of Archaic archaeological sites in some cases could be linked to the practice of land preparation without occupation. However, a single human-generated conflagration followed by departure of the people without returning would be difficult if not impossible to distinguish from a natural fire event because of the spike in microfossil indicators of disturbance without sustained elevated percentages of those microfossils.

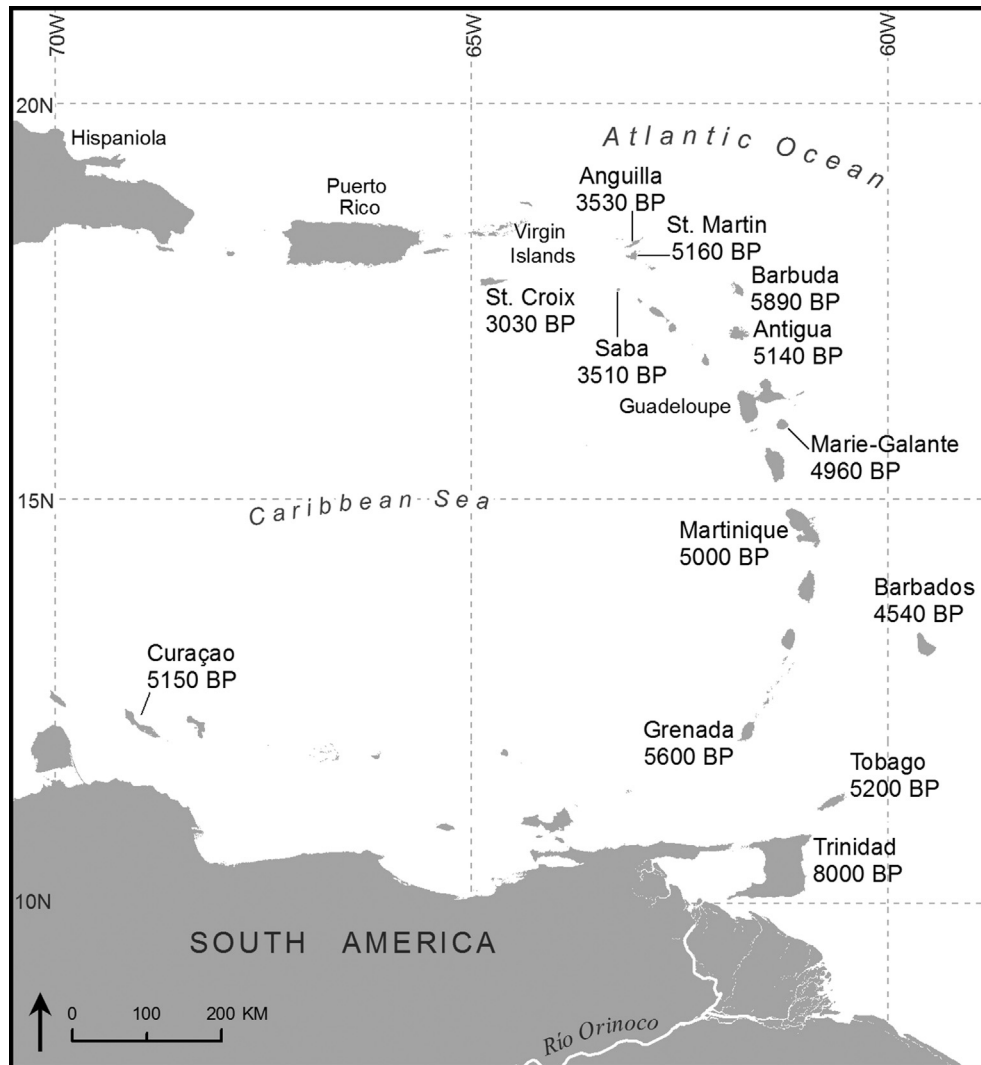


Fig. 8. Map of the eastern Caribbean showing the earliest calibrated median radiocarbon dates associated with archaeological deposits or anthropogenic landscapes.

Balée and Erickson (2006, p. 1) observed “wherever humans have trodden, the natural environment is somehow different, sometimes in barely perceptible ways, sometimes in dramatic ways.” Environmental differences, or perturbations, are discernible given appropriate recovery and analytical techniques. We documented anthropogenic landscapes at times when and places where archaeologists traditionally have assumed humans were not present (Burney, 1997a, 1997b; Jones, 1994; Neff et al., 2006; Pohl et al., 1996).

The effects of human actions may be more apparent or dramatic in island ecosystems than elsewhere because of their circumscribed relatively isolated geographies (Kirch, 1997). In terms of island historical ecology, the Pacific has been the focus of the most wide-ranging and detailed studies (Athens et al., 2002, 2014; Kirch, 1996; Kirch and Hunt, 1997; Vitousek et al., 2004). For the Caribbean, Fitzpatrick and Keegan (2007) observed that the earliest occupants of the islands must have impacted them through land clearing probably through the use of fire. As documented in the present study, fire seems to have been the tool of choice in modifying and eventually managing Caribbean landscapes for millennia. More generally, Foley et al. (2014, p. 85) suggested that from earliest human history fires “may have caused the first appreciable anthropogenic effects on ecology.”

Data from the current project suggest blended strategies of scouting, initial colonization, population infilling, abandonment, and re-occupation as a continuous process throughout the full range of human history in the Caribbean. Concerning initial island colonization, reliance on standard archaeological data from excavated sites is not sufficient. Archaeological surveys and excavations should be combined with sediment data collected from judiciously selected settings for the potential of containing preserved microfossils indicative of human-derived disturbances or modifications to paleolandscapes.

In a number of cores, disturbance indicators and attendant economically useful plant taxa were documented early in the Holocene followed by the absence or considerably diminished presence of disturbance indicators but continued presence of economically useful taxa. As landscape ecologist Monica Turner remarked, “All landscapes have a history [and that] ... disturbances can also leave legacies that persist for decades to centuries” (Turner, 2005, p. 321). And as historical ecologist William Balée observed, “intermediate disturbance may have lasting legacies ... in terms of redefining vegetation patterns” (Balée, 2006, p. 78).

From the perspective of island biogeography and human colonization history in the Caribbean, ideas developed by Rouse (1986, 1992) need to be revisited. Rouse introduced, modified, and refined

ideas about multiple colonization events of the islands and subsequent cultural developments. In addressing the early ceramic-age or Saladoid occupations from the Orinoco Valley through Puerto Rico, c. 2500 cal yr BP, Rouse documented a series of cultural complexes purportedly older in Venezuela and successively younger moving through the eastern Caribbean. He developed and refined the stepping-stone model of island colonization during the early ceramic age, arguing that groups of horticulturalists targeted high volcanic islands and bypassed low islands lacking large forests (Rouse, 1992). Some archaeologists have refuted the stepping-stone model, arguing that evidence to date indicates the earliest ceramic-age colonists jumped directly from South America to the northern Lesser Antilles and Puerto Rico (Fitzpatrick, 2013; Fitzpatrick et al., 2010; Keegan, 2010).

Based on dated anthropogenic landscapes identified in the current study and previously reported ^{14}C dates from Archaic sites, we propose that the stepping-stone model applies also to the initial colonization of the eastern Caribbean (Fig. 8; Tables 3 and S2). One might view the old dates from Antigua and Barbuda and St. Martin as contradicting this argument. As discussed earlier, there were two independent entry routes for the earliest colonization of the West Indies: the Yucatán Peninsula from the north and northern South America from the south.

The core-and-blade technology documented in many of the Archaic sites on Antigua culturally links these assemblages to the groups in the Greater Antilles and ultimately to the Yucatán (Davis, 1993, 2000). Old dates associated with Archaic sites on Antigua and Barbuda and St. Martin should be considered along with contemporaneous and older dates from Puerto Rico, Hispaniola, and Cuba (Wilson, 2007, Fig. 2.6). When Archaic occupations on Antigua and Barbuda and St. Martin are grouped with those from the Greater Antilles and Yucatán then the stepping-stone model makes sense for first colonization of the eastern Caribbean from northern South America and Trinidad.

6. Island historical ecology, paleolandscapes, and first colonization

Pollen and phytolith data presented in this paper reveal tropical island paleolandscapes teeming with a diverse range of plant taxa, as most humid-tropical landscapes do that are not separated by hundreds of kilometers from other islands intimately linked to mainland areas (Fritsch and McDowell, 2003; Kirch, 2010a, b). Except for Nariva Swamp on Trinidad and Pointe Figuiier on Martinique, all cores bottomed out in contexts that pre-dated human colonization. As such, we were afforded opportunities to document directly the effects of initial island colonization on local landscapes. In no cases did we identify extirpation of existing or introductions of new plant taxa with the first arrivals of humans. To be sure, major shifts were identified in some of the microfossil spectra reflecting changes in the organization of associated floristic communities.

In total, these data reveal important aspects of the humanizing process of natural landscapes. There is no evidence that first colonists introduced new cultigens or exotic plants in general. Yet coming out of Trinidad or northern South America these newest arrivals to the islands brought their foraging, collecting, and hunting lifestyles with them, along with preconceived notions for how their new landscapes should be structured. Landscapes in many of the islands were broadly recognizable and comparable to ones from their homelands.

In terms of colonization processes and issues of landscape learning, we argue that initial humanization of new places is linked directly to broad-spectrum subsistence adaptations. Boomert (2000) made this point in regard to the foraging, collecting,

fishing, and hunting strategies of the earliest occupants of Trinidad, c. 8000 cal yr BP, which were related to the same lifestyles of their ancestors in the marshlands of northeastern South America and coastal Central America. Regarding first colonization of the Americas, Paleo-Indians were traditionally linked to a focal subsistence economy specialized to big-game hunting (Martin, 1984; Mason, 1962; Waguespack and Surovell, 2003). This view may have been skewed by preservational bias in the form of spectacular lithic assemblages and faunal remains of large animals. Older excavations that did not employ fine-sieving techniques and flotation reinforced such conceptions. With the use of more-rigorous recovery methods it now appears that the earliest colonists to the Americas relied on a broad range of plant and animal resources depending on characteristics of local habitats (e.g., Byers and Ugan, 2005; Cannon and Meitzer, 2004; Fiedel, 2000). The broad-spectrum subsistence adaptation, linked to specific characteristics and taxonomic diversity of local habitats, may be thought of as a form of some mix of opportunistic foraging, collecting, hunting, and fishing (Gingerich, 2011).

More relevant comparisons for the current investigation relate to other island contexts. When appropriate recovery and analytical methods were employed, the oldest-known Pleistocene sites in the Bismarck and Solomon islands of the Pacific revealed subsistence strategies based on a broad range of terrestrial and marine resources, including plants and animals (Kirch, 2000; Leavesley, 2006; Loy et al., 1992). Similar observations concerning diverse resource sets have been made for Neolithic and pre-Neolithic or Epipaleolithic occupations in the Mediterranean (Knapp, 2010; Phoca-Cosmetatou, 2011).

Addressing the first Mediterranean islanders, Dawson (2011) observed that colonization does not necessarily equate to full-blown settlement. Instead, the term “colonization” subsumes a range of non-mutually exclusive occupational strategies, including temporally and spatially narrow visitations linked to the activities of small scouting parties (Cherry, 1990; Dawson, 2011). Similar to the Caribbean Saladoid, considerably more Early and Middle Neolithic sites are documented in the Mediterranean than earlier ones, although Dawson (2011) noted that with ongoing research there is increasingly more evidence for pre-Neolithic occupations. With systematic paleoenvironmental studies, the view of the pre-Neolithic presence across the Mediterranean islands no doubt will be considerably modified to take into consideration the potential for small but perhaps widespread and numerous scouting and colonizing parties, resulting in anthropogenic landscapes that had fundamental implications for later Neolithic communities.

7. Final comments

First colonization of new landscapes, especially in the context of archipelagos, was by small groups of people difficult to identify archaeologically. Once people ventured into the frame of the island world they traveled quickly, following a mix of strategies including scouting-and-moving on or scouting-and-settling. Alternative colonizing strategies result in somewhat different trajectories of landscape modification and management. Once people occupied or even subtly modified a natural habitat, the legacy of human history has been inscribed into the landscape. Later groups of different people or descendants of the original colonists will make yet additional modifications and so on through time, so that by today the landscape contains a cumulative record of anthropogenic history.

In this investigation of Caribbean paleolandscapes and island colonization, it is clear that people were moving into places comfortably if only broadly recognizable to them in terms of floristic communities. Yet the scale of the Caribbean archipelago is

considerably different than others in the world. The x , y linear distances of c. 11,600 km by 8600 km approximate the geographic extent of Oceania, which dwarf the distances of c. 2900 km by 1600 km in the Caribbean (Kirch, 2000, Map 1; Wilson, 2007, Fig. 1.1). With such differences in geographic magnitude, there will be wide variation in colonization rates, push–pull factors, and degrees of landscape familiarity and resulting trajectories of landscape engagements.

To identify variable trajectories of landscape engagements, research must be explicitly interdisciplinary, incorporating the expertise and perspectives of archaeologists, geographers, soil scientists, ethnobiologists, paleoecologists, and climate scientists. In so doing, understanding will be furthered concerning interrelated domains of island or continental survival strategies including colonization patterns, modifications of and adjustments to varying landscapes, and the continuum between environmental degradation and sustainability. The successes of these kinds of studies hinge on carefully considered, systematic, and fine-grained data-collecting protocols; close collaboration among disciplinary specialists; and willingness to consider alternative perspectives as research progresses. Systematic paleoenvironmental investigations are crucial to continue in archipelago settings, especially to fill out topographic and geographic variability. As the effects of modern climate change, sea-level rise, economic development, and globalization continue it is essential that these kinds of studies be conducted in a timely manner. Otherwise, the settings that contain preserved proxies of paleoenvironments and past human activities will be gone before we know about them.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.quascirev.2015.10.014>.

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