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# Plantscapes of dwelling: Precolonial household mounds, phytocultural dynamics and the ensuing human ecosystems at El Flaco and El Carril (cal. AD 990–1450), northern Dominican Republic

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## ABSTRACT

Caribbean Amerindian societies had sophisticated regional socio-political and economic systems linked to important crops by the late 15th century when Spanish conquerors initiated the invasion of the Americas. These systems soon helped change the dynamics of the world's foodways, and scarce but mounting archaeological and ethnohistoric evidence suggests that the Spaniards and later European intruders gained symbolic and factual control of primary subsistence scenarios in the region by exploiting the Amerindians' plant foodways systems, lands and political institutions. The aim of this study is to better understand the emergence and evolution of human–plant interrelationships before 1492, and the role which this played in the consolidation of foodways systems that later benefitted early European survival and domination in the Americas. To achieve this, we applied the first onsite multiproxy approach in the insular Caribbean based on phytoliths and other auxiliary data to stratigraphically arranged soil layers from several household mounds of two precolonial settlements in northern Dominican Republic (Hispaniola). Results indicate that these settlements were established in ecotonal lower montane moist/mesic forests with differential biodiversity, and varied socio-environmental choices and constraints encouraged the configuration of divergent plantscapes of dwelling there. The applied analytical perspective demonstrates the necessity of expanding, deepening and refining the used approach to illuminate the human and environmental dynamics which helped shape the ancient plantscapes in the Caribbean at the eve of the European irruption of the Americas.

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## 1. Introduction

Several ancient artificial mounds recently excavated at two settlements in northern Dominican Republic (Fig. 1) have yielded a series of stratigraphic and artifactual features that reveal their complexity and multifaceted genesis, always associated with diverse dwelling activities (Hofman et al., 2018; Hofman and Hoogland, 2015; Veloz Maggiolo et al., 1976). Across time, these “household” mounds (commonly labeled as trash middens or trash mounds in the specialized literature) were locales outside of houses simultaneously nourished with intentionally discarded artifacts, kitchen refuse, rocky fill removed from

nearby locations, and naturally occurring colluvial soils from surroundings forests, together with vegetal debris from cultivated and opportunistic plants that probably grew on them. Specific material constituents of these mounds (i.e., animal and plant food remains, related byproducts and ashes) were periodically deposited by the use of these same spaces as hearth waste dumping areas, or as active kitchen settings. Sometimes, other superstructural activities such as the burying of the dead, contributed additional materials and cultural meanings to these dwelling components or mounds (e.g., Hofman and Hoogland, 2015; Keegan and Hofman, 2017). These archaeological features were formed outside the houses by a combination of natural and cultural processes which eventually incremented their size and height, representing what can be called true human ecosystem engineering works (sensu McKey et al., 2010). It is not possible to establish with certainty if these household mounds were expected to be, from the beginning of their formation, the topographic protuberances that they finally turned out to be. However, due to these locales being embedded in different activities through time, their meanings could have been similarly variable, precisely according to the diverse dwelling activities and broader societal processes to which people and these particular locales were attached to.

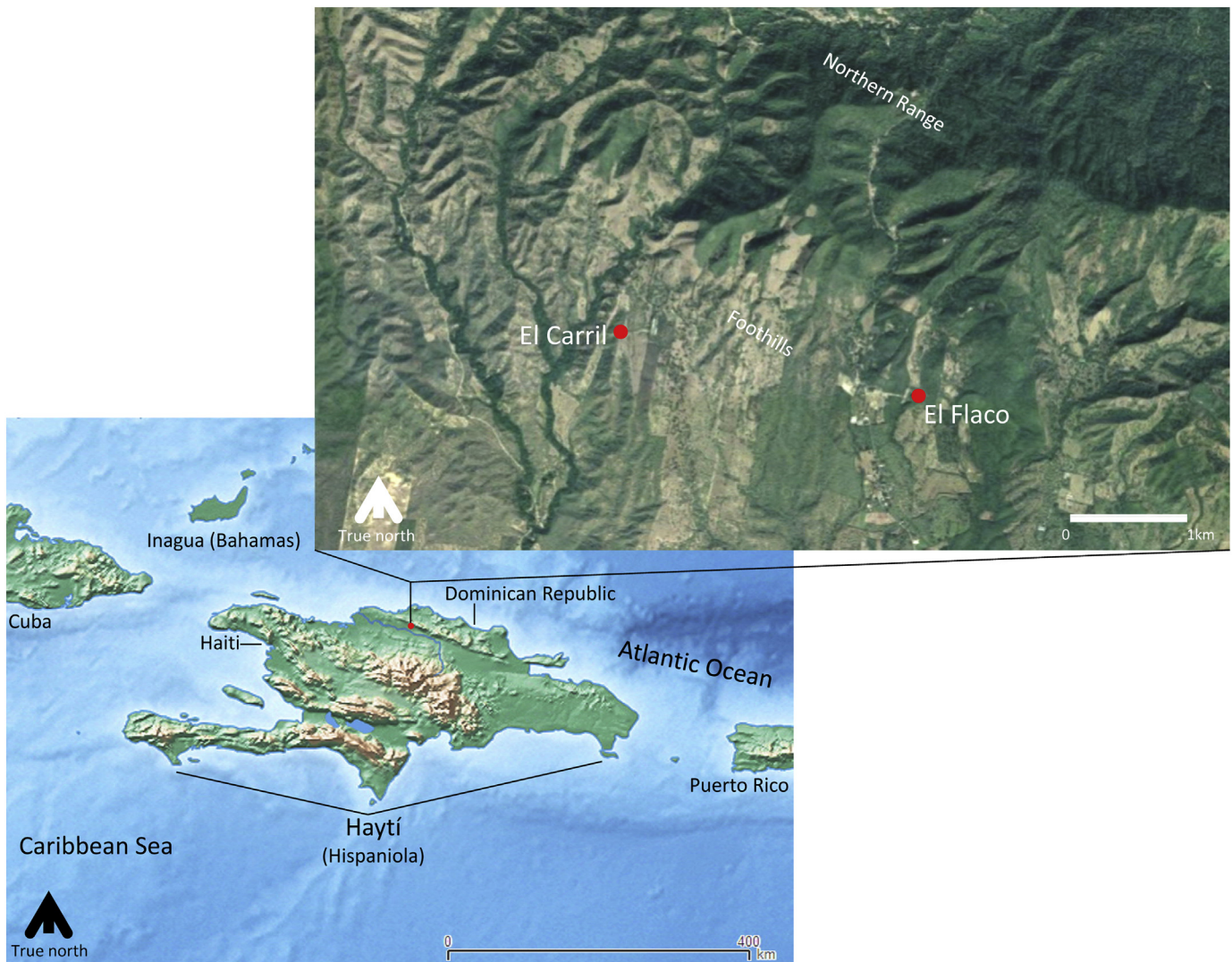
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**Fig. 1.** General location of the studied region and archaeological settlements of El Carril and El Flaco, Valverde Province, Dominican Republic. Satellite image: Map Data©2019 (Google Maps™).

Taking advantage of the mixed human and natural genesis of these archaeological features, the main objective of this study is to identify which plants were integrated into such multi-layered household mounds, why they were, and what can be inferred from this. Thus, from a local, onsite perspective, this work applies a multiproxy analytical approach based on phytoliths, basic geochemistry, and archaeological stratigraphy to soils coming from two household mounds of El Flaco (cal. AD 994–1452, median probability dates) and El Carril (cal. AD 1097–1262, median probability dates) respectively (Hofman, 2017; Hofman and Hoogland, 2015). From this, we will gain new insights into the human and floral dynamics that laid the foundation for distinct food systems which were later exploited by Europeans from 1492 onwards.

The above scenario suggests that phytoliths recovered from these features could inform about the very local floral environments that existed before human arrival, particularly the plantscapes that were later created, transformed and used through time in the surroundings of the ancient houses by means of the socio-environmental dynamics of dwelling (sensu Ingold, 2000). From this *dwelling perspective* the household – i.e., the locale where people dwell – can be seen as the main node of a small-scale dwelling network to which other dwelling components (e.g., the house itself, objects, activity settings like kitchens, home gardens, refuse areas and underlying social behaviors) are multi-directionally connected by fluid socio-spatial vectors. Thus plantscapes,

in this context, are some of the resulting and ever-changing products of such interconnections.

The current study attempts to contribute to filling in some gaps of previous paleoethnobotanical and paleoecological approaches regarding plantscape formation and ensuing phytocultural dynamics. Even though phytoliths can be subjected to different dispersal and taphonomic factors once they are integrated into the ground, it has also been demonstrated in recent studies that these microbotanical remains accurately reflect the broad vegetation composition of the immediate surroundings of studied sites (e.g., An et al., 2015; Watling et al., 2016). In the first place, due to the unique physical–chemical properties of phytoliths (rigid plant opal silica bodies), they preserve well in many Neotropical buried soils (Pearsall, 2015; Piperno, 2006), thus providing unique opportunities to garner relevant data on the general background vegetation and some targeted plants that may have gone unnoticed in previous archaeobotanical studies due to poor macrobotanical and starch preservation. Second, the morphometric qualities of phytoliths make them ideal tools for differentiating their plant sources at different taxonomic levels, from order to species level (Zurro et al., 2016). Third, because several plant orders and families (e.g., some herbs, grasses, and palms) produce phytoliths that can be confidently associated with well-known environmental scenarios (Ball et al., 2016), the analysis of their differential behavior in particular moments and through time would allow us to also pay attention to the underlying environment and the

vegetation in and around the studied household mounds. Finally, because phytoliths from many different taxonomic groups could potentially be recovered, several plants and plant parts other than targeted organs identified with previous approaches (wood, fruits, seeds, tubers and rhizomes) may be identified and interpreted.

## 2. Caribbean Amerindian plantscapes of dwelling

The first depictions of forest management practices by Caribbean Amerindian societies were offered by Christopher Columbus in his journal of his first voyage to the Americas in 1492. He recorded what he observed in the mountainous region near Monte Cristi (today's northwestern Dominican Republic), describing it as beautiful highlands and hills running east to west with most of the land worked by people (Colón, 2006) – perhaps also referring to the region of our study. His descriptions suggest that the landscapes and forests from this region might have been considerably modified by Amerindian societies, primarily for agricultural purposes. In this regard, Fernández de Oviedo (1851) observed later in the first quarter of the 16th century that the indigenous people of Hispaniola used slash and burn for preparing the land, especially in forested areas. This practice, together with another one widely known as *montones* (agricultural mounds), were in vogue in Hispaniola (today's Haiti and Dominican Republic) at least from the late 15th century, both being used to produce Amerindian main staple crops such as sweet potato (*Ipomoea batatas* (L.) Lam.), maize (*Zea mays* L.), and manioc (*Manihot esculenta* Crantz) (Las Casas, 1909). However, besides the chronological distance between Fernández de Oviedo's notes and the precolonial times in which said indigenous practices could have emerged, Columbus' first descriptions of the big smoke columns near settlements indicates that at least the use of intentional fire on cleared lands was a regular forest management practice, attesting to the precolonial origin of this practice in the island's forests (Colón, 2006). Therefore, based on the earliest Spanish descriptions of Amerindian lands, it is feasible to accept that at least late precolonial and early colonial indigenous communities in the Greater Antilles may have been engineering their forests and cultivation plots on a regular basis for plant production purposes, either by slashing and burning selected forest patches, or by building up *montones*.

Slashed and burned fields were production systems dependent on both the existing top soil and newly added organic material derived from the burning of vegetation (Fernández de Oviedo, 1851). *Montones*, on the other hand were artificial, roundish mounds made up of loose and fertile soil layers (Fernández de Oviedo, 1851; Las Casas, 1909). For instance, considerable numbers of *montones* measuring around 3 m wide and 70 cm high were usually aligned in rows, sometimes forming fields with thousands of them (Las Casas, 1909). It is believed that this agricultural system was efficient enough to produce huge amounts of tuberous food crops such as manioc and sweet potato (Cassá, 1974; Moscoso, 2003). However, there is another Amerindian plant production scenario that was not clearly described by the early chroniclers: the orchards or home gardens. Regarding this, an evident distinction in some early accounts (Fernández de Oviedo, 1851) was made between tilled or carved lands (*labranza*), and orchards (*huertos*), the first being associated with the engineered fields mentioned above. The orchards, in turn, seem to be gardens spatially associated with the immediate surroundings of Amerindian villages and households. In these places many other important neotropical (condiment, food, ritual, medicinal) plants such as chili pepper (*Capsicum* L.), yampee (*Dioscorea trifida* L.f.), peanut (*Arachis hypogaea* L.), squash (*Cucurbita* L.), pineapple (*Ananas comosus* L. Merr.), lerén (*Calathea allouia* (Aubl.) Lindl.), soursop (*Annona* L.), papaya (*Carica papaya* L.), avocado (*Persea* Mill.), annatto (*Bixa orellana* L.) and cojoba (*Anadenanthera peregrina* (L.) Speg.) were likely grown (e.g., Cassá, 1974; Fernández de Oviedo, 1851; Newsom, 2008; Moscoso, 2003; Pagán-Jiménez, 2002). Orchards likely created in partially forested scenarios were probably maintained by simply weeding the ground

(Fernández de Oviedo, 1851), and could have been constantly improved (e.g., fertilized with household byproducts) due to their proximity to the households.

Besides these early Spanish plant management descriptions, the only reliable information on the plantscapes of dwelling comes from paleoethnobotanical research (Newsom, 1993; Newsom and Wing, 2004; Pagán-Jiménez, 2013, 2007). These investigations have provided the basis to better understand different precolonial phytocultural processes in the insular Caribbean by offering varied chronological snapshots of Amerindian knowledge, use and culinary practices surrounding identified plants. However, paleoethnobotanical research has been directed mainly towards the study of broad, general contexts within the confines of selected ancient settlements, usually single refuse areas, without considering detailed stratigraphic sequences of the sampled materials to garner in-depth temporal insights on plantscape formations, variability and transformation. Interpretations provided by these investigations by Newsom and Pagán-Jiménez (referred above) have been useful to portray wide, site-level scenarios on such human-plant interrelationships, but not specific, unique dwelling-related practices involving peoples, (economic) plants and their floral surroundings. The nature and contextual foundations of those studied botanical remains do not allow direct assessments of how, and under what socio-environmental circumstances they were procured and produced. Thus, indirect inferences on these topics have been produced (e.g., Newsom, 2008; Pagán-Jiménez, 2007), although mostly grounded in the cultural biography (sensu Gosden and Marshall, 1999) of the identified plants. Therefore, determining whether these plants were produced, procured, and processed next to the households or in places further from the settlements requires more intensive paleoethnobotanical research of suitable locations adjacent to the settlements and dwellings.

Paleoecological studies in the Caribbean have offered interesting clues to better understand when and how natural floral environments began to be transformed into plantscapes (e.g., Castilla-Beltrán et al., 2018; Lane et al., 2008; Siegel et al., 2015). However, until now, produced interpretations have not been useful enough to chronologically correlate registered anthropogenic changes in the floral landscape with the places directly transformed by human agency. These studies have always been conducted in natural spots, typically far from these humanized places.

## 3. Two ancient Caribbean settlements: El Flaco and El Carril

El Flaco was a hamlet that rose on the southern flank of the Northern Range (Fig. 1). This *cordillera* is the northernmost one of the Dominican Republic, running from east to west. El Flaco is about 2680 m<sup>2</sup> (0.268 ha) and was regularly occupied between cal. AD 990 and 1452 (median probability date range from 13 radiocarbon samples; Hofman and Hoogland, 2015).<sup>4</sup> During the earlier, apparently ephemeral occupation, the inhabitants of the hamlet were producing a mixed pottery tradition reflecting both Ostionoid and Meillacoid features. Later on, the main occupation of the site was started by people principally associated with the so-called Chicoid pottery tradition. This predominant pottery assemblage includes Meillacoid ceramics, and even the incorporation of technological and stylistic characteristics of this tradition into the Chicoid expressions (Hofman et al., 2018; Hofman and Hoogland, 2015). Based on the radiocarbon dates, we estimate that the hamlet was occupied on several occasions. The occupation stages ascribed to cal. AD 1254–1299 and cal. AD 1396–1452 seem to have left more material culture in, and landscape modifications to the site according to the general spread of radiocarbon dates throughout the different hamlet contexts (Hofman and Hoogland, 2015). The settlement activities produced a complex, engineered landscape consisting of several leveled areas where houses were built. The parent material, but

<sup>4</sup> Dates referred in this article were previously calibrated with Calib 7.0.4 and the calibration curve Intcal13.

also soils, artifactual waste, and hearth remains removed from these sectors sometimes formed what have been labeled as *earthen ridges* or *walls* surrounding some of the household areas (Hofman et al., 2018; Hofman and Hoogland, 2015). Also, the extracted material from different leveling episodes, together with domestic (food) waste and other artifacts, were deposited in more conspicuous mounds, sometimes just above or below particular ash layers. The excavation of the leveled areas revealed the circular layout of several house structures, having a maximum diameter range of around 9 m (Hofman and Hoogland, 2015; Keegan and Hofman, 2017). In some cases, circular cooking huts of 3–4 m in diameter were registered next to the households, with hearths in their interior.

At least six household mounds were uncovered during the archaeological investigations of El Flaco. These were formed through time by several layers representing the accumulation of refuse, usually resulting in thick layers of very fine ash with large amounts of land snails, other faunal remains, and pottery. These layers were sometimes covered with whitish, gravelly fill (almost pure calcareous parent material) coming from the leveled areas. Within these mounds, additional ash layers were deposited from other areas (cooking huts), or they were simply formed there due to the use of these same spots as active kitchen areas at different points in time. Eighteen human burials were recovered in three household mounds displaying a diverse and complex array of burial practices, including keeping the graves opened until the bodies were desiccated (Keegan and Hofman, 2017). In this hamlet, the southernmost household mound (mound F) was sampled for the current analysis.

The other ancient settlement, El Carril, also lies on the southern flank of the Northern Range, just 2.5 km west of El Flaco (Fig. 1). The site seems to have been a big village that covered an area of around 43,000 m<sup>2</sup> (4.3 ha). El Carril was intermittently occupied from about cal. AD 1097–1262 (median probability date range from 22 radiocarbon samples; Hofman, 2017) by peoples producing admixtures of Ostionoid/Meillacoid and Meillacoid/Chicoid pottery traditions, while also having access to pure Meillacoid and Chicoid influences as reflected in a portion of the pottery assemblage. According to the available chronological data, this settlement was active in at least two contemporary stages with El Flaco: one by around cal. AD 1123–1154 and the other between cal. AD 1228 and 1262. Besides this micro-regional merging of occupational stages, both settlements show they were interspersedly occupied from cal. AD 994 to around 1452, with El Carril being more intensively occupied from around cal. AD 1200–1260, and El Flaco from around cal. AD 1254–1300, and finally from cal. AD 1396 to 1452 (Hofman et al., 2018). Archaeological works at El Carril have revealed a highly complex engineered landscape consisting of leveled surface areas in the lower sections of the site, household mounds, backfill mounds, and possible agricultural mounds or *montones* (Hofman, 2017; Sonnemann et al., 2016; van Dijk, 2019; Veloz Maggiolo, 1972; Veloz Maggiolo et al., 1981). In total, more than 100 artificial mounds have been registered (van Dijk, 2019).

As in the case of El Flaco, the excavated leveled areas revealed layouts of several houses and possible cooking huts that are currently under analysis (Hofman et al., 2018). The household mounds already studied at El Carril possess similar stratigraphic characteristics and artifactual items to those from El Flaco. Several of these household mounds have yielded disarticulated, dispersed human remains. One of the uncovered household mounds (mound 68), which was the tallest of those investigated, was sampled for the current analysis.

## 4. Materials and methods

### 4.1. Materials

Soil samples obtained from one household mound per settlement were submitted to phytolith analysis. Basic geochemical (soil pH, phosphates) and stratigraphic analyses were employed as auxiliary methods

to better understand the phytolith results and the nature of some underlying social and environmental processes which affected the formation of these mounds. At El Flaco, a 107 cm long soil core was extracted from the highest point of mound F – next to excavation units 35 and 36 – by means of direct-push coring with a stainless steel auger of 5.08 cm diameter. The auger penetrated several buried A horizons comprised of layers with different combinations of artifacts, soil matrixes and ash. The lowest buried A horizon was registered from 86 to 94 cm below surface (cmbs); the underlying interface was between this layer and the bedrock (horizon B), and finally the calcareous bedrock (horizon C) from 97 cmbs. The resulting soil core was gently scraped in segments every 2 cm, and then a total of 24 samples of ca. 30 ml each were obtained in 5 cm intervals. In some instances, the sampling interval was reduced to include any subtle change in the stratigraphy. Samples were stored in new, small zip lock bags and were delivered to Pagán-Jiménez' lab at the Faculty of Archaeology, Leiden University.

In El Carril, a vertical sequence of soil samples was extracted from the south stratigraphic profile of unit 38, located in the highest point of mound 68. Horizontal drilling by means of direct-push with plastic augers 15 cm long and 2.54 cm in diameter was done from the bottom to the top of the profile at 10 cm intervals, covering in total a vertical length of 200 cm. Before the introduction of each auger, every sample point in the profile was carefully scraped with a clean hand trowel. After the introduction of augers, the remaining portions of each were completely wrapped with clean printer paper and taped to avoid cross contamination during the introduction and extraction processes. Later, each plastic auger was extracted from the profile and stored in new, individual zipper bags for further delivery to Pagán-Jiménez' lab at Leiden University. A total of 22 soil samples, approximately 45 ml each, were extracted. The interface (horizon B) between the deepest buried A horizon and the calcareous bedrock begins at 165 cmbs. The bedrock (horizon C) starts at 185 cmbs.

### 4.2. Methods

#### 4.2.1. Phytolith analysis

From each soil sample, a previously homogenized sub-sample of 1.5 ml was taken. Carbonate dissolution and organic matter digestion of soils by Pagán-Jiménez followed a modified version of Pearsall's (2015) protocol, whereby the Schultz's solution was replaced with hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) (14%) and nitric acid (HNO<sub>3</sub>) (67%) solutions. Lithium Metatungstate (LMT) at a density of 2.3 g/cm<sup>3</sup> was used to extract the phytoliths. Finally, small pinches (ca. 0.05 ml) of the previously homogenized phytolith extract were mounted with Permount on slides for further analysis.

A Leica DM750-P optical microscope with an attached MC170-HD digital camera and respective software were used to sort, classify and record phytolith specimens at 40× and 10× magnification. Phytolith classification was based on 61 morphotypes and multiple variants of them derived from Pearsall's (2015, 2019) classification system, though partially modified following other authors (e.g., Madella et al., 2005; Piperno, 2006; Watling and Iriarte, 2013). The minimum number of phytoliths randomly counted per sample was 250 (Piperno, 2006; Strömberg, 2009; Zurro et al., 2016) and each one was assigned to different taxonomic levels ranging mostly from families to sub-families, and in a few cases to genus and species. In some instances the minimum count could not be reached due to very low phytolith content. After reaching the minimum phytolith count per sample, a systematic scanning for phytoliths corresponding to known economic (edible) plants was done in the remaining, non-inspected portion of each sample slide. We kept any phytolith registered by these means separated from the 250 count. Phytolith fragments were excluded from the total count per sample. All morphotypes were distributed within four main floral categories for this analysis: arboreal, herbs (including sedges), grasses, and edible. Grass phytoliths were kept separated from those produced by other herbs for two main reasons: (a) their classification

to different sub-family levels gives basic information on broader environmental aspects (Twiss et al., 1969), and (b) the production of grass phytoliths is extremely high, so they could likely be over-represented when compared to many other herbs. The fourth category (edible) was used for grouping phytolith morphotypes of any taxonomic category that could be used as foodstuff. Other potentially edible or industrial taxa were assigned to main floral categories (arboreal/woody, herbs, grasses). Finally, main phytolith categories and specific morphotypes were grouped into six broader and referential categories: (a) plantscape composition, (b) surface disturbance, (c) potentially edible/industrial plantscape, (d) edible plantscape, (e) moist/dry plantscape, and (f) moisture indicators. It should be noted that within the “moisture indicators” group we included diatoms. These microorganisms were systematically counted and regularly photographed during the 250 phytolith count per sample, but were not all formally identified. In sum, these six broader referential categories were created to better illustrate and differentiate between potentially natural and/or anthropogenic dynamics and induced transformations of the floral component, and to later decipher possible interrelationships between both realms.

We based our identifications on several phytolith reference works (e.g., Chen and Smith, 2013; Collura and Neumann, 2017; Dickau et al., 2013; Pearsall, 2019, 2015; Piperno, 2006, 1998; Piperno and Pearsall, 1998; Twiss et al., 1969; Watling et al., 2016; Watling and Iriarte, 2013), and also on our own reference collection of modern phytoliths from Neotropical wild grasses, trees, herbs and some cultivars or domestic species such as maize, squash and several palm and Marantaceae specimens collected in Puerto Rico, the Dominican Republic, and the Netherlands. Discrimination of recovered phytoliths from key economic specimens such as domestic squash (*Cucurbita* sp.) and the cross-shaped phytoliths of maize leaves was based on main characteristics described for them in our own modern reference collection, and on published literature (e.g., Bozarth, 1987; Pearsall, 2015; Piperno, 2009, 1998; Piperno and Pearsall, 1998; Piperno et al., 2002, 2000). Therefore, tentative identifications here proposed for the domestic *Cucurbita* phytoliths as possibly pertaining to the *moschata* species relies on the following: as in *C. moschata*, the morphology (shape) of recovered phytoliths throughout all positive soil samples is highly uniform and consistent (mostly globular and sometimes elongated), their surface displays quite regularly distributed and deep facets or scallops, being opposite hemispheres composed of differing scalloped patterns associated with their formation loci (i.e., hypodermal or mesocarpal cells), the maximum size of 18 selected phytoliths range from 54.59 to 96.75  $\mu\text{m}$ , with 67.58  $\mu\text{m}$  ( $\pm 11.361$ ) being the mean size length. All these morphometric characteristics have been strongly associated with the phytoliths produced by domestic *Cucurbita* species with hard rinds, but mostly with those described for *C. moschata* (Bozarth, 1987; Piperno, 2009, 1998; Piperno et al., 2002, 2000). Cross-shaped variant 1 phytoliths attributed to maize leaves in this paper does not follow discriminant function analyses as proposed by Piperno (2006, 1998) and other researchers (McKey et al., 2010). We decided to include only clear and non-doubtful “mirror-image,” variant 1 crosses of maize whose shortest (width) axis length lies near or above 20  $\mu\text{m}$ . This width length is even above the average width of maize's cross variant 1 (which is of 12.5 and 15  $\mu\text{m}$ , according to Piperno, 2009), but is in agreement with leaf cross variant 1 phytoliths commonly documented in our reference collection of modern Chococoño and Racimo de Uva landraces (Colombian and Ecuadorian respectively). So, because multivariate statistics were not employed to discriminate between maize and non-maize cross-shape phytoliths, we are aware that the identification and relative frequencies of maize cross-shaped phytoliths (variant 1, but other crosses as well) has been underestimated in this work. Finally, we analyzed leaf phytoliths of other native and exotic modern grasses currently growing on-site or in peripheral areas of the studied sites (e.g., *Chloris barbata*, *Paspalum dilatatum*), confirming that these do not produce mirror-image, variant

1 crosses, even less crosses of metric proportions as described above or elsewhere.

Ancient phytolith data were processed with Tilia software, version 2.1.1 (Grimm, 1993) to graphically illustrate the main results. Then, we ran basic statistics based on CONISS (constrained cluster analysis by incremental sum of squares) for identifying meaningful phytolith zones throughout the stratigraphy (Grimm, 1987). Produced zones were based on relative frequency values previously calibrated for each targeted morphotype (see *Supplementary Material 1*). Then, these zones were projected onto other graphs (pH and phosphates results) to identify potential behavioral interrelationships among different sorts of data.

#### 4.2.2. Auxiliary methods: pH, phosphate, and stratigraphic analysis

Duplicated soil samples were used for measuring the potential of hydrogen (pH). This helps to understand the taphonomical behavior of phytoliths and other elements, such as phosphates, that could have been likely produced from anthropogenic activities like disposal or intentional accumulation of organic material. Calcareous-derived soils in arid or semi-arid regions usually produce alkaline to neutral pH values (9–5.5) because of the stability of the parent material (Holliday and Gartner, 2007). However, if rainfall constantly interacts with these soils, lixiviation will acidify its matrix. Anthropogenic activities could also change the pH of soil. The accumulation and decomposition of organic matter tends to acidify the soil matrix, while activities allowing the accumulation of calcium, magnesium and sodium (e.g., ashes) could notably increase its alkalinity (Barba Pingarrón et al., 2014; Simniškýtė-Strimaitienė et al., 2017). In this study, a soil to water ratio (vol.) of 1:5 was used for preparing the extract to be measured. Distilled water ( $\text{H}_2\text{O}$ ) was the extract medium. Samples were shaken by hand for 1 min, then left to soak for 20 h. Measurements of the extracted solution were taken after immersing the probe of the digital pH meter ( $\pm 0.05$  accuracy) in it for around 3–4 min. The device was calibrated with buffers of 4.0, 6.86 and 9.18 at 23 °C just before taking measurements; though it was verified every 7 samples with the 4.0 buffer.

The extractable phosphorous (P) was measured in the same soil samples used for pH analysis. Past settlement and dwelling activities such as food processing (of meat, plants, fish, shells, bones), cooking (charcoal, ashes), and the use or discard of organic matter and other substances (e.g., urine, excrement) notably increase the amount of soil P (Holliday and Gartner, 2007; Sjöberg, 1976). The reactive state of P, known as phosphate, is formed in soils after the degradation of organic products and inorganic compounds, and the eventual bonding of P with other element ions already present in soils. Thus, stable and highly resistant chemical compounds of inorganic and organic phosphates are produced after these human-induced processes occur, and the amount of them may increase in sites with prolonged organic and inorganic deposition (Holliday and Gartner, 2007).

In this study, we have developed a basic phosphate analysis to measure orthophosphates (a soluble form of phosphate) based on colorimetry, with ascorbic acid as the reducing solution. The phosphate extraction was carried out by means of the simplest extracting solution – distilled  $\text{H}_2\text{O}$ . The same samples and soil solutions previously tested for pH were allowed to remain soaked in  $\text{H}_2\text{O}$  for a total of 22 h. The supernatant (10 ml of soil extract) of each sample potentially containing soluble phosphates was transferred to a test vial. Then, 5 drops of a solution of sulfuric acid 50% and ammonium molybdate 1% was added and the sample was shaken for 10 s. Next, 1 drop of ascorbic acid 10% was added to the sample, shaken, and finally left to rest for 5 min or until the reaction ended (a blue color is created if phosphates are present). Finally, measurements were made with a visual colorimetric scale ranging from 0 to 0.8 mg/l, having increments of 0.03, 0.1, 0.2 and 0.4 mg/l respectively. Because measured soluble phosphates in this study are only easily extractable ones with  $\text{H}_2\text{O}$ , we are aware that the total amounts of phosphates in the samples were not able to be measured. However, the colorimetric scale effectively measures the absence and

presence of these phosphates, thus allowing us to compare phosphate content variations through the soil layers. In some instances, phosphate content was above the highest measurable amount of the used scale (0.8 mg/l), so we registered these samples with the value of 1 mg/l and used dashed lines in respective graphs to signify that these values above 0.8 mg/l are unknown.

Finally, the stratigraphic analysis was grounded in the registry and differentiation of layers based on their visual (color, anthropogenic inclusions) and textural characteristics. These layers were continually or intermittently deposited after several, sometimes intense anthropogenic activities, so we labeled them from top (current surface) to bottom (bedrock) with Latin numerals. Results of this analysis can be consulted in *Supplementary Material 2*, while synthesized graphic representations are included in *Figs. 2 and 4* as well. Because many of these layers were largely ancient anthropogenic soil surfaces, or formal kitchen and even kitchen dumping areas where ashes and other organic/inorganic components were deposited, for the purpose of this analysis it is impractical to run a formal pedogenetic analysis. Broad interpretations of registered layers' formation process are thus based in the data acquired from archaeological inspection of the extracted soil core and exposed stratigraphic profile.

## 5. Results

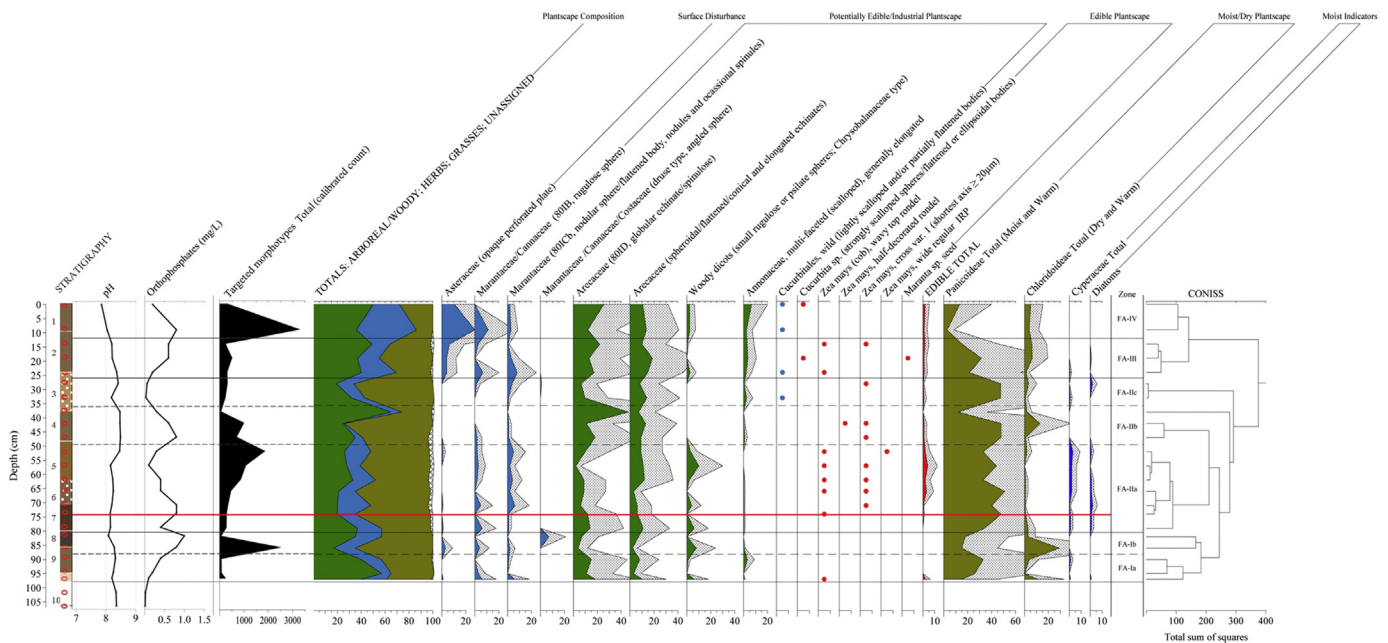
### 5.1. Household mound "F" at El Flaco

Synthesized results are shown in *Fig. 2* and selected microremains recovered from both settlements are illustrated in *Fig. 3*. Four main phytolith zones (FA-I to FA-IV) were created after running CONISS analysis, and additional sub-zones were produced for two of them (FA-I and FA-II). Overall, phytolith preservation was good throughout the soil sequence made up of 10 differentiated layers. However, the minimum count of 250 phytoliths per sample could not be reached at several points within registered layers, some of them being rich in organic content (*Fig. 2*: zones FA-I to III; see also *Fig. SM1-B*). The soil sample set revealed pH values that fall between slightly to moderately alkaline, so extreme alkalinity does not account for low phytolith counts in these particular spots. Two of the referred zones (FA-I and bottom of FA-IIa)

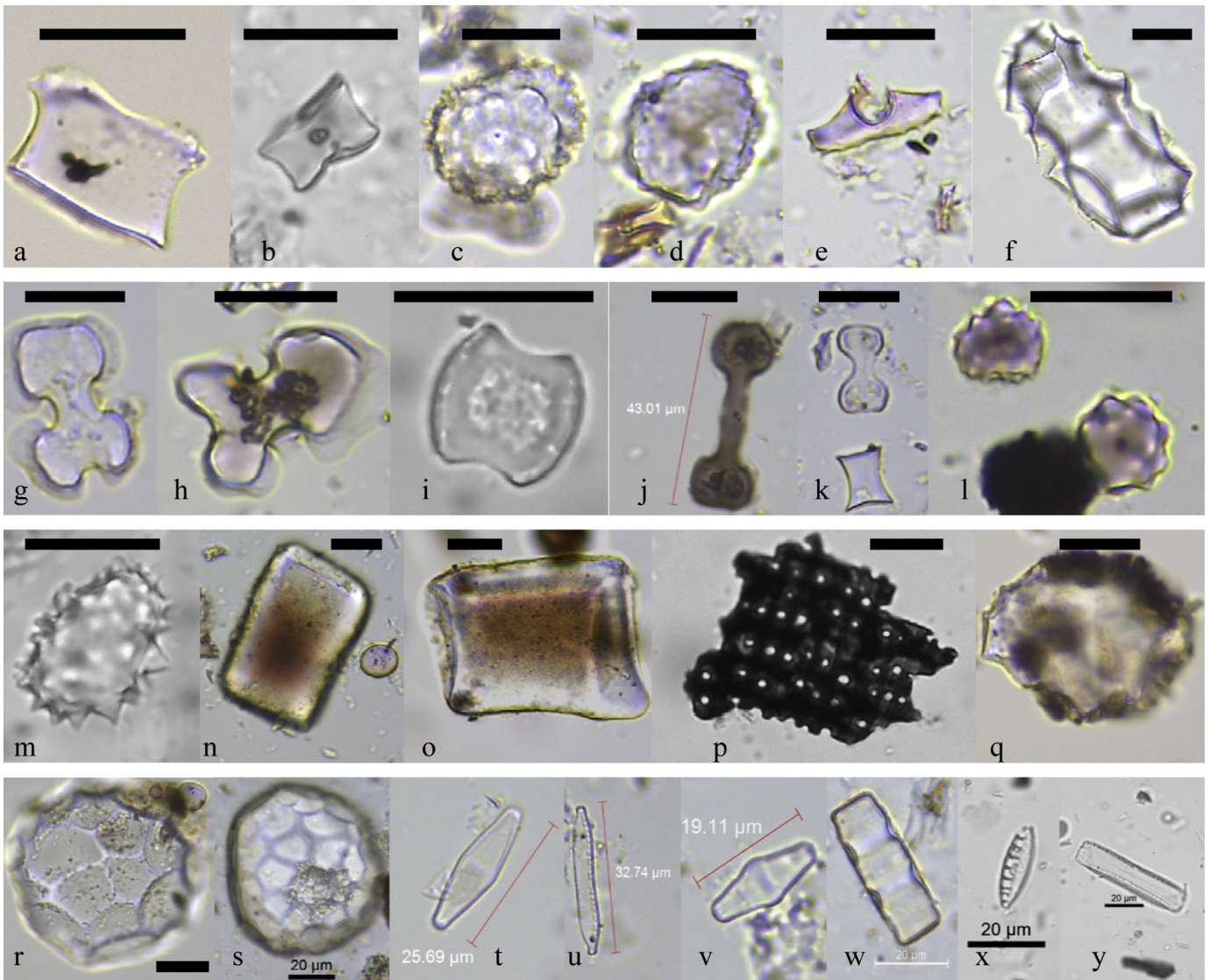
were developed before the earliest registry of human activities in the household mound. Interestingly, these specific low count phytolith spots seem to be linked to major forest dynamics produced just before and after a noticeable increment of grasses (*Chloridoideae*) associated with dry and warm environments. This increase coincides with a less pronounced increment of other herbs (*Marantaceae*, *Asteraceae*) and a parallel decrease in several arboreal (bark-phytoliths producers and *Arecaceae*-palms) taxa. This apparently dry and warm environmental stage (sub-zone FA-Ib, bottom of layer 8), directly dated to (mean probability) 299 cal. BC (UGa-43555:  $2190 \pm 20$ , sediment's organic content), led to an abrupt decline of all phytolith producing plants, concomitant with an increase of phosphates and a subtle decrease of alkalinity in the upper soils of layer 8 (*Fig. 2*), which is a very dark brown, silty loam layer resting below the deepest anthropogenic layer of the mound (i.e., top of layer 7). This is different from the above, higher portions of the soil sequence (sub-zones FA-IIa and IIb, and FA-III) that yielded low phytolith counts, but higher frequency values of targeted morphotypes which may have been related to several dwelling activities that fueled their accumulation. For example, this is evident in sub-zone FA-IIc (layer 3) where intense onsite burning activities, together with a slight rise in pH and the lowest values of phosphates and edible plants, correlate well with firing materials other than plant and faunal food derivatives and related byproducts.

#### 5.1.1. Zone FA-I

The lower section of this zone (FA-Ia) reveals the earliest floral composition of the soil sequence by showing a clear predominance of arboreal (palm, other woody dicots, and *Annonaceae*) phytoliths over other vegetation types (*Fig. 2*). Phytoliths from herbaceous taxa typically associated with understory vegetation (*Zingiberales*: *Heliconia*, *Marantaceae*, *Cannaceae*, *Costaceae*) (e.g., *Bruna and Kress, 2002; Meléndez-Ackerman et al., 2003*), and also the gradual increase of phosphate values from the top of layer 10 and bottom of layer 9, suggest that a subtropical lower montane, and probably moist forest dominated by palms and woody dicots began to develop here, while the presence of grass phytoliths likely illustrates the early stages of forest emergence and succession (*Brokaw and Scheiner, 1989*) in which resistant grasses typically colonize these new spaces first. Potentially edible fruit bearing



**Fig. 2.** Phytolith percentage diagram of household mound "F" (El Flaco), and results of auxiliary analyses (stratigraphy, pH and phosphates) (see also *Fig. SM1-B*). The red line separates pre-human (below) from anthropogenic contexts (above). Exaggeration factor is 3.



**Fig. 3.** Selected phytoliths and other microremains recovered in household mounds “F” and 68, El Flaco (FL) and El Carril (CA) settlements, northern Dominican Republic. *a* and *b*, wavy top rondels (maize’s cob, FL-74 and 52 cmbs); *c* and *d*, nodular spheres with flattened ridged bodies and occasional echinates and microechinates (Marantaceae, FL-62 and 24 cmbs); *e*, papillate trough (*Heliconia* L., FL-79 and 62 cmbs); *f*, multi-faceted (polyhedral) body (Annonaceae, FL-62 cmbs); *g* and *h*, cross variant 1 (maize’s leaf, CA-70 and 60 cmbs); *i*, short saddle (Chloridoideae grass, FL-86 cmbs); *j*, burned, long shaft bilobate (Panicoidae grass, CA-145 cmbs); *k*, bilobate (top) and rondel (bottom) (Panicoidae grass, CA-60 cmbs); *l*, partially burned globular echinates (Arecaceae, possibly *Sabal domingensis* Becc., FL-95 cmbs); *m*, elongated globular echinate (Arecaceae, possibly *Roystonea borinquena* O.F.Cook, FL-52 cmbs); *n*, blocky body and globular psilate (unidentified tree’s wood or bark, and tree leaf [respectively], CA-130 cmbs); *o*, blocky body (unidentified tree’s wood or bark, CA-70 cmbs); *p*, opaque perforated plate (Asteraceae, FL-9 cmbs); *q*, lightly scalloped sphere (order Cucurbitales, FL-0 cm); *r* and *s*, scalloped spheres (*Cucurbita* cf. *moschata*, CA-60 and CA-50 cmbs respectively); *t*, symmetric biraphid diatom (*Navicula* sp., CA-120 cmbs); *u*, nitzschiod diatom (*Hantzschia amphioxys*, CA-120 cmbs); *v*, symmetric biraphid diatom (unidentified, CA-120 cmbs); *w*, centric diatom (cf. *Melosira* sp., CA-145 cmbs); *x*, pennate diatom (unidentified, FL-28 cmbs); *y*, epitheoid diatom (unidentified, FL-28 cmbs). Black scale bars represent 20  $\mu$ m. Other bars show their own length reference.

trees of the Annonaceae family form part of the arboreal component of this forest. Similarly, four maize cob phytoliths (wavy top rondels) were also registered here. Because these are isolated finds of a single domestic species in a layer clearly formed before any human activity in the mound, we suppose that these phytoliths were displaced from above by ancient taphonomic processes and/or modern contamination (e.g., a precolonial “intrusive” activity such as the digging of holes, or modern soil transference during sampling from upper anthropogenic layers). Sub-zone FA-1b points to a predominance and apparent increase of Chloridoid grasses probably associated with open and dry-warm mesic forests. Based on the lack of archaeological indicators and on a single radiocarbon date (UGa-43555:  $2190 \pm 20$ ; sediment’s organic content was dated) from this same soil sample, these changes are not associated at all to any human interference in the environment (Fig. 2; see also Fig. SM2-A). At this point, palm phytoliths have diminished

while phytoliths of other tree taxa (woody dicots) and different herbs are noticeable (Marantaceae, Cannaceae, and probably Costaceae). Opaque perforated plates produced by Asteraceae flowers are also evident in this zone probably showing, together with the predominance of Chloridoid grasses, that some environmental disturbances took place here, thus promoting the growing and accumulation of phytoliths from these very early colonizing plants (Guariguata and Ostertag, 2001). Interestingly, these scenarios are linked to the early development of a more mature, organic soil (layer 8) according to phosphate values, but are also in tandem with an abrupt decline of all phytolith producing plants (Fig. 2; see Heartsill Scalley et al., 2010 for a modern case study of hurricane effects on wet forests). However, later (top of layer 8) phytoliths of almost all plant groups seem to slightly increase, along with palms, Marantaceae/Cannaceae plants and Panicoid grasses as well, while Chloridoid grasses and Asteraceae abruptly diminishes.



### 5.1.2. Zone FA-II

This zone was divided into three sub-zones (Fig. 2). Sub-zone FA-IIa reveals the first clear human interference in the stratigraphic history (top of layer 7) of the mound. A partially built/managed plantscape is dominated by mixed vegetation related to partially open montane, probably mesic secondary forests. Bark-phytolith producing trees, palms and other herbaceous taxa are maintained, or even produced, but an increase of Panicoid grass phytoliths indicative of moist and warm environmental conditions, and the first sustained incidence of maize cob and leaf phytoliths are registered together with charcoal particles, small amounts of ashes, a rise phosphate values, and the appearance of diatoms from very moist or aquatic environments. Indeed, it is from the lower section of this sub-zone that a combined set of moisture indicators (Cyperaceae phytoliths and diatoms) begin to be regularly registered until the end of this sub-zone. However, at the middle of this sub-zone (layer 6), a true ash layer was produced with maize leaf and cob phytoliths as part of this anthropogenic matrix which still retain important, but lower phosphate values (Fig. SM2-A). Main plant groups remain with subtle variations across soil matrixes of this sub-zone. The upper section (layer 5) reveals higher phosphate values together with a slight increase of palm globular echinates that probably represents a single species (Fig. 2). Conversely, small rugulose and psilate spheres produced mainly by woody dicots decrease, and Annonaceae phytoliths as well, to eventually disappear at the upper end of this sub-zone (top of layer 5). Maize cob and leaf phytoliths are still present through the upper portion of this sub-zone, although other maize rondels (half-decorated) and irregular phytoliths with short protrusions (or IRP) ascribed to maize are also registered.

Later, there is a boost in phosphate values in sub-zone FA-IIb that coincides with an increment and predominance of palm and Panicoid phytoliths throughout layer 4. However, a new and gentler rise of Chloridoid phytoliths, together with a slight predominance of this and other Panicoid grasses seem to point to a period of possible switching of environmental conditions (dry to moist and warm) from the middle to the top of layer 4 (Fig. 2). The upper section of this sub-zone (bottom of layer 3) reveals a clear drop of almost all phytolith producing plants including those of edible and industrial taxa and phosphate values, except palms and other arboreal taxa producing blocky phytoliths. This newly formed layer is the latest, true ash deposit of the mound in which palms, Panicoid grasses and other trees (bark phytoliths producers) were probably used as fire starters or as fuel during the earliest stages of deposition. Sub-zone FA-IIc accounts for a distinct phytolith behavior in most of the upper section of the same true ash layer mentioned above. Different to the basal section of this anthropogenic matrix (layer 3), the mix of ashes and soils predominantly yielded Panicoid grass phytoliths and a lower contribution of tree (mostly palm) and other herbaceous phytoliths. Humidity indicators such as diatoms and Cyperaceae phytoliths re-emerge (Fig. 2), as well as those of some edible/industrial plants such as maize and Annonaceae. This plantscape scenario is linked with the lowest phosphate values produced in the stratigraphic sequence. For the first time, few lightly scalloped, partially flattened spheres produced by several taxa within the order Cucurbitales were registered.

### 5.1.3. Zone FA-III

This zone converges with the uppermost portion of layer 3 (true ash layer described above) and with most of layer 2 (excluding its top) (Fig. 2). The lowest section revealed a slight increment of phytoliths from main taxonomic groups, together with a mild decline of Panicoid grasses. Thus, arboreal morphotypes combined with Marantaceae and/or Cannaceae phytoliths predominates here. The upper section shows the presence of Asteraceae opaque perforated plates, suggesting that soil surface disturbances took place while simultaneously, phosphate values rose. An increase of arboreal phytoliths (probably two different palm species, woody dicots, other bark-phytolith producing trees and Annonaceae), when combined with phytoliths from Zingiberales

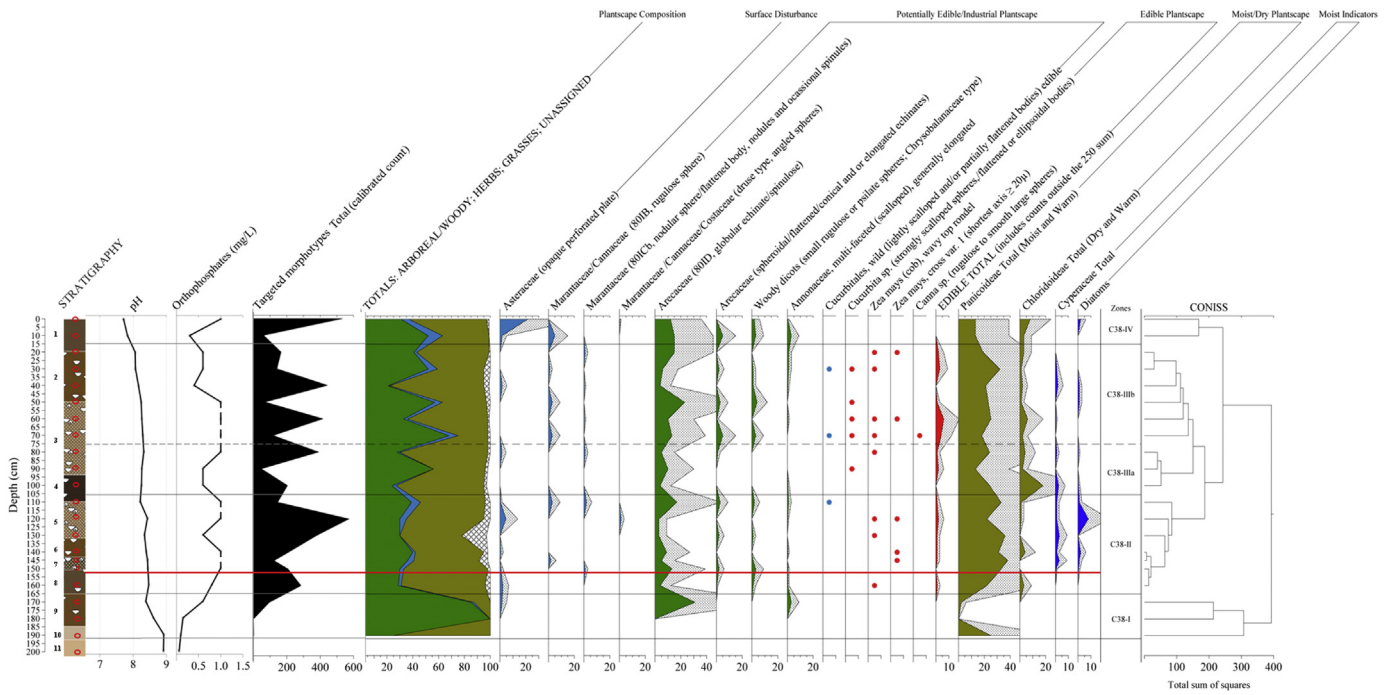
(Marantaceae, Cannaceae), shows that a partially forested plantscape developed in the vicinity of the household mound. Both Panicoid and Chloridoid grasses persisted in this sub-zone, possibly pointing to the prevalence of natural forest gaps or intentionally cleared areas. However, the consistent presence of Chloridoids associated with dry and warm forests, as well as the gradual decline of Panicoid grasses, suggest that drier conditions in the area began to prevail through this sub-zone. Phytoliths of maize leaves and cobs, and a wider set of Annonaceae morphotypes (possibly revealing more than one species) attest for the apparent maintenance and use of these plants in the surroundings. Nonetheless, for the first time we recorded strongly scalloped spheres consistent with phytoliths produced in the hard rind of domestic squash (*Cucurbita cf. moschata*), as well as cylindrical bodies with irregular scallops (Pearsall's morphotype 22VIIAa) produced in the seeds of *Maranta Plum. ex L.* (Fig. 2).

### 5.1.4. Zone FA-IV

This is the latest phytolith zone registered in the stratigraphy of this household mound, consisting in the upper section of layer 2 and layer 1. All main plant groups are represented here, though phytoliths from arboreal (mostly palms and some woody dicots) and several herbaceous plants (Marantaceae, Cannaceae, Asteraceae, Cucurbitales) clearly dominate over remaining grass phytoliths. This suggests that a very mixed subtropical, lower montane and mostly mesic secondary forest developed in the household's immediate surroundings across zone FA-IV until present day (Fig. 2). Except for some *Cucurbita* sp. phytoliths identified on the current topsoil (layer 1) and several phytoliths from Cucurbitales recovered in the bottom of the same layer, other phytoliths corresponding to domestic plants such as maize and *Maranta cf. arundinacea* (arrowroot) vanished from the soil record. Currently, the broad floral composition of this area is dominated by a combination of young trees and many shrubs of distinct species, forming a very young, and partially closed secondary montane mesic forest. Until recently, segments of the study area were used as agricultural plots to cultivate manioc, maize, common bean and squash. All these species require cultivation in completely cleared plots. Nowadays this forest is apparently regenerating largely by natural processes after abandonment (see Zimmerman et al., 2000). At least within the confines of the archaeological site area, no palms or Marantaceae (registered in the top of the stratigraphic sequence) could be identified after various surveys conducted between 2016 and 2018. However, it is possible that plants from these taxa were kept or maintained in the area until some decades ago, being likely eradicated due to more aggressive or focalized agricultural practices in modern times (livestock production, open plot cultivation of manioc and maize). In contrast, we have observed in the field that several Asteraceae taxa and different grasses (Panicoids and Chloridoids) quickly colonized cleared spots of the site, as suggested too by phytolith results of the upper section of zone FA-IV.

## 5.2. Household mound 68 at El Carril

Synthesized results (Fig. 4; see also Fig. 3) show that four main phytolith zones (C38-I to C38-IV) were identified with CONISS, and only one zone (C38-III) was subdivided into sub-zones (C38-IIIa and C38-IIIb). Phytolith preservation and recovery in this mound was good and consistent throughout the soil sequence made up of 11 layers (Fig. SM2-B). Only five spots in the stratigraphy (layer 10, bottom and top of layer 9, top of layer 4, and bottom of layer 3) did not reach the minimum count of 250 phytoliths per sample (Fig. 4; Fig. SM1-B). These spots are parts of layers with different origin, coloration, and textural and artifactual composition. On the one hand, the bottom of layer 9, being a silty loam, has been highly influenced by underlying calcareous parent material. This layer was developed before the earliest registry of human activities in this mound. Layer 10 is the upper portion of the mentioned parent material (clayey weathered bedrock and "sandy" weathered bedrock, respectively). Thus, as pH values suggest



**Fig. 4.** Phytolith percentage diagram of household mound 68 (El Carril), and results of auxiliary analyses (stratigraphy, pH and phosphates) (see also Fig. SM1-B). The red line separates pre-human (below) from anthropogenic contexts (above). Exaggeration factor is 3.

(Fig. 4), these sample spots are soil matrixes in which phytoliths hardly preserve (Pearsall, 2015) due to its high alkalinity. On the other hand, layer 4 is a dark brown silty loam full of limestone debris, while layer 3 is a huge true ash layer together with silty loam, limestone debris, noticeable amounts of land snails, and charcoal particles. These two layers were developed in tandem with several dwelling activities. Phosphate and pH values in these spots are consistent with favorable phytolith deposition and preservation, so we estimate that some cultural factors such as extremely high temperatures due to heat-related activities (cooking, pot making) could explain the slight reduction of phytoliths here.

**5.2.1. Zone C38-I**

This zone delimitates the lowest portion of the stratigraphic sequence where parent material (layer 10) and the first organic surface (layer 9) were formed (Fig. 4). Phytolith data from the bottom of this zone indicates that sparse vegetation, mostly Panicoid grasses, began to emerge in layer 10. This kind of ground cover was probably the first organic enriching component of the soil matrix. Just after this very early stage of forest development, up to the end of this zone, palm phytoliths suggest that this group quickly became the dominant taxon, while arboreal taxa represented by Annonaceae and other bark-phytolith producers also began to populate the area, revealing the continuity of forest succession and soil enrichment according to increasing phosphate and decreasing pH values. Based on this data, it seems plausible to think that a subtropical lower montane mesic to moist forest, likely dominated by palms, emerged during this time.

**5.2.2. Zone C38-II**

Phytoliths from the lower section of this zone reveal two main aspects: (a) the first registered human interference on the floral environment by the integration and management of edible domestic and industrial plants, and (b) the maturation and prevalence of a lower montane, probably mesic forest in the immediate surroundings of the studied site. Soil development shows a tendency towards progressive organic enrichment according to phosphate and pH values, while human activities (firing, cooking) that helped create two separated

ash layers (layers 7 and 5) yielded maize, and slight but variable frequencies of Annonaceae, Marantaceae and Cucurbitales phytoliths that imply the management of edible and industrial plants linked to firing and cooking activities (Fig. 4). The sustained prevalence of Panicoid grasses, together with the minimal but continuous presence of Asteraceae plates, suggests that surfaces across this zone were continuously disturbed. Nevertheless, palms, woody dicots and other bark-phytolith producing trees were key elements of the plantscape. Herbaceous taxa typically classified as understory vegetation (Marantaceae, Cannaceae, Costaceae) in many moist subtropical forests is patchy in this zone. However, the behavior of these phytoliths coincides with that of moisture indicators (Cyperaceae phytoliths and diatoms) when they project as intermittent peaks mostly correlated to registered ash layers.

**5.2.3. Zone C38-III**

Sub-zone C38-IIIa shows a conspicuous predominance of both Chloridoid and Panicoid phytoliths (bottom of layer 4), together with a simultaneous vanishing of Marantaceae/Cannaceae, and a drop in phosphate values which suggests possible environmental changes towards drier, warmer conditions (Fig. 4). Upper sections of this sub-zone point in the formation of layer 3, which is a true ash layer mixed with a silty loam matrix and inclusions of terrestrial and marine shells, limestone debris and charcoal particles, all relate to firing and kitchen activities. These elements seem to be contributing factors to the increased phosphate values registered in this and the following sub-zone. There is a general increment of phytoliths of main plant groups here. For example, there is a rise in the number of arboreal phytoliths, mainly those produced in wood and bark, but also those such as palm globular echinates. However, Panicoid phytoliths also increase and even predominate over other groups until the end of the sub-zone while Chloridoids are still present, but in negligible amounts. Finally, phytoliths from edible/industrial taxa such as Marantaceae emerge again, and phytoliths from important edible plants like maize are registered, together with the first appearance of scalloped spheres produced by the rind of domestic squash (Fig. 4).

Sub-zone C38-IIIb marks the upper and final section of layer 3 (the true ash context described above), and the formation and development of the uppermost layers of this mound (Fig. 4). Arboreal phytoliths and Marantaceae/Cannaceae clearly dominate the lower portion of this sub-zone, with those produced in the wood and bark of trees (blocky structures, strongly angled, irregular spiny bodies) being the most common. This predominance constantly switches with that of Panicoid grasses until the end of this sub-zone in layer 2. Moisture indicators (Cyperaceae phytoliths and diatoms) reveal themselves together and for the last time in layer 2. Phytoliths of potentially edible and industrial taxa (Marantaceae, Cucurbitales, Annonaceae) are continuously present, and those produced by known edible taxa such as maize and squash are notably consistent from the bottom until the top of this sub-zone, with this probably being the last one connected to precolonial household activities.

#### 5.2.4. Zone C38-IV

This zone represents the upper, final soil depositional event registered in household mound 68 (Fig. 4). However, from the beginning until the end of this zone (current surface) there is a sustained declining tendency of Panicoid phytoliths, which is inversely proportional to an increment of Chloridoid grasses that today dominates the ground cover of the area. Palm phytoliths also increase from this point and there is a noticeable presence of Asteraceae opaque plates suggesting surface disturbance in upper, modern soils of the mound. Marantaceae/Cannaceae phytoliths vanish, as do one of the moisture indicators (Cyperaceae phytoliths) and known edible plants such as maize and squash. Only some potentially edible plants such as Annonaceae and palms are still present. Phytoliths recovered from current surface soil reflect combined vegetation composed of trees, grasses and other herbs. Among trees, palms and woody dicots contribute the greatest number of phytoliths, followed by other bark-phytolith producers. Regarding the grasses, both Panicoid and Chloridoid contribute similar amounts of phytoliths, though Chloridoid shows a tendency to increase from lower/deeper spots of layers 2 and 1. Present-day vegetation at El Carril is mainly dominated by an exotic Chloridoid grass (*Cynodon plectostachyus* (K.Schum.) Pilg.) that is grown to feed cattle. However, there are important palm (*Sabal domingensis* Becc.) patches in some areas where small clusters of herbs (mostly bushes, Asteraceae) develop as understory vegetation.

## 6. Discussion

### 6.1. Forest dynamics

It is widely known that phytolith production is highly variable among different taxonomic groups (e.g., Dickau et al., 2013; Pearsall, 2015; Piperno, 2006; Watling et al., 2016, 2015). Due to this fact it is evidently difficult to produce accurate interpretations of the predominance of one taxon over another when data comes from a single horizontal sample spot. Within the different taxonomic groups considered here, grasses are known to produce huge amounts of phytoliths compared to other plant groups such as trees (woody dicots, Annonaceae), and many other herbs (Marantaceae, Cannaceae, Cucurbitales, etc.). Palms constitute an exception. Many palm plant segments such as leaves, stems, flowering/fruit branches, fruits, bark and pith, produce great amounts of echinate, spiny and strong nodular phytoliths of globular, flattened, conical and elongated shapes (Benvenuto et al., 2015; Huisman et al., 2018; Morcote-Ríos et al., 2016). Thus, when total percentages of grass and palm phytoliths are very close, or below the total percentage of other arboreal or herbaceous phytoliths in a single sample spot, it is feasible to assume that these plants likely predominate over grasses or palms. Based on the same sample spot example, we must also assume another bias that cannot be fully solved. This is, any floral composition in a singular sample spot reflects different plant populations and communities that could

have developed naturally, or were humanly induced, at different points in time (with a difference of months to decades). Even though phytolith studies extracted from surface soils in modern vegetation plots have revealed a strong correlation between existing plants and recovered phytoliths, it has also been demonstrated that phytoliths from plants not growing in these plots are usually registered (e.g., An et al., 2015; Koning, 2018; Watling et al., 2016). Thus, more than just focusing on the distribution of relative frequencies of different taxa within and across horizontal sampled spots, the combination of phytolith categories and associated taxa in such variable contexts should be seen as a multidimensional scenario reflecting, at least partially, different stages of forest emergence and succession with or without human interference.

Taking all of the above into account, phytolith results obtained from both household mounds (F and 68) reveal different plantscape histories likely influenced by several important environmental and socio-cultural factors. Following the first stages of natural forest emergence in El Flaco and El Carril (suggested by grass phytoliths indicative of early colonizing organisms), our data indicate that lower montane moist forests dominated by palms and woody dicots developed in both sites prior to any human interference. However, understory vegetation comprising mostly Zingiberales taxa (*Heliconia* sp., Marantaceae, Cannaceae and/or Costaceae) emerged only at El Flaco prior to human interference, thus suggesting that this forest could have been part of the margins (e.g., an ecotone) between lower (and closed) montane, moist forests and mesic (lightly canopied) forests. In general, these early stages of forest emergence and succession seem to have been characterized by more plant biodiversity at El Flaco than at El Carril. In both places, these processes were registered in the interface zones of the stratigraphy where weathered bedrock and parent material are structurally mixed with the lowermost portion of the first organic surface ever produced at the sites. The soils above zones FA-Ia and C38-I, respectively, show the relative dominance of arboreal vegetation (mostly palms) over an important presence of grasses (principally Panicoids). Thus, a correlation of important pedogenetic factors is evident in these zones during the earliest stages of forest emergence and succession: from the weathered bedrock to upper layers, there is a general decline of pH that is inversely proportional to the gradual increase of phosphates. This is consistent with the contribution of organic matter (litter) to the soil from forest development.

### 6.2. Shifting environments and the emergence and evolution of plantscapes of dwelling

Before the arrival and settlement of humans to El Flaco, compared analysis of selected phytolith environmental indicators (Chloridoideae, Panicoideae, Arecaceae, bark-phytolith producers) suggest that a shift from a moist to a dryer period occurred (top layer 9). Later environmental conditions interpreted from these indicators suggest a new shift similar to pre-existing conditions. However, combined data from upper phytolith zones at both sites (from and above zones FA-IIa and C38-II), implies that the arrival and settlement of human populations did not significantly affect general forest composition. This inference is plausible when the vertical behavior of phytoliths and other environmental indicators are observed. The later introduction of edible plants, the management of these and other potentially industrial/edible plants, and human interference of the forests' natural succession cycles certainly helped create dynamic plantscapes of dwelling that seem to have developed differently at both sites.

First, people from El Flaco and El Carril arrived and initially interacted with lower montane moist forests with different characteristics. At El Flaco, what seems to have been an ecotonal forest was already populated by potentially edible and industrial, understory plants (e.g., Zingiberales, Marantaceae, Cannaceae, Costaceae), while some of these taxa at El Carril appear to have been introduced or encouraged later by virtue of cultural needs (food, food wrapping leaves, medicine)

(Fig. 4). In this regard, the meaning and usefulness of these plants were probably the same for the people of both sites, but the differential availability of them could have triggered distinct ways of managing respective plantscapes as well as other intra- and inter-settlement dynamics to access them.

Second, during the occupations of the sites several phytolith environmental indicators (e.g., grasses, herbaceous taxa) show dim, but important shifts of overall environmental conditions. At El Flaco, the rise of Chloridoid grasses in the upper section of anthropogenic layer 4 (Fig. 2: zone FA-IIb) is inversely proportional to several understory (Marantaceae/Cannaceae) and arboreal taxa (e.g., palms, woody dicots). Even though this suggests the apparent prevalence of drier environmental conditions during this time, people continued managing (producing, processing, consuming) important edible plants such as maize. At El Carril, a very similar shift from moist to drier environmental conditions could have occurred as indicated by the increase of Chloridoid phytoliths in anthropogenic layer 4 (Fig. 4: bottom of sub-zone C38-IIIa). However, people from this site seem to have not continued managing edible plants vigorously until moister conditions returned later.

Third, the registry of edible and several potentially industrial components of the plantscape is highly associated with true ash layers, or with vertically adjacent soils of them in El Carril, but not in El Flaco. In both household mounds, true ash layers are horizontally correlated to firing and burning activity areas, and the cooking of foodstuff in hearths is the most compatible one. In El Carril, one of the accumulated ash pocket-like layers (Fig. SM2-B: layer 7) yielded maize leaf phytoliths as well as palm and Marantaceae/Cannaceae phytoliths, while the other two true ash layers (layers 5 and 3) revealed a wider plant assemblage consisting of maize cob and leaf phytoliths, along with palm and Marantaceae/Cannaceae phytoliths, squash rind scalloped phytoliths, and partially flattened scalloped phytoliths from Cucurbitales (Fig. 4). This suggests that some food plant byproducts (maize cobs and leaves), and even leaves likely used for wrapping foodstuffs (Marantaceae, Cannaceae) were discarded and intended as fuel in El Carril, maybe during food processing, cooking and eating in the same kitchen areas. At El Flaco, phytoliths from different portions of edible and potentially industrial plants (maize, palms, Marantaceae/Cannaceae, Cucurbitales) were also discarded and probably used as fuel, according to phytolith data from ash layers 6 and 3. However, phytoliths of a higher number of edible plants were consistently recovered in rich organic soil matrixes (layers 7, 5, 4 and 2) that are not directly related to firing/cooking activities (Fig. 2). Different from El Carril, it is possible that byproducts of these plants were consistently discarded in these layers as fertilizing agents, but it is also plausible that source plants may have been produced in these soils previously enriched with other organic and inorganic substances (animal food byproducts, human waste, etc.). Interestingly, published (Ciofalo et al., 2019) and preliminary starch grain data (Pagán-Jiménez, unpublished data, 2019) obtained in different plant processing, cooking and serving artifacts from other household mounds and leveled kitchen areas in El Flaco, indicate that maize, but also manioc, chili pepper, cocoyam (*Xanthosoma sagittifolium* (L.) Schott), possibly cacao (*Theobroma cacao* L.), palm fruit and guáiyiga (*Zamia* L.), among others, were processed and consumed principally in contexts next to the houses (exterior of houses, kitchen areas, cooking huts, etc.) and not necessarily in areas directly related to the true ash layers of the studied mound.

Diatoms recovered in the studied samples can provide additional perspectives on the socio-cultural behaviors that possibly affected the formation of layers in the household mounds. Several nitzschoid, centric, and symmetric biraphid diatoms (e.g., *Hantzschia* sp., *Melosira* sp., *Navicula* sp. and other unidentified diatoms; Fig. 3) that develop in freshwater and brackish environments, and even in subaerial terrestrial habitats (Antonelli et al., 2017; Stanek-Tarkowska et al., 2017) were registered throughout the soil sequences of both household mounds. However, similar to the edible plant phytoliths, their presence strongly

correlates with true ash layers or with soils lying just below or above them (Figs. 2 and 4). At El Carril, diatoms were found mainly in the matrix of ash layers 7, 5 and 3, showing also a synchronous, positive correlation with Cyperaceae phytoliths, another indicator of moisture used. Differently, at El Flaco diatoms were registered in ash layers 6 and 3, but also in layers 7, 5 and 2 strongly related to Cyperaceae (moist) phytoliths, and being layers unrelated to firing or cooking activities. The presence of these moisture indicators out of the ash layers, but also connected to a wide array of phytoliths from edible plants, could be indicative of the intentional addition of freshwater or river soils to the mounds for irrigation or soil improvement purposes. However, based on the evident synchronous correlation of diatoms and Cyperaceae phytoliths with identified ash layers and food remains at both sites, we estimate that their presence in these matrixes is likely due to the intentional transportation and use of freshwater from nearby rivers and creeks in pre-firing and firing activities associated with hand-craft activities (e.g., pottery production), or the processing and cooking of foodstuffs (e.g., meals, beverages or simply drinking water).

No other scenarios of soil dispersion or circumstances that could allow diatom community development exist to help explain the almost exclusive presence of diatoms together with moisture-adapted plant phytoliths in the ash layers, or in layers disconnected from firing and cooking activities. The closest water bodies to the El Flaco and El Carril settlements are ephemeral or low-energy creeks 80 and 300 m down-slope and to the west, respectively. Similarly, no alluvial or heavy colluvial depositional events linked to water bodies have ever been registered in these sites. Parent material of calcareous (marine) origin, which is a potential source of fossil diatoms, is usually part of all registered layers. However, the analysis of deeper calcareous matrixes at both sites did not yield any diatoms. Soil composition of ash and other organic layers (mostly silty loams) does not allow enough water retention so that diatoms can develop well (sensu Stanek-Tarkowska et al., 2017). Finally, the water table at both sites, a potential contributor of moisture to the soils that could encourage diatom development, has never been registered even at archaeological excavation units that reached approximate depths of 1.40 and 2.40 m at both sites, respectively.

In sum, the people who lived at different points in time at El Flaco developed a relatively small hamlet(s) that seem to have been better integrated into pre-existing forest structure. Agroforestry and orchard-type plant production were probably their main local plant subsistence systems. Understory vegetation that is typical of ecotonal, lower montane moist/mesic subtropical forests was maintained through time, and probably encouraged due to their usefulness and economic importance. In contrast, the inhabitants of El Carril engineered a bigger settlement, probably a village, active for almost 200 years and composed of many houses, accessory structures and many dozens of mounds, with some likely being montones (agricultural mounds) as the ones later described by the early Spanish chroniclers in Hispaniola. Due to these factors, the original forest in El Carril must have been subjected to more pressure and distinct ways of management in order to keep portions of the original components of the pre-existing forest structure. Agroforestry was clearly applied there through time, although other ways aimed at consciously increasing food plant production were practiced. At El Carril, a mixed plantscape composed of trees (notably palms) was maintained, but the construction of dozens of possible montones suggests, in accordance with phytolith results, that the production and use of edible plants was intense probably due to higher local demographics (e.g., Hofman et al., 2018, 2014; Ulloa Hung, 2013), or because it was required as part of broader exchange and/or political networks in which plant foodstuffs seem to have played an important role (Pagán-Jiménez, 2007; Pagán-Jiménez and Lazcano-Lara, 2013; Rodríguez-Ramos and Pagán-Jiménez, 2006).

As indicated previously, the settlements were contemporaneous during two different occupation stages from cal. AD 1123 to 1262. By this time period, El Carril was a huge village, probably populated by

lots more people than El Flaco. Besides other important artifactual and technological components shared during this time between these settlements, phytolith data from the studied household mounds bring interesting clues that deserve mention. Marantaceae/Cannaceae plants producing nodular and globular spheres, and druse type, angled spheres appeared at El Carril only after the very initial settling of the village. This early and apparently sporadic occupation event is evidenced by the presence of charcoal particles, Asteraceae phytoliths (surface disturbance) and maize cob phytoliths specifically documented at the lower-most section of zone C38-II (Fig. 4). However, Marantaceae/Cannaceae plants disappeared from the phytolith record until the next, sustained occupation stages at El Carril (Fig. 4, top of layer 5, ash layer). From that time on, these plants were itinerantly present in El Carril until the last registered occupation events, coinciding with several dwelling-based activities associated with mixed pottery traditions (Ostionoid–Meillacoid–Chicoid). These potentially economic plant types were present at El Flaco long before its initial occupation, showing that they were natural floral components of an apparent ecotonal forest. Even though these plants could have been part of the natural environment of these and other forested areas in the region, thus being potentially collectable from the wild, their economic importance and possible cultural maintenance was evident at El Flaco, and also in El Carril during its different occupations.

The cultural value of domestic squash among the late inhabitants of both settlements is also revealing. Phytoliths from this plant were registered at El Carril in layers probably corresponding to the middle occupation stages, while their ubiquity increased in later layers probably related to the final occupation of the settlement, before cal. AD 1262. In contrast, squash phytoliths recovered in El Flaco's household mound are extremely sparse and they occurred only in layers that seem to correspond to its final occupation stages, probably between cal. AD 1425 and 1452. El Carril was unoccupied by that time, but the inhabitants of El Flaco were still producing cultural products (e.g., Chicoid with some Chicoid/Meillacoid mixed products) which were previously in vogue at El Carril. Interestingly, parallel phytolith studies recently conducted in hearth (fireplaces) matrixes from El Flaco, likely corresponding to the final stages of human occupation, revealed that squash phytoliths are commonly found in matrixes, both inside and outside of these features, though more frequently on the outside of hearths (Koning, 2019). In short, it seems that economic plants beyond those traditionally associated with these cultural traditions (e.g., maize, manioc, sweet potato) point to the sharing and maintenance of well-defined plantscapes of dwelling.

## 7. Conclusions

For the first time in the Caribbean islands, this study has briefly revealed several continual episodes of the long and complex histories surrounding precolonial human–plant interrelationships from an onsite, dwelling perspective. Peoples who inhabited the El Flaco and El Carril settlements seem to have confronted slightly different floral environments since their arrival, even though both areas are relatively contiguous. The last 600 years before the Spanish irruption into northern Dominican Republic – and Hispaniola in general – probably marks one of the most ethnically diverse periods of the Caribbean (Herrera Malatesta, 2018; Hofman et al., 2018, 2014; Jean, 2019; Keegan and Hofman, 2017; Oliver, 2009; Pané et al., 1999; Ulloa Hung, 2013; Veloz Maggiolo, 1972; Veloz Maggiolo et al., 1981; Wilson, 1993). Therefore, it is feasible to expect that the cultural variability already registered in the area was also imprinted in some way or another onto the landscape by means of the creation of plantscapes and ensuing culinary traditions. It can be seen that due to the different choices offered by studied environments, the interrelationships of the peoples from El Flaco and El Carril produced diverse plantscapes nurtured by local (settlement) socio-cultural dynamics and broader regional interaction networks. Moreover, original, pre-human floral scenarios, when

intertwined with a human value system notably rooted in multifaceted interactions with other peoples and their landscapes, could have persuaded them to select these areas over others to develop their settlements and foodways dynamics.

Overall, this work has expanded the range of identified edible and potentially industrial plants in Caribbean paleoethnobotany by revealing the presence and use of squash (*Cucurbita* cf. *moschata*) through many of the analyzed samples. Phytoliths produced by other plants of the Cucurbitales order were also identified at both settlements, although they could not be confidently identified to the genus or species level. However, several of these phytoliths share some morphometric traits previously recorded in bottle gourd (*Lagenaria siceraria*) (Bozarth, 1987; Piperno et al., 2002), a versatile plant historically targeted due to its hard, container-like fruit. Other plants poorly documented in previous paleoethnobotanical studies come from the Annonaceae family of which very important species (soursop or *Annona muricata* L., *A. squamosa* L., *A. glabra* L., etc.) have been historically relevant for many Neotropical cultures. Annonaceae leaf phytoliths recovered in this study may be revealing the maintenance and use of some of these edible trees, but also of any other “wild” Annonaceae tree (many of them endemic to the Greater Antilles) that were economically important due to their wood, rather than their fruits (Acevedo-Rodríguez and Strong, 2019; Loggier, 1978).

Similarly, phytoliths ascribed to *Heliconia* sp., Marantaceae, Cannaceae, and Costaceae were registered. These plants were not only potentially economic taxa because of their attractive leaves (for wrapping foods) and starchy rhizomes, but also because they are important floral indicators for understanding the conditions, development and transformation of the understory vegetation in some lower montane moist/mesic subtropical forests. Palm phytoliths were probably one of the most interesting findings recorded in this study. Even though many authors have established that phytoliths produced by palms are difficult to identify to the genus or species level (Benvenuto et al., 2015; Huisman et al., 2018; Piperno, 2006), we found that the morphometrics of several globular and elongated echinate phytoliths are restricted to distinct species that could be confidently discriminated in the ancient phytolith record, but we noted this just after the scanning, sorting and statistical analysis of phytolith morphotypes. For instance, globular echinates produced in many organs of *Sabal domingensis* possess very acute spines and are very regular in shape and size, raging frequently from 5 to 15 µm. This palm species is very common today in the studied area and is the one that currently grows in El Carril. Archaeological phytoliths of palms with these characteristics were consistently registered (Fig. 3l) in both sites. There are also other echinates with very different morphometrics (Fig. 3m) that are likely produced in the leaves *Roystonea borinquena* according to our reference collection. This clearly attests to the natural distribution or cultural sustenance of a wider diversity of palms in both El Flaco and El Carril. Based on documented globular and elongated echinates with varying size ranges, we esteem that at least three different palm species might have been represented in the phytolith assemblage uncovered by this study.

The registry of other important food plants such as maize confirms previous starch grain studies in this and many other precolonial sites in the Dominican Republic and wider Caribbean (Ciofalo et al., 2019; Mickleburgh and Pagán-Jiménez, 2012; Pagán-Jiménez, 2013, 2012a, 2012b, 2007; Pagán-Jiménez et al., 2019). This time, maize was identified through the recovery of diagnostic phytoliths produced in their cobs (wavy top rondels, silicified epidermal IRP) and leaves (large, mirror-image variant 1 crosses).

We have shown that the acquired phytolith data, when combined with basic geochemical (pH, phosphates) and diatom registries, help identify and characterize very basic physicochemical properties in soils. From this, we inferred possible underlying natural, but also socio-cultural behaviors possibly correlated to the intentional enrichment of mounds for plant production purposes, or the consistent deposition of diatoms due to freshwater management in dwelling activities.

Future studies of archaeological sites with household, trash, shell, agricultural, residence, and burial mounds in the Caribbean and beyond should apply multiproxy approaches involving microbotanical remains, and more extended and refined geochemical and geophysical analyses in order to detect any patterned changes to the soils that could be linked to broader socio-environmental processes like the ones briefly explored here. These kinds of research can produce robust data to properly discuss the socio-cultural and socio-environmental aspects surrounding key topics of ancient human developments in Caribbean societies (Herrera Malatesta et al., 2019). We have taken such a step in ongoing studies of other archaeological mounds from El Flaco and El Carril. We expect to produce detailed explanations about the dynamic plantscapes of dwelling that we are currently examining, in order to better understand local and regional precolonial foodways traditions in northern Dominican Republic, and elsewhere in the Caribbean.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.revpalbo.2020.104160>.

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