Environmental Historical Archaeology of the Galápagos Islands: Paleoethnobotany of Hacienda El Progreso, 1870-1904

by

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Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

in the
Department of Archaeology Faculty of Environment

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Abstract

After their discovery in 1535, the Galápagos Islands remained sporadically inhabited until 1832 when they were legally annexed to the Republic of Ecuador. For three centuries, the archipelago was visited by pirates and whalers, and was later the location of industrial size plantations, one prison, and an American army base. Today, the archipelago is one of the most visited tourist destinations in the Americas. These events have permanently modified the local landscape but also the terrestrial and maritime ecology. In this research, I explore the ecological effects of the initial human occupation of the archipelago. The overall goals are to explore the initial human-plant interactions during the 19th century and how social, economic, and political relations formed the social landscapes of the early occupation of San Cristóbal Island. I combine the theoretical frameworks of Historical Ecology with the methodological frameworks of Environmental Historical Archaeology and Garden Archaeology. The integrated analysis of historical written records, historic cartography, and microbotanical remains were the research model. The internal layout and agricultural lands of Hacienda “El Progreso” (1870-1904) were studied.

Keywords: Historical Ecology; Environmental Archaeology; Industrial Plantation; 19th century prison, Ecuador
Dedication

To my beautiful daughter Rafaela, for her infinite patience during my academic journey.

Te amo con todo mi corazón
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## List of Acronyms

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<tr>
<td>ABG</td>
<td>Agencia de Regulación y Control de la Bioseguridad y Cuarentena para Galápagos</td>
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<tr>
<td>GAIAS</td>
<td>Galapagos Academic Institute for the Arts &amp; Sciences</td>
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<tr>
<td>GSC</td>
<td>Galapagos Science Centre</td>
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<tr>
<td>INPC</td>
<td>Instituto Nacional de Patrimonio Cultural (Ecuador)</td>
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<td>PNG</td>
<td>Galapagos National Park</td>
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<td>SENESCYT</td>
<td>Secretaría de Educación Superior, Ciencia, Tecnología e Innovación (Ecuador)</td>
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Chapter 1. Introduction

The Galápagos Islands are considered one of the last pristine natural paradises on earth. However, during the past four centuries the local plant and animal populations have experienced a continuous process of change caused mainly by anthropogenic activity. After accidental discovery by Bishop Tomas de Berlanga in the name of Spain, the Galápagos Islands remained seasonally inhabited by pirates and whalers. They were the place later selected by planters to build industrial-size plantations for sugarcane, coffee, and quinine trees. Following this, the Galápagos were the location of US Army camps during the Second World War and nowadays are one of the most important tourist destinations in the Americas. The ecological consequences of these events are partially documented in historical records but have been little explored archaeologically.

It is believed that humans never occupied the archipelago before European discovery in 1535. Heyerdahl and Skjølsvold (1974) presented evidence suggesting that pre-Columbian groups from coastal Peru and Ecuador visited the islands, but this proposition is still in dispute (Anderson et al. 2016). After independence from Spain in 1822 and separation from Gran Colombia in 1830, the new nation of Ecuador claimed the archipelago as national territory. The government then negotiated concessions of some islands with private companies for extracting fur, leather, salt meat, fish, turtle oil, and to implement industrial-scale plantations in order to maintain sovereignty over the islands. In this scheme, Ecuadorian businessmen Manuel J. Cobos, Angel Cobos, and José Monroy focused their efforts on obtaining a long-term concession to plant and export sugar cane (Saccharum officinarum) and coffee (Coffea arabica L.) from San Cristóbal Island –formerly named Chatham. They created a large plantation called El

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1 The Quinine tree (Cinchona pubescens) was introduced to the Galápagos during the 1850s as the host plant for a moss from which purple dye was extracted. The bark of the Cinchona tree has been the source of the chemical quinine, which is effective against malaria. A large plantation of this tree was initially located on Santa Cruz Island. Today this plant is considered an invasive plant species in the entire archipelago.
Progreso in the humid highland interior of the island, 1000 km west of the South American Pacific coast. From a few hectares in 1879, the El Progreso enterprise had grown to ~3000 ha by 1904, the year that Cobos was murdered by convict laborers, causing the decline of the largest company in the Galápagos archipelago in the early 20th century.

This industrial-scale plantation occupied most of the southwestern portion of the island. By 1904 El Progreso was producing approximately 500 tons/yr. of sugar and great quantities of alcohol. Water was extracted from one of the few sources of fresh water in the entire archipelago, El Junco Lake, located 7 km away in the interior of the island. An irrigation system composed of metal pipes and canals was built to transport the water from the lake to the fields. In addition, over 100 km of roads were constructed and a 10 km railroad transported sugar products, coffee, tortoise oil, lime, salted and dried fish, meat, and leather to a deep-water port built for a dedicated cargo fleet. Almost 400 laborers lived and worked on the hacienda lands; many of them were convicts and indigents from the mainland (Latorre 2011, 2002). The hacienda managed to continue after Cobos' death but eventually ceased operations in 1917. Since then, smallholder farmers have occupied some of the original El Progreso lands to grow their crops. Weeds invaded the abandoned fields and the useable machinery was returned to the mainland or removed by the remaining workers and visitors (Latorre 2002). Today, the original hacienda land is a modern parish of the Province of Galápagos and is divided into small parcels used for farming.

The *Historical Ecology and Archaeology of the Galapagos Islands* project aimed to explore the human history and ecological consequences of human colonization of San Cristóbal Island from an archaeological perspective. The internal layout and the former agricultural lands of Hacienda El Progreso were the research focus. The project was divided into four main components for investigating the material and biological remains of the operation and the social relationships inside the plantation: zooarchaeology, paleoethnobotany, material culture analysis, and landscape transformation. This
multidisciplinary project was a collaborative research effort between academic institutions in Canada and Ecuador.

My dissertation refers to the paleoethnobotanical component of the project. I explored the ecological effects of the first anthropogenic activities on the Island; specifically, plant use and the introduction of Eurasian crops and livestock. The overall goal of my research was to explore the relationships between plants and humans during the colonization period on the island (1860-1880). I combined the analysis and interpretation of micro and macro botanical remains with written records in order to explore the ecological effects, landscape modification, and social landscapes that resulted from the establishment of the industrial-scale plantation of El Progreso. Environmental Historical Archaeology and Garden Archaeology were the main methodological models structured around a theoretical framework of Historical Ecology.

The specific objectives were:

(1) Explore the ecological consequences of agriculture, deforestation, and plant introduction to the native plant communities of San Cristóbal Island;

(2) Explore the characteristics of the native ecology of San Cristóbal Island with soil phytolith analysis and test its application for palaeoecological research;

(3) Explore the use of native and introduced plant species with the analysis of wood charcoal and charred seeds;

(4) Understand the socio-political context of El Progreso plantation and how this is reflected in the constructed landscapes;

(5) Challenge the category of pristine environment that defines the ecology and landscapes of the Galápagos Islands.

The participants were: Department of Archaeology at Simon Fraser University; the Department of Anthropology at University of Victoria; the School of Social Sciences and Humanities of San Francisco de Quito University; the Galápagos Academic Institute for the Arts and Science (GAIAS); and the Galapagos Science Centre, USFQ/University of North Carolina Chapel-Hill. Fieldwork was undertaken during the summers of 2014 and 2015 on San Cristóbal Island, Ecuador.
This is a paper-based dissertation where I present the results of the paleoethnobotanical research at El Progreso. In Chapter 1, I introduce the research project, outline the main objectives, present an overview of the conceptual and methodological frameworks applied, and summarizes the main archaeological and palaeoecological context of the region. Chapter 2 presents the results of the soil phytolith analysis in the Scalesia Zone of San Cristóbal Island. The overall goal was to investigate the potential of phytolith analysis to explore human impact on local vegetation. Chapter 3 presents the results of wood charcoal and analysis of macroremains from the archaeological site of El Progreso. The goal was to explore the early interactions between colonizers and the native vegetation of San Cristóbal Island since the 1860s. Chapter 4 presents the first phase of the comparative collection of phytoliths from native, endemic, and introduced plants of San Cristóbal Island. Chapter 5 explores the possible causes that shaped a conflictive landscape inside the plantation. I discuss how a capitalist operation shaped the social landscape of Hacienda El Progreso during the late 19th century. Finally, chapter 6 is a synthesis of the results where I suggest further steps for paleoethnobotanical research in the Galápagos Islands.

1.1. The Biological Dimensions of Colonial Landscapes

Colonization can be studied by exploring the alterations to the environment or the landscape. All human activities have consequences to the environment, and as Cosgrove (2008:37) has pointed out, “any sensitivity to the history of landscape and its representations in the western tradition forces the recognition that human history is one of constant environmental modification, manipulation, destruction and creation, both material and imaginative”.

The implementation of ecological approaches to explore the history of capitalism and industrialization is a common practice in the archaeology of historical sites. Understanding the human-environment relationships resulting from colonization is a research interest for biologists, environmental historians, human geographers, and historical archaeologists. The interest in the biological and environmental effects of colonialism developed during the last two decades of the 20th century as result of the environmental concern caused by the effects of industrialism. The overall research
interest is to examine the ecological histories of colonized landscapes based on the combined analysis of archaeological, historical, and biologically-derived data (Reitz and Shackley 2012). Topics such as the movement of plants and animals (Deagan 1996a; Fisher et al. 2009; Reitz et al. 2008); soil degradation (Bowen 1999; Gale and Haworth 2002); food remains from European colonies in the New World (DeFrance and Hanson 2008; Trigg 2004); urbanism (Mrozowski 2014, 2012, 2006a; Nassaney and Abel 2000), and introduced diseases (Campbell 2002; Larsen 2002) have been explored.

Hardesty (2009) has proposed the existence of four theoretical paradigms to explore past human-environment relationships: evolutionism, historical ecology, ecological Marxism, and environmental humanism. Historical ecology is an interdisciplinary research program concerned with comprehending temporal and spatial dimensions in the relationships of human societies to local environments and the resulted effects of these relationships. This program is concerned with the qualitative types of human-mediated disturbance of natural environments and the effect of these on species diversity (Balée 2006, 1998; Balée and Erickson 2006; Crumley 2003; Szabó 2015). The goal is to document the historical context (natural and social) of human–environmental interactions. Here, landscape is understood as the cumulative material expression of historical trajectories (Crumley et al. 2001). It is an actor-based approach focused in understanding the decisions and actions of social agents that uses historical analogs to interpret the human–environmental interaction. The two types of historical analogs considered to explain environmental change and human adaptation are nature analogs, which consider only the acts of nature, and dialectical human-nature analogs, which consider the interaction between human and environment as acts of nature. Archaeology and historical ecology then combine physical data (modern climate, soils), documentary data (agricultural history, fire history), archaeological data (plant and animal remains), and ethnographic data (Hardesty 2009:72).

Four core postulates for the historical ecology research program have been proposed: (a) Practically all environments on Earth have been affected by humans; (b) human nature is not programmed genetically or otherwise to lessen or augment species diversity and other environmental parameters; (c) societies defined by various socioeconomic, political, and cultural criteria impact landscapes in dissimilar ways, as some landscapes are less disturbed (and richer in species) than others; and (d) human
interactions with landscapes in a broad variety of historical and ecological contexts may be studied as a total (integrative) phenomenon (Balée 2006:76). In this scenario, historical ecology attempts to interconnect methodological frameworks from both the social sciences and life sciences to document the natural and social historical context of human–environmental interactions (e.g., Bowser and Zedeño, 2009; Crumley et al., 2001; David and Thomas, 2008; Johnson, 2007; Knapp and Ashmore, 1999; Walker, 2012).

Ecological Marxism is a political action in disagreement with the explanatory principles of the 1960s. Here, the forces of nature -the conditions of production- are considered similar to the forces and relations of production in classic Marxism. The focus here is on ecological degradation related to the capitalist mode of production. The social transformation necessarily involves reconciliation between the forces, relations, and conditions of production (Benton 1996). The emergence of schools such as Ecological Marxism or Socialist Ecology are the result of the dialog between anti-capitalist and ecological movements of the 1990s and the interest in the environmental degradation caused by the capitalist mode of production (e.g. Leone et al. 1987; McGuire 2008).

1.1.1. Environmental Historical Archaeology

The biological consequences of colonization that get more attention in archaeology are: introduced diseases, soil degradation, movement of plants and animals, and industrial agriculture. Kathlen Deagan (2008) and Stephen Mrozowski (2006b, 2010a) have called this multidisciplinary research model ‘environmental historical archaeology’, which refers to the adoption of the environmental archaeology framework to investigate human-nature relationships in historical periods with archaeological methods. Environmental historical archaeology is a research framework concerned with investigating the recursive relationships between people and their environments during the “historic” periods of the past (Deagan 2008), which encompass the periods after the arrival of European and African populations to the Americas. The focus is on the integration of environmental data (animal, plant, geological, and chemical) with the archaeological record and historical information from documents and oral sources.
Environmental archaeology emerged during the late 1970s from interest in the geological and biological aspects of the archaeological record. This research framework refers to the exploration of the interactions between humans and their environment, with the use of scientific techniques to study environmentally and biologically produced data (Reitz and Shackley 2012; Branch et al. 2005). The focus is to understand the natural and cultural processes that have generated the environmental contexts for human populations in the long-term and also in recent times. An environmentally-oriented historical archaeology contributes to a more complete understanding of the biological dimensions of cultural processes of both colonizers and colonized. Topics of interests include climate, soil development, ecology, succession, adaptation of biotic communities, and human impact on landscapes.

Since its first proposal by Deagan (1996), this framework has gained worldwide acceptance and today is a consolidated methodology. The justification for the environmental approach in historical archaeology is based in the idea that the recent past saw significant environmental change with lasting consequences for the present (Landon 2005). European exploration and colonization spread plants, animals, and diseases around the planet on a massive scale with immense and sometimes devastating consequences (Crosby 1986). Social expansion and migration brought social conflict with indigenous peoples and the institution of new subsistence, economic, and resource-use patterns. With industrialization, the scale of resource exploitation increased and the human-land interactions were altered in significant ways shaping the world that we live today.

The combined analysis of environmental data and written information from historical contexts is considered for the study of three broad subjects: class relations, landscape history, and ecological dynamics. Some of its most important interests include global colonialism, urbanism, slavery, labour, class structures, industrialization, and environmental degradation (Hardesty 2009; Mrozowski 2006b; Orser 1996).

**Class Relations:** The interest in exploring expressions of identity and the class relationships among different social groups in urban and rural settlements is a significant aspect of environmental historical archaeology. This type of research is focused in understanding the diversity of class relations in contexts such as cities, parks,
farms, plantations, prisons, gardens, or buildings from a variety of historical and archaeological remains including material culture, tableware, or architecture. The environmental evidence in these contexts is habitually associated with food remains and the use and distribution of space (Baugher 2010; Mrozowski 2006a; Wurst 2015).

**Urbanism, Industrialism, and Landscape transformations:** Organization of space according to specific socio-political regimes is another significant research topic in historical archaeology, of which the ecological history of urbanism is one research focus. The aim is to understand the socio-political motivations and the physical impacts of the intentional modification of landscape resulting from construction processes, and use of, urban areas, industrial and residential facilities, or plantations (e.g. Brannon 1999; Delle 2014, 1999; Mrozowski 2014, 2012; Mrozowski, et al. 2011; Mrozowski 2010a, 2010b; Brownlow 2006; Cowie 2011; Gibb et al. 2009; Murphy and Wiltshire 2002).

**Ecological dynamics:** The exploration of the ecological costs of conquest and colonialism is also an integral part of historical archaeology. The aim of environmental and biological research is to portray modifications to the landscape and understand the ecological dynamics resulting from imposed socio-political agendas in the modern world. The substitution of the cultivated species and the associated alteration of agricultural regimes is a major impact of colonization. The imposed agricultural regimes cause important changes in landscape use and the distribution of agricultural fields. Archaeologists, historians, and conservationists are interested in understanding the direct and indirect vegetation dynamics produced by the introduction of Eurasian crops in order to obtain information of the behaviour and adaptation of plant communities to the human imposed changes (e.g., Camus and Solari 2008; Lara et al. 2012; Solari et al. 2011).

**1.1.2. The Archaeology of Cultivated Landscapes**

Cultivated landscapes are designed areas consciously planned to reflect the real or desired economic, social, or political status of their builders (Branton 2009). Ornamental gardens, agricultural fields, or backyards are some examples of cultivated
landscapes. These landscapes are considered living places used by social groups or individuals to communicate messages about social order and status. They are a hybrid representation of the natural and the cultural worlds interacting in the same geographical setting.

The archaeology of cultivated landscapes and gardens aims to investigate the physical and symbolic creation of these constructed landscapes. Garden archaeology considers these landscapes as the material representation of cultural behaviors. With the analysis of layouts and plans, material culture, and botanical remains archaeologist attempt to understand the function and possible meanings of these features. (Brown 1991; Carroll 2003; Cummings 1994; Currie 2005; Gleason 1994; Goodwin et al. 1995; Horrocks et al. 2008; Krueger 2013; Leone 1989, 1988; Leone et al. 2005; Miller and Gleason 1994; Taylor 1983).

Since the emergence of garden archaeology in the 1990s, the practice of paleoethnobotany has been an important component in the study of modern world agriculture, horticulture, gardening, and diet. Macro and micro-botanical evidence in form of charred seeds, wood charcoal, phytoliths, spherulites, diatoms, starch grains, and pollen grains are the proxies analyzed. The combined analysis of botanical evidence and historical information creates multiple sources of data in the exploration of the human-plant relationships in the Modern World. The contribution of these types of multidisciplinary projects relies on the potential of the approach to “extend temporal depth for regions with suitable historical data and vegetation types with distinctive soil phytolith signatures” (Morris et al. 2009:95). A large number of current palaeoethnobotanical studies present the combination of botanical proxies and historical documents. (e.g., Becks 2012; Currie 2005; Evett et al. 2012; Horrocks et al. 2008; Malek and Fondation des Parcs et jardins de France 2013; Seiter and Worthington 2013; Trigg and Leasure 2007).

The paleoethnobotany component of the Historical Ecology and Archaeology of the Galápagos Islands project was conceived to contribute to this research interest. Environmental Historical Archaeology is a growing field to study new world contexts in Latin America. The project presented here contributes to the research interest in both
the regional and the interest to exploring the effect of colonization on insular ecosystems.

1.2. Archaeobotany of the Far Eastern Pacific Islands

An archaeobotanical framework has been applied in the far eastern Pacific Islands region to investigate the use and domestication of plants, and local vegetation history (Flett and Haberle 2008; Glynn and Ault 2000). The far eastern Pacific islands region encompasses insular systems from Mexico to southern Chile. The region lies predominantly in the tropics and some sub-tropical latitudes from the 19°N to near 35°S. Four small oceanic archipelagos and three isolated islands form this region: The Revillagigedo Islands (Mexico); Clipperton (France), Cocos (Costa Rica), Malpelo (Colombia); and the Galápagos Islands (Ecuador) are located north of the equator. The Desventuradas and the San Ambrosio Islands (Chile) are located south (Figure 1).

In contrast to other Pacific archipelagos, archaeologists have little investigated the islands of the far eastern Pacific. A majority of these Islands were first occupied after European colonization of South America. The Galápagos Islands were documented in 1535, the Cocos in 1541, and the Juan Fernandez Islands in 1575 (Flett and Haberle 2008). None of these islands are known to have been occupied by indigenous Pacific Amerindian groups. The archipelagos settled more recently are the Juan Fernandez and the Galápagos, where groups of whalers, buccaneers, and fishermen created temporary settlements. Permanent habitation of these archipelagos started in the late 19th century (Anderson et al. 2002; Froyd et al. 2010; Heyerdahl and Skjølsvold 1974; Larson 2010; Latorre 2011, 1999; Schofield 1989; Vargas 1986).

A variety of field and laboratory techniques including analysis of fossil pollen, macrobotanical remains, and charred wood from archaeological and historical sites have been applied in the region to explore environmental history and local palaeoecology. The research has led to the emergence of a considerable body of information and a significantly understanding of the vegetation history of these insular systems. The information addresses two main areas: (1) palaeoenvironmental reconstruction, and (2) anthropogenic impacts.
The far eastern Pacific islands region is one of the most recently human settled areas of the world. This fact has created the misconception that these locations are living pristine ecological laboratories where it is possible to understand the principles of evolution and adaptation (e.g., Bassett 2009; Hennessy and McCleary 2011; Quiroga 2013; Watkins 2008). In this regard, having a solid database of the environmental history of the region assists in understanding the ecology of the islands in both pre and post-colonization times. Palaeoecological research plays a transcendental role in recognizing the historical processes of the origin and movement of plants and animals on the islands.

Palaeoecological research during the past forty years has contributed to the definition of the insular ecosystems of the far eastern Pacific region. Techniques such as the study of fossil pollen (Colinvaux 1968; Colinvaux and Schofield 1976a, 1976b;
Colinvaux 1972; Collins and Bush 2011; Newell 1973; van der Knaap et al. 2012; Leeuwen et al. 2008; corals (Glynn and Ault 2000); the effects of El Niño Southern Oscillation (ENSO) (Andrus et al. 2008; Conroy et al. 2008; Kessler 2006, 2006; Rein et al. 2005; Restrepo et al. 2012; Riedinger et al. 2002); fluctuations in Sea temperature (SST) (Fiedler and Talley 2006; Conroy et al. 2009), macrobotanical remains (Coffey et al. 2010, 2012); soil chemistry (Seddon et al. 2011; Stoops 2014, 2013); and compound-specific isotopes (Zhang et al. 2007; Zhang and Sachs 2007), form the current body of palaeoecological data from the far eastern Pacific islands.

The geological record suggests that two types of islands comprise the region: oceanic islands and continental fragments. This difference in geological origin is key in understanding the biodiversity of the region. Oceanic islands originated from submarine volcanic activity in the Pacific, Cocos, and Nazca oceanic plates. These oceanic islands have never been connected to the continents. For this reason they were populated initially by plant and animal species that dispersed to the islands from the American mainland (Whittaker and Fernández-Palacios 2007). On the other hand, continental fragments are geologically dependent or originated from the mainland. Santa Maria, Moche, and Chiloe islands are examples of continental fragments. The Revillagigedos, the Galápagos, Cocos, the Desventuradas, and the Juan Fernandez islands present the volcanic origin. The Revillagigedos and the Galápagos are geologically recent systems containing still-active volcanoes. The southern archipelagos are older and their volcanoes are long extinct and eroded; however, several communities of plants and birds are present here, which have their origins in the continental biotas (see: Cody 2006; Currie 2010; Gillespie and Baldwin 2010; Glynn and Ault 2000; Grehan 2001; Haberle 2003; Vargas et al. 2012; Whittaker and Fernández-Palacios 2007).

These differences in geological origin are the reason for the existence of different and unique local ecosystem. The origins of plant and animal communities then have different sources and ages. The majority of Islands in the region seem to be floristically related to the mainland that successfully reached the islands by overseas dispersal, and moreover, succeeded in establishing persistence (Cody 2006:2). Examples are the Cocos and Galápagos that show floristic links with continental areas including Central America, the Caribbean islands, and North America (Trusty et al. 2012; Tye and Francisco-Ortega 2011). On the other hand, phylogenetic data have revealed that the
closest relatives of some island endemics are found not on a continent but on a
neighbouring archipelago, indicating the importance of both continents and islands as
important sources of insular biodiversity (Trusty et al. 2012:36).

The evidence illustrates that dispersal mechanisms including wind, birds, and
ocean currents, plays a transcendental role in the vegetation history of the far eastern
Pacific islands. The islands of Cocos and Malpelo, for instance, present a flora of Central
American relationship and origin. In Cocos many exotic plants have been documented,
especially fruit trees, papayas, and pumpkins. Up to 155 species of vascular plants have
been reported from the island and 48 species of non-vascular cryptogams. On the other
hand, the vegetation in the Revillagigedos Islands is xerophytic with low and shrubby
forests. Here, 186 species and subspecies have been identified, of which 43 are
endemic (Mueller-Dombois 1998). In the Galápagos Islands the vegetation zones and
ecosystems are well known due to intensive botanical research (e.g. Guezou et al. 2010;
Hamann 1974; Tye and Francisco-Ortega 2011; Wiggins et al. 1971).

Some discussion exists about the role of wind dispersal in the region, especially
in the case of Cocos and Galápagos. For instance, Sato et al. (1999) and Waller (2007),
propose that winds are not a clear dispersion mechanism process because surface
winds flow in a south-westerly direction across Cocos Island (Alfaro 2008), whereas in
the Galápagos, the predominant winds are from the southeast during the cool/dry
season (July to December), and mostly from the east the rest of the year (Trueeman and
d’Ozouville 2010). In this scenario, for most of the time these winds converge between
the two island groups rather than passing from one over the other. However, winds have
not prevented birds from moving between the islands. These results coincide with some
other areas of the Pacific, where phylogenetic studies clearly demonstrate that
organisms have colonized many islands by a stepping-stone pattern mostly following
bird migration routes (e.g., Harbaugh et al. 2009; Keppel et al. 2009; Wright et al. 2001).

Analysis of data from corals and lake sediments have been the major research
focus for investigating the environmental history of the region. According to Conroy et al.
(2008:1167), these proxies are suitable sources of palaeoecological data because
“corals from the tropical Pacific provide exceptional temporal resolution (monthly to
seasonal) and lake sediments can provide continuous records extending over several
millennia and typically have high temporal resolution”. The record suggests that two climatic shifts during the last 2000 years have affected the region. First, an important variation of El Niño southern oscillation (ENSO) occurred during the mid-Holocene. The data show that ENSO frequency was substantially reduced during the early to mid-Holocene and increased in frequency in the last few thousand years. In Galápagos, an ENSO increase is reported to have occurred during 2000–1000 cal. yr BP bringing increased frequency and intensity of precipitation (Rein et al. 2005; Conroy et al. 2008). Second a “La Niña like” pattern occurred in the tropical Pacific during AD 1250–1800, with cooler sea surface temperatures (SST) causing cooler and drier terrestrial conditions (Conroy et al. 2009).

According to Conroy et al. (2008), many ENSO reconstructions lack data with time depth, high resolution, continuity, or good locations within the central ENSO region. Consequently, the authors have recently proposed a new analysis of the grain size data from El Junco lake sediments in Galápagos. The cores indicate past lake level variability likely associated with changing seasonal precipitation and ENSO frequency. The recent data suggest higher lake levels and wetter conditions through the Holocene, with an abrupt transition to greater rainfall at 3200±160 and 2000±80 cal years BP. A period of increased ENSO frequency in the early Holocene between 9200 and 9000 cal years BP has also been recognized.

In order to comprehend the environmental context of the human colonization period of the region, a general understanding of the economic context of the 18th and 19th centuries in South America is necessary. Large areas of the Pacific coast were deforested as consequence of the intensive development of monocrop industry. Deforestation brings ecological effects such as invasive plants, erosion, and plagues (Wunder 2001). It is necessary then, to comprehend the historical context of late 18th and early 19th century’s agriculture in coastal South America to understand the economic and socio-political scenarios during the initial population of the insular systems.

1.2.1. Past climate events in historical records.

Several aspects of the climate history of the region are mentioned in historical documents. Research exploring historical documents and employing methodologies of
both climatology and history to reconstruct past weather conditions is referred to as historical climatology (Pfister et al. 2001). Environmental descriptions exist since early colonial times in Spanish America. These records include descriptions of landscape and climate by explorers and conquistadors who traveled on both the mainland and ocean. Fluctuations in temperature, precipitation, and drought periods are mentioned in detail in Spanish, Dutch, French, and English logbooks.

A transcendental work for historical research on climate in the region is the Climatological Database for the World’s Oceans: 1750-1854 (CLIWOC project) (García-Herrera et al. 2005). This work contains climate and meteorological data collected by ship crews during the period 1750-1854 while visiting the South American Pacific coast. The content of the CLIWOC logbooks consists of the date, geographical position, wind direction, wind force, weather, sea state, sea ice reports, temperature, and air pressure. These records are significant in understanding the environmental context at the time of discovery and conquest of the insular systems.

The effects of El Niño southern oscillation (ENSO) are constantly mentioned by the sailors and travelers in early documents, because the environmental effects of this current determined the movement of ships along the Pacific coast and impacted agriculture and fishing activities. The descriptions of ENSO events are also suitable temporal markers and allow researchers to understand the historical context and the history of human movement, population, and economic activities in this region. García-Herrera et al. (2008) have proposed a research plan focused on creating a chronology of El Niño southern oscillation (ENSO) events in northern Peru based on primary historical sources. The chronology of events refers to periods of abundant rainfall and river discharge in the Trujillo area from AD 1550 to AD 1900. Records of flooding and failure in fishing are the variables considered. A total of 59 events are identified being the 17th century the least active and the 1620s, 1720s, 1810s, and 1870s the most active decades. “These periods reveal non-stationary behaviour in warm ENSO occurrence with alternating periods of high and low activity lasting as long as 50 yr” (Garcia-Herrera et al. 2008:1960).

3 Few published logbooks from the USA, Germany, Sweden, and Denmark found in the Dutch archives, have been digitized (see details in: García-Herrera et al. 2005).
This work includes a discussion of previous data proposed by Quinn and colleagues (Quinn et al. 1987) about ENSO documentary chronologies. Quinn’s work was based on secondary historical data to demonstrate ENSO effects. They initially proposed 93 events over the period 1500-1900. Several attempts to reinterpret Quinn’s data have been achieved (e.g., Hamilton and Garcia 1986; Ortlieb 2000; Ortlieb and Macharé 1993). The reinterpretation of the data proposes that the events previously considered strong could be from another source and not ENSO related. Quinn associated higher precipitation in southern Peru to ENSO events; however, that seems to be a feature of La Niña events. In this sense, Ortileb suggest that from the 93 cases proposed by Quinn, only 26 can be consider as clear ENSO events. In summary, a total of 33 strong ENSO events can be defined since the 1500s in the Pacific coast of South America.

More recently, the work of Prieto and García-Herrera (2009) incorporates the analysis of historical documents with the study of environmental change in South America since the time of European arrival. Climate records in Spanish documents were written at the time of the foundation of cities to document and plan future agricultural schedules in the highlands and fishing calendars on the coast. Colonial governments and religious fraternities kept these records as complementary information to mercantile transactions, receipts, or inventories. The Cartas Anuas, Actas Capitulares, and the archives of the Jesuits appear as the most important sources of environmental information.

In this scenario, the Galápagos Islands appear as the most important source of ecological information for the far eastern Pacific island region. This is the largest insular system in the far eastern Pacific and it lies entirely on the equator, which has caused high frequencies of endemism of plant and animal communities. The location, geological origins, and ecology have been largely studied to understand the modern environment and the palaeoenvironment of both the islands and the south American pacific coast (e.g., Bush et al. 2010; Colinvaux and Schofield 1976a; Colinvaux and Schofield 1976b; Dunbar et al. 1994; Lea et al. 2006; Riedinger et al. 2002; Ortlieb and Macharé 1993).
1.2.2. **Paleoecology of the Galápagos Islands**

The Galápagos archipelago comprises 19 major islands and many smaller islets and it lies across the equator about 1000 km west of the coast of Ecuador. The archipelago comprises a total land area of 7,880 km² within a geographical area of 45,000 km². The largest island is Isabela (4,855 km²), where the peak of Volcano Wolf forms the highest point at 1,701 m a.s.l. All the other islands represent single shield volcanoes in various stages of erosion. The islands were formed between 0.3 million and 6 million years ago by volcanic activity at the Galápagos Hot Spot (Geist 1996). The oldest exposed rocks date from 3 million years (Christie et al. 1992; Werner et al. 1999). Geochemical and palaeomagnetic data from the islands demonstrate a complex interaction between the hot spot of Galápagos and the nearby Cocos–Nazca spreading centre, with the hot spot varying from being to the south (19.5–14.5 Ma) to the north (14.5–12 Ma), to being coincident (11–12 Ma) (Neall and Trewick 2008:3304).

Numerous palaeoecological studies have been conducted to understand the vegetative history of the archipelago. In addition, the human presence on the Galápagos Islands is recent, as human introduction of non-native species only started about 500 years ago (Froyd et al. 2010; van der Knaap et al. 2012). A fundamental contribution in the study of the ecology of the region is the definition of the vegetative zones by Wiggins et al. (1971), which are a reference point for the entire region.

The work of Paul Colinvaux (1972) and Colinvaux and Schofield (1976a, 1976b), are pioneering on understanding the vegetation history of the Galápagos using pollen analysis. Their research focused on the pollen record from “El Junco” Lake in San Cristobal Island. The analysis of sediments revealed stability in the taxa represented in the pollen and spore records throughout the Holocene (Colinvaux and Schofield 1976a, 1976b). The low lake levels inferred in the mid-Holocene suggest that before 5,000 BP wetter conditions prevailed in the islands (Colinvaux 1972; Riedinger et al. 2002). They attribute changes in the amounts of some taxa over the past four hundred radiocarbon years to cattle disturbance and forest clearance. However, no special attention was paid to the period of human population of the islands.
The work of van der Knaap et al. (2012) with fossil pollen from bogs on Santa Cruz Island, defined three distinct time periods in the fossil pollen sequences of Galápagos. First, a pre-human impact period (prior to AD 1535) where no pollen of introduced plant species exists. Secondly, an early human-impact period (between AD 1535 and ~1973), characterized by the expansion of *Pteridium* spores and increasing of microscopic charcoal. Finally, the late human-impact period (from AD ~1973 onwards) characterized by the expansion of *Cinchona* pollen, a human introduced taxa.

Recently, Restrepo et al. (2012) have demonstrated with high-resolution pollen analysis from El Junco Lake that natural climate variability or El Niño events have not significantly affected the delicate ecosystems of the islands. They propose that the local vegetation has had stability during the past 2,600 years. On the other hand, it seems that modern climate change appears to be changing the functioning of the ecosystem in Galápagos. “Unprecedented levels of upslope transport of pollen from the lowlands within the last 30 years suggest increased convection, and are consistent with a warming of warm/wet season temperatures” (Restrepo et al. 2012:1864). Conroy et al (2008) already discussed this topic proposing that the main driver of Galápagos climate change through the Holocene appears to be “orbitally induced changes in seasonal insolation, changes in the tropical Pacific sea surface temperature (SST) gradient, changes in the position of the Inter-Tropical Convergence Zone (ITCZ), or the strength of the Asian Monsoon” (Conroy et al. 2008:1178).

The consideration of the effects of *garúa* (fog) on the climate of insular systems is a proxy recently considered by Collins and Bush (2011). They argue that the seasonality of the presence of garúa is vital to the moist-adapted endemics of the highlands, providing the only location free from moisture stress. The importance of garúa has been extended to the lowlands of the Galápagos as demonstrated with observations of sea surface temperature (SST) and actual air temperatures, extending the importance of garúa to climate beyond its limits.

Dunbar et al. (1994) used stable isotope ratios in uplifted corals from the west coast of Isabela Island to reconstruct annual sea surface temperature variability from AD 1587 to 1982. They analysed variance in the ENSO frequency band, which was usually about 4.6 years, but shifted to higher frequencies in the early to middle 1700s and the
middle 1800s (Dunbar et al. 1994). Riedinger et al. (2002) also focused on El Niño activity, used the mineralogy and geochemistry of laminations preserved in saline lakes to identify their approximate intensities. They conclude that over the past 1000 years, there have been 36 strong events and five moderate events, while in the 1000 years before that, there were only 14 strong events and 152 moderate events.

Seddon et al. (2011) investigated ecological resilience in a mangrove ecosystem in the Galápagos. They used stable carbon isotopes (d13C) and AMS radiocarbon dating to examine two key ecological responses to environmental changes over the past 2,700 years in mangrove systems: community compositional change and increasing pollen accumulation rates. In addition, geochemical data was used to examine the long-term environmental changes. Global scale geophysical modelling was also employed to “predict longer-term estimates of relative sea-level (RSL) change as a result of post-glacial isostatic adjustment (GIA)” (Seddon et al. 2011:2). They propose that tidal inundation and disturbance can be tolerated by the coastal communities of Galápagos mangrove through responses linked to vertical accumulation of sediment in the coastal line.

Paleoecological, geological, and botanical data from the Galápagos Islands show climate stability during the early and mid-Holocene interrupted by an abrupt climate change during the past 2000 years reflected in the increase of ENSO events. The ecological and geographical characteristics of this archipelago have been considered as transcendental in the study of evolution, dispersion, and adaptation of living organisms. However, the effects of human population have not had the same consideration for biologists. Few recent palaeoecological research in Galápagos aims to understand the environmental changes in the past 1000 years (Flett and Haberle 2008).

4 The aim is to apply sedimentological and biotic proxy analysis that include: Grey-scale analysis to record frequency of colour changes related to sediment type; magnetic susceptibility to determine the concentration and composition of magnetic minerals and associated climatic variability, anthropogenic disturbance, fires, and forest clearance; loss on ignition to estimate the organic and carbonate contents of sediment; and X-ray fluorescence to quantify variations in 30 elements.
1.3. Population History of the Far Eastern Pacific Islands

Even though local biotic conditions allow the existence of large communities of plants and animals, many of the islands of the far eastern pacific remained unpopulated by humans until European arrival to the Americas. The islands appear to have been long identified by indigenous groups of South America; however, the evidence of their permanent occupation is scarce. The islands of the far eastern Pacific were discovered in the middle 16th century during the exploration of the Pacific Ocean. Spanish sailor Hernando de Grijalva discovered the Revillagigedos Islands in 1533 but the Islands remained abandoned for the following three centuries and only short visits for scientific explorations took place. The archipelago was finally populated in 1869 by a group of American, Australian, and Canadian immigrants (Brattstrom 1990).

Spanish Fray Tomas de Berlanga accidentally discovered the Galápagos Islands in 1535 while sailing from Panama to Peru. In 1570, mapmaker Abraham Ortelius plotted the Galápagos Islands, calling them the Isolas de Galápagos, or "Islands of the Tortoises" based on sailors' descriptions of the tortoises inhabiting the islands. By the 17th century, the Galápagos Islands became a popular hideout for British buccaneers who pirated Spanish ships and looted settlements in Central and South America. By the 18th century, British and American whalers and sealers began to visit the islands regularly to set up an industry center in the Pacific Ocean. The first known human settler on the Galápagos was Patrick Watkins, an Irish crewmember on a British ship, who was put ashore at Floreana Island in 1807. It was not until 1832, when the Galápagos Islands were annexed by Ecuador as a territory, that a formal settlement was established. These early colonists set up small farms on Floreana and Santa Cruz Islands (Ahassi 2007; Froyd et al. 2010; Latorre 2011; Consejo de Gobierno de Régimen Especial Galápagos 2014).

Spanish sailor Juan Fernández discovered the southern archipelagos of Juan Fernandez and the Desventuradas Islands in 1574, while sailing south between Callao (Peru) and Valparaíso (Chile) along a route to avoid the Humboldt oceanic current. During the 17th and 18th centuries the islands were used as temporary camps and hideout for pirates and whalers. During the maritime fur trade era of the early 19th century the islands were a source of fur seal skins, causing the near extinction of Juan
Fernández fur seal (*Arctocephalus philippii*). The islands were first populated in 1849 with the approval of the Chilean government. Ninety-six veterans and 171 civilians were sent to build a military fort and an adjunct village. In 1966, the Chilean government renamed the Islands as Alejandro Selkirk (previously named Isla Más Afuera) and Robinson Crusoe (previously Isla Más a Tierra).

Human populations have constantly modified the ecosystems and physical landscapes of the far eastern Pacific islands. Human discovery and population appears to be the major cause of dynamic changes in plants and animal populations. Whittaker and Fernández-Palacios (2007) have proposed four reasons why island species are affected and reduced by human action: introduction of non-native species, the spread of disease, direct predation, and habitat degradation or loss. In Galápagos, for instance, anthropogenic degradation has been estimated to have impacted about 5.5% of the Archipelago; specially, the humid zones where agriculture is possible (Watson et al 2009).

Agriculture appears as the most important threat to the endemic vegetation and animal populations. The impact of introduced non-native species can be seen in forms of predation, alterations to pollination and dispersal networks, or hybridization. It is proposed that there are at least 754 alien vascular plant taxa representing 468 genera in 123 families in the Galápagos Islands (van der Knaap et al. 2012; Guézou et al. 2010). All records indicate a large increase, up to 21%, of pollen from introduced species from AD 1535 onwards, coinciding with the archaeological records for first human activities on the Galápagos islands (Froyd et al., 2010).

Introduced species such as *Cinchona pubescens*, *Rubus niveus*, and *Psidium guajava* have transformed highland habitats on the larger islands with fertile soils (Jäger et al. 2013). Recently, using a high resolution study of macroremains extracted from bogs in Santa Cruz Island in Galápagos, Coffey et al. (2010) confirmed that *Ageratum conyzoides*, *Solanum americanum*, *Ranunculus flagelliformis*, *Brickellia diffusa*, *Galium canescens*, and *Anthephora hermaphrodita* were introduced by humans to the Islands. In this scenario, the worst invasive plant species appears to be the herbs elephant grass (*Pennisetum* sp.); the shrubs red cinchona (*Chinchona pubescens*), marabu (*Dichrostachys cinerea*), cuban hemp (*Furcraea cubensis*), white sage (*Lantana*...
camara), miconia (*Miconia calvescens*), strawberry guava (*Psidium cattleiaum, Psidium guajava*), chilean guava (*Ugni molinae*); the succulents coirama (*Kalanchoe pinnata*); and the red quinine tree (*Cinchona succirubra*) (Eckhardt 1972; Schofield 1973; Whittaker and Fernández-Palacios 2007).

The work of Restrepo et al. (2012) proposes that the resilience and stability of the Galápagos ecosystem changed with the arrival of grazing animals. Historical records mention that during the colonization of the Revillagigedos, one hundred goats and twenty-five cows were introduced from the continent. Similar numbers of domestic animals were transported to the Galápagos and the Juan Fernández Islands in the 1840s. Fluctuations in the abundance of *Alternanthera* and *Acalypha* were probably linked to an inferred increase in grazing activity that set a new ecological trajectory for the upland landscape after the 1930s (Restrepo et al. 2012). The most damaging invasive animal communities introduced to the islands are the Argentinean ant (*Linephitema humilis*); the triclad flatworm (*Platydemus manokwari*); the feral pig (*Sus scrofa*), the domestic cat (*Felis catus*), the feral goat (*Capra hircus*), the house mouse (*Mus musculus*), the maori, brown, and ship rats (*Rattus exulans*, *Rattus norvegicus*, and *Rattus rattus*), and the common rabbit (*Oryctolagus cuniculus*) (Whittaker and Fernández-Palacios 2007).

Little is known about the pre-Columbian visits or occupation to the far eastern Pacific islands. The hypothesis that humans never populated these places is generally accepted. Archaeological and palaeoecological data support the hypothesis that it was unlikely there had been significant human activity in the islands before European arrival (e.g., Anderson et al. 2016, 2002; Froyd et al. 2010; Haberle 2003; Cáceres and Saavedra 2004; Mackenna 1883; Takahashi et al. 2007). However, only the Galápagos and the Juan Fernández Islands have been archaeologically studied. Overall, the only evidence to date of a possible indigenous presence in the islands of the far eastern Pacific comes from a few ceramic shreds found in Galápagos, which were associated with Andean cultures (Heyerdahl and Skjølsvold 1974).

The location of the Galápagos between Easter Island and the South American mainland, along with the fact that the islands are the largest in the far eastern Pacific and are known to have been a bountiful source of meat, fish, and fresh water, has led to
speculation that ancient seafarers might also have lived on the islands. However, no clear signs of pre-Columbian structures, monuments, middens, or ancient agricultural features have been found. Archaeological evidence comes in the form of surface and subsurface fragments of pottery of unclear origin (Heyerdahl and Skjøtsvold 1974; Latorre 1999).

Archaeology in the Galápagos has a short history. Four archaeological projects have been conducted: the Norwegian Archaeological Expedition led by Thor Heyerdahl in 1953; the Walt Disney Galápagos Expedition led by J.C. Couffer and C. Hall in 1954; the geology/archaeology field school organised by the Escuela Superior Politecnica del Litoral (ESPOL, Guayaquil) led by Raul Maruri in 1963; and the ANU-led expedition to the Galápagos in 2005. The archaeological survey of Heyerdahl and Skjølsvold in Santa Cruz Island suggest that some of the ceramics found in Santa Cruz Island have a coastal Ecuadorian and Peruvian origin, and pre-dated a European presence in the region. This conclusion was based on typological similarities between the Galápagos collection and pottery from mainland Ecuador and Peru, which was thought, in the 1950s, to be pre-Columbian. At the time, there was an important discussion regarding this conclusion both in favour and contrary. For instance, Bushnell (1957) and Evans (1958), find the archaeological conclusions plausible while others argue that some of the identifications of Galápagos pottery were ‘daring’ and did not provide direct confirmation of pre-Spanish visits to Galápagos (Ryden 1958). In 1967, Robert Suggs published a ‘statistical re-analysis’ of the Galápagos data (Suggs 1967), critiquing Heyerdahl’s archaeological methods and conclusions, and concluded that the hypothesis of aboriginal visits to the Galápagos must be rejected. It is possible that the ceramic analysis provided misinterpreted results and the found sherds are of Spanish origin rather than indigenous origins.

The most recent fieldwork conducted by the ANU project focused on coring and sampling lakes and archaeological sites on Santa Cruz and Isabela Islands. Localities investigated were Whale Bay, James Bay, Black Beach and Buccaneer Bay, previously defined as archaeological locations by Heyerdahl and Skjølsvold (1990). Suitable landing sites on Santa Cruz, Santiago, San Cristobal, and Isabela Islands were surveyed for the first time. About 1600 artefacts were found in excavations; one third were ceramic fragments and the rest were pieces of metal, glass, charcoal, shell, and bone. The initial
conjecture was that the assemblages recovered date to the historical era, rejecting the previous speculations of a possible pre-Columbian human habitation.

The Juan Fernandez Islands also have been archaeologically investigated. Research there is limited to historic sites dating to the 18th century, specifically, the campsites of Scottish sailor Alexander Selkirk (e.g., Anderson et al. 2002; Cáceres and Saavedra 2004; Takahashi et al. 2007). Three field seasons were conducted. First, the work of Anderson et al. (2002) looking for pre-Columbian occupation sites on Robinson Crusoe Island. The sites of Cumberland Bay, English Bay, French Bay, and La Vaquería were surveyed in 2001. The results suggest a possible pre-Columbian presence according radiocarbon dates from charcoal. However, the material culture was once again, associated with the time of conquest. Second, the excavation of army campsites created by the Chilean army in the village of Puerto Ingles (English Port) and Selkirk cave took place. This site is attributed to be the habitation site of Alexander Selkirk (Cáceres and Saavedra 2004). The material record showed the existence of glazed and unglazed ceramics and small fragments of porcelain. In addition, faunal remains of fish, shells, and terrestrial mammals were identified. The evidence from the village shows the use of heavy weapons such as cannons to protect the village.

The work of Takahashi et al. (2007) surveyed and excavated the site of *Aguas Buenas*, in the upper lands of Robison Crusoe Island. The site, a rectangular structure formed by stonewalls, was also attributed to be the main habitation site of Alexander Selkirk, discussing previous arguments about its location. During excavation, several fragments of ceramics and metal were found, the most important being a bronze fragment of an instrument recognized as an astrolabe, a navigation instrument used during the 18th century.

Little paleoethnobotanical research has been achieved in this region. The work of Froyd et al. (2010) is the only project focused in understanding the early use of plants by humans in the far eastern Pacific Islands. The anthropological project was focused on identifying wood charcoal fragments from five historic campsite locations in the Galápagos Islands: James Bay and Buccaneer Bay on Santiago Island; and Whale Bay, Las Palmitas, and Cabo Colorado on Santa Cruz Island. One of the objectives was to understand the resultant impact on native vegetation of the possible introduction of non-
indigenous woods. The results presented a diverse charcoal assemblage with up to six taxa present; five native and one introduced species. Charcoal of larger native trees such as *Bursera graveolens* and *Piscidia carthagenensis*, smaller tree taxa such as *Acacia/Prosopis*, and shrubby species including *Scutia spicata* and *Vallesia glabra* are present in the sites studied. The charred wood remains suggest that the plants were used as fuel during the historic period, with median calibrated ages ranging between AD 1575 and AD+ 1825. *Acacia/Prosopis* appears as the most common type utilized with charred remains present at five of the six sites. Burning of the non-native tree species *Cinchona pubescens*, was revealed in the surface campsite at James Bay. *Cinchona* is an escaped cultivar introduced to Galápagos ca. 1846 (Hamann 1974). “The presence of *Cinchona* charcoal at James Bay on Santiago Island, where the species does not occur, indicates both the transport of an object or fuel wood for burning and also the likelihood of more recent use of the campsite” (Froyd et al. 2010:213). The analysis suggests that geographically driven rather than species-specific methods of wood collection were used by the buccaneers.

An interesting exercise aimed to visualize pre-anthropogenic landscapes in the Galápagos was completed by Trueman et al. (2003). Applying a multidisciplinary approach that combines historical documents, aerial photography, and oral history, the authors attempted to reconstruct the landscape of Santa Cruz Island back in the 1960s as an exercise that predicts the movements of humans across the islands. The results provide historical vegetation maps that show the extent of land affected by human activity, which in this case is about the 80% of the area of the Island.

The scarce archaeological evidence confirms the information present historical record that the far eastern Pacific region was first populated in the 18th century. The paleoecological record supports this hypothesis; however, only small number of projects have been focused in exploring the history of human population of the islands due to a focus in understanding long-term environmental changes and evolution. In this sense, historical written records are notable sources of data to understand the particularities of the population history of these Islands.

In this scenario, the project Historical Ecology and Archaeology of the Galápagos Islands aims to contribute to the current knowledge regarding the first human occupation
of the archipelago. The main goal is to present original archaeological data from San Cristóbal Island, which its human history has little been investigated.
Chapter 2. Soil Phytoliths as indicators of Initial Human Impact on San Cristóbal Island, Galápagos.


2.1. Abstract

Human impact and recent vegetation dynamics on San Cristóbal Island in the Galápagos were studied based on phytolith analysis within the framework of Environmental Historical Archaeology. Soil phytoliths from agricultural land at the former El Progreso plantation (AD 1870-1904) demonstrate changes in vegetation composition from arboreal to open habitats. Variations in the concentrations of grass phytoliths suggest vegetation change started in the middle 19th century, associated with colonization and the first permanent human occupation of the archipelago. Phytolith analysis and Tree Cover Index are the main indicators of plant introduction and human impact. Environmental Historical Archaeology was the central methodological model structured around a conceptual framework of Historical Ecology. This paper provides a comprehensive overview of the phytolith spectrum present in different locations of the Scalesia zone in San Cristóbal Island, which can guide future work on palaeoenvironments and the historical ecology of the Galápagos archipelago.

Key words: Phytoliths, Galápagos Islands, Human impact, Historical Ecology, Ecuador.
2.2. Introduction

Since its declaration as a World Heritage Natural Site by UNESCO in 1978, the Galápagos Islands have acquired the reputation of being one of the last pristine natural paradises on earth. Thousands of scientists, environmentalists, and tourists from all over the world visit the Islands every year looking for some of the last landscapes not affected by human actions. Local governments and tourism businesses deliberately emphasize the notion that travelling to the Galápagos will transport the visitor to a place where evolution is constantly taking place. Consequently, the archipelago is one of the most visited tourist destinations in the Americas with more than a half a million visitors a year.

However, during the past four centuries the local plant and animal populations have experienced extensive changes caused mainly by anthropogenic activity. After their discovery in 1535, the Galápagos Islands remained sporadically inhabited until 1832 when they were legally incorporated as Ecuadorian territory. For three centuries, the archipelago was visited by pirates and whalers, and was the location of several industrial-size plantations, one prison, and an American army base. Beginning in 1835, the Ecuadorian government provided incentives to colonization which increased the rates of introduced and invasive plants and animals on the islands.

The exploration of the ecological costs of colonialism is an integral part of historical archaeology. The aim of environmental and biological research in historical archaeology is to reconstruct modifications to the landscape and understand the ecological dynamics resulting from imposed socio-political agendas in new settings (Deagan 2008; Mrozowski 2010b, 2006b). In this work, I explore the ecological effects of the initial human presence in the Galápagos archipelago. I present the results of an archaeobotanical study in the Scalesia Zone of San Cristóbal Island. The overall goal was to investigate the potential of phytolith analysis to explore human impacts on local vegetation; specifically, the ecological impact caused by human permanent population. Secondary goals were to explore vegetation composition before human arrival, to detect human disturbance, and to evaluate the preservation of phytoliths in local soils.
2.2.1. Study area and background

The Galápagos are a group of volcanic Islands located below the equator in the Pacific Ocean, 1000 km west of the Ecuadorian coast (Between: 01°40’ N 01°36’ S; 089°16’ and 092°01’ W). The Galápagos archipelago comprises approximately 128 named islands and islets but only four are inhabited: Isabela, Floreana, San Cristóbal, and Santa Cruz. These volcanic islands formed about three million years ago. The age of the islands increases moving from west to east because of the drift of the Nazca tectonic plate away from the East Pacific Ridge to the southeast over a hotspot (Gromme et al. 2010; McBirney and Williams 1969; Simkin 1984). This study was located in the southeastern highlands of San Cristóbal; the easternmost, and one of the oldest, islands in the Galápagos (Figure 2).

The structure of the islands is that of coalescent and/or superposed lava streams in the lower parts and cones of different pyroclastic material at higher elevations (Stoops 2014). Soils are formed after decomposition of lava flow surfaces caused by moisture. The modern landscape is covered with poorly developed black soils; older soils are brown Andisols, and the oldest surfaces show eroded and highly cohesive Red soils (Franz 1980). Soil pH averages from 6.37 to 6.52 in the humid highlands of San Cristóbal Island (Percy, 2015, personal communication).

The islands are situated on the equator; however, they do not have a tropical climate due to the influence of two interacting ocean currents: the Inter Tropical Convergence Zone and El Niño Southern Oscillation (Trueman and d’Ozouville 2010). Local climate is influenced by altitude; the average annual temperature oscillates from 20 to 31°C, and only two seasons are recognized: cool and dry between June and December, and warm and rainy between January and May. The annual precipitation varies from 700-3000 mm and on the windward slopes of the mountains a mist, called garúa, is responsible for continuous humidity throughout the cool season (Stoops 2014:2).
In Galápagos, approximately 600 plant taxa exist of which about 32% are endemic. Seven vegetation zones are identifiable: Littoral (or Coastal) Zone, Arid Zone, Transition Zone, The Moist Zones: Scalesia Zone, Zanthoxylum (or Brown) Zone, Miconia Zone, Pampa or Fern-Sedge Zone (Wiggins et al., 1971). The environmental setting selected for this project is the Scalesia Zone, which extends from 200 to 400 m a.s.l. This zone, also called the Humid, or Agricultural Zone is home to a variety of endemic taxa such as Scalesia pedunculata, Psidium galapageium, Pisonia floribunda; and the native trees Cordia lutea and Piscidia carthagensis\(^5\) (Lee 2006; McMullen 1999; Wiggins et al. 1971). Today, the vegetation is characterized by the presence of invasive trees and shrub species such as guava (Psidium guajava), blackberry (Rubus niveus), plum rose (Syzygium jambos), multicolored lantana (Lantana camara), and

\(^5\) Other native taxa confined to the Scalesia zone are: Adenostemma lavenia, Adiantum henslovianum, Andiatum macrophyllum, Asplenium auritum, Asplenium cristatum, Asplenium formosum, Blechnum occidentale var. puberulum, Blechnum polypodioides, Conyza bonariensis, Desmanthus virgatus, Epidendrum spicatum, Justicia galapagana, Lycopodium dichotomum, Lycopodium passerinoides, Polypodium aureum, Polypodium phyllitidis, Psychotria rufipes, and Tournefortia rufo-sericea.
several grasses from the genera *Brachiaria*, *Eragrostis*, *Panicum*, and *Pennisetum* (Guézou et al. 2010, 2016).

The Galápagos Islands have a short human history. It is believed that humans did not occupy the archipelago before European discovery. Heyerdahl and Skjølsvold (1974) presented evidence suggesting that pre-Columbian groups from coastal Peru and Ecuador visited the islands, but this proposition is still in dispute (Anderson et al. 2016). The first European to document the archipelago was the Spanish Bishop Tomas de Berlanga in 1535. During the following two centuries, the Islands remained seasonally inhabited by pirates and whalers. In 1832, the Galapagos were incorporated into the new Republic of Ecuador. By the mid 19th century the Galapagos were being colonized by planters to create plantations of sugarcane (*Saccharum officinarum*), coffee (*Coffea arabica* L.), and quinine trees (*Cinchona pubescens*)

Ecuadorian businessmen Manuel J. Cobos and José Monroy obtained a long-term concession to plant and export sugar cane and coffee from San Cristóbal Island —formerly named Chatham Island. They created a large plantation called El Progreso in the humid highland interior of the island. This industrial-scale plantation occupied most of the southwestern portion of the island from 1860 to 1920 (Latorre 2002, 1991). The ecological consequences of these events are partially documented in palaeoecological and historical records but have been little explored archaeologically.

### 2.3. Historical ecology and the phytolith record as an indicator of human activities

Historical Ecology is an interdisciplinary research program concerned with understanding the temporal and spatial dimensions of interrelationships between human societies and environments (Balée 2006; Balée and Erickson 2006; Crumley 2003;

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6 The Quinine tree (*Cinchona pubescens*) was introduced to Galápagos during the 1850s to be the hosting plant for a moss where purple dye was extracted. The bark of *Cinchona* trees has been the source of the chemical quinine, effective against malaria. Today this plant is considered one of the worst invasive plant species in the entire archipelago;
Szabó 2015). Historical ecology focuses on the cultural production of landscapes, both materially and ideologically, in an attempt to interconnect methodological frameworks from the social and life sciences, in order to document the natural and historical context of human–environmental interactions (Johnson 2007; Knapp and Ashmore 1999; Walker 2012).

The first postulate of the Historical Ecology program proposes that practically all environments on Earth have been affected by humans and no pristine ecologies exist (Balée 1998). In Balée’s words, human activity has significantly affected most of the earth’s surface, which has been progressively transformed into managed cultural landscapes. Techniques and methods from paleoethnobotany can play a strategic role in exploring initial human-plant relationships in colonized landscapes and previously uninhabited places such as Islands. In this regard, phytolith analysis is an appropriate method to explore aspects of the human impacts to vegetation cover on the Galápagos Islands.

Phytoliths are opaline silica bodies formed when hydrated silicon dioxide is deposited on and between cells of a growing plant. They occur in stems, leaves, roots, fruits, and the inflorescence of certain plants. Their main function in vascular plants appears to be structural support (Strömberg et al. 2016). Phytoliths remain in the soil after plant tissues decay and are incorporated in the soils via the accumulation of organic matter, weathering of the parent material, bioturbation, and other soil-forming processes (Alexandre et al. 1999; Piperno 2006). The phytolith record has the advantage of relatively high spatial resolution due to the limited dispersal of phytoliths (Fredlund 2005).

The key to successfully using phytoliths to interpret vegetation changes in the recent past is to combine the phytolith record with independent lines of evidence for vegetation shifts derived from historical or other paleoecological data (McCune et al., 2015:613). Phytolith analysis has also been successfully applied in exploring vegetation dynamics and human impact on modern landscapes (Cabanes et al. 2012; Evett et al. 2012; Horrocks et al. 2008; McCune et al. 2015; Morris et al. 2010, 2009; Stinchcomb et al. 2011). The aim of this phytolith study on San Cristóbal Island was to understand
vegetation changes caused by colonization and the construction of El Progreso plantation.

2.4. Materials and methods

Phytolith analysis is an established tradition in the Americas (Fredlund and Tieszen 1994; Iriarte 2003; Mulholland 1989; Twiss 1992; Twiss et al. 2001). In the Neotropics several studies have identified grasses and arboreal taxa through the morphological characteristics of phytoliths (Albuquerque et al. 2013; Coe et al. 2015; Dickau et al. 2013; Morcote-Ríos et al. 2015; Pearsall et al. 2003; Piperno and Pearsall 1998; Watling et al. 2016). Research on phytoliths has also been applied to the study human-plant relationships on islands (Bowdery 2014; Horrocks et al. 2015, 2013; McCune and Pellatt 2013; Pearsall and Trimble 1984).

On San Cristóbal Island, columns for palaeoecological sampling of exposed profiles was the primary field technique (Pearsall 2000). Four test pits (60x60 cm) were excavated to a maximum depth of 60 cm to sample the soils from the last 200 years. These were excavated in four locations of the Scalesia Zone: village, abandoned field, forest, and agricultural field (Table 1 & Figure 2). The test pits exposed vertical faces allowing placement of the columns (15x60 cm).

For soil collection, the matrix was troweled into sterilized 15 ml plastic test tubes from the bottom up. The spacing unit was 5 cm and visible horizon boundaries were avoided. Each sample contained a maximum soil volume of 10 ml. The sampling tool was washed with distilled water after each sample was taken to avoid cross-contamination. Altogether, 52 samples were collected; 13 from each location including topsoil, which usually contains the highest phytolith concentration (Fishkis et al. 2009). Altitude, extant vegetation, soil type, and soil colour were field-noted. In addition, modern plant specimens of local trees and grasses were collected for phytolith extraction.
Table 1. Geographical information and historical descriptions of the vegetation surrounding the places where paleoecological columns were excavated

<table>
<thead>
<tr>
<th>Column name</th>
<th>Location &amp; Elevation</th>
<th>Current Vegetation types</th>
<th>1911 description (Stewart 1911)</th>
<th>1971 description (Wiggins et al. 1971)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GLP-PRG-PLB-CLM1_VILLAGE</td>
<td>215391E/9899598N 334m a.s.l.</td>
<td>Garden</td>
<td>Moist Region</td>
<td>Scalesia zone</td>
</tr>
<tr>
<td>GLP-PRG-PLB-CLM2_ABANDONED</td>
<td>215897E/9898656N 290m a.s.l.</td>
<td>Secondary forest</td>
<td>Transition Region</td>
<td>Scalesia zone</td>
</tr>
<tr>
<td>GLP-PRG-PLB-CLM3_FOREST</td>
<td>216548E/9901639N 336m a.s.l.</td>
<td>Forest</td>
<td>Moist region</td>
<td>Scalesia zone</td>
</tr>
<tr>
<td>GLP-PRG-PLB-CLM4_AGRICULTURE</td>
<td>214498E/9900227N 235m a.s.l.</td>
<td>Grassland</td>
<td>Moist Region</td>
<td>Scalesia zone</td>
</tr>
</tbody>
</table>

The first column, CLM_1_VILLAGE, was placed in the south profile of an archaeological test pit excavated in the rear yard of a modern house in the village of El Progreso, which was the location of the plantation village in the 19th century (0°54'27"S 89°33'27"W). Four horizons were observed: an active soil layer 8 cm thick (Munsell: 5YR 2.5/2); a 12 cm modern cultural layer (Munsell: 5YR 3/2); followed by a clay A horizon (Munsell: 5YR 3/3) with dead roots, charcoal, and cultural material possibly from the hacienda period; and a mineral horizon composed of solid red clay (Munsell: 2.5YR 3/4). This location was covered by mixed vegetation including ornamental plants, several types of grasses, herbs, and a few palms. The test pit was excavated in an area that is thought to have been the location of a communal kitchen when the plantation was in operation.

The second column, CLM_2 ABANDONED FIELD, was placed in the north profile of a test pit excavated south-east of the urban center (0°54'57"S 89°33'9"W). Three horizons were observed here: an active soil layer 7 cm thick (Munsell: 5YR 2.5/2); followed by a 20 cm thick clay-rich A horizon (Munsell: 5YR 3/4); and a mineral horizon composed of solid red clay (Munsell: 2.5YR 3/4). This location is covered by a
secondary forest resulting from the abandonment of a former agricultural field. Today, this area is covered by the introduced tree *Syzygium jambos* (plum rose).

The third column, CLM_3 FOREST, was placed in the north profile of a test pit excavated near the border between the agricultural zone and the National Park Zone of San Cristóbal Island (0°53'20"S 89°32'48"W). The same three horizons observed in CLM_2 were visible here. This location is dominated by several shrubs and small trees including native *Bursera graveolens*, *Zanthoxylum fagara*, and *Cordia lutea*; and the introduced *Psidium guajaba* and *Citrus sinensis*. The native herb *Rynchospora nervosa* was also present at this location.

Finally, CLM_4 CULTIVATED FIELD was placed in the north profile of a test pit excavated in a modern cultivated field (0°54'6"S 89°33'55"W). Three horizons were observed: an active soil layer 5 cm thick (Munsell: 5YR 4/3); a 15 cm A horizon (Munsell: 5YR 3/4) with dead roots and charcoal, and a 45 cm B horizon (Munsell: 5YR 3/3) interrupted by a 5 cm silty-clay layer (Munsell: 5YR 4/4) This location is currently a fallow field covered by grasses from the Panicoid and Chlorideae subfamilies and used to grow corn (*Zea mays*) and fruits. It was probably a sugar cane field in the late 19th century.

### 2.4.1. Laboratory protocols: Phytolith Extraction and Tree Cover Index (D/P)

Phytoliths were extracted from soils with a combination of two protocols: wet oxidation and dry ashing (Albert and Weiner 2001; Albert et al. 1999; Piperno 2006; Zhao and Pearsall 1998), with minor modifications by (Astudillo 2011; Mercader et al. 2011, 2010) (Supporting material 2.8.1). The aim was to quantify the progressive loss of soluble minerals from the mineral and organic matrix. This combined process destroys calcium, phosphate, and organic compounds in order to isolate the biogenic silica through flotation in heavy liquid at a specific gravity of ~2.4 (Jones and Beavers 1963).

Classifying criteria follow those presented by the International Code for Phytolith Nomenclature 1.0 (Madella et al. 2005). The evidence was compared to a local reference collection of native and introduced economic plants (Chapter 4 of this
dissertation), and published evidence from tropical South America (Ezell et al. 2006; Fernández Honaine et al. 2009, 2006; Iriarte et al. 2004; Iriarte and Paz 2009; Korstanje and Babot 2007; Korstanje and Cuenya 2010; Morcote-Ríos et al. 2015; Pearsall; Pearsall et al. 2003; Perry et al. 2007; Piperno 2009; Piperno and Pearsall 1998). Morphological features scrutinized were size, bi-dimensional outline, three-dimensional classification, and surface texture. Counting took place at 400X magnification within 24 hours of mounting in ten adjacent but not overlapping lines across the cover slip. All samples were analysed under differential interference contrast (D.I.C.) microscopy. Close examination of phytolith morphology was conducted on photographic frames using OLYMPUS Stream Basic 1.8 image analysis software.

Tree cover index (D/P) was selected as a quantitative method to define the characteristics of vegetation cover prior to human arrival. Tree cover index uses the ratio of certain forest phytoliths to grass phytoliths in order to give a measure of vegetation structure in absolute and relative terms (Strömberg 2009). In other words, a decrease in D/P ratios shows the change from forest to open or savannah-like habitats (Coe et al. 2015, 2014, 2013; Evett et al. 2007). Indexes were obtained from phytolith concentrations following (Alexandre et al. 1997; Bremond et al. 2005). D/P values less than 1.16 were defined as “open habitat” and values greater than 1.82 as “forest”, following Bremond et al. (2005:284). In this study, D=Dicotyledonous phytoliths (Globular psilate morphotype) and P=sum of Poaceae grass phytoliths (Bilobate, polylobate, quadra-lobate, saddle, rondel, and cuneiform bulliform cell morphotypes). Other dicotyledonous, grass, and non-identified phytoliths were not included in this formula.

2.5. Results

A total of 56.149 g of soil was processed for phytolith extraction. Biogenic silica averages 6.27% of the total dry mass and the number of phytoliths counted was 8,076 (Table 3, Supporting material). Five main groups of phytolith morphotypes were identified: (1) panicoid phytoliths (scutiform lanceolate, bilobate, polylobate, cuneiform

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7 Microscope: Olympus BX53 D.I.C.
bulliform, and quadra-lobate morphotypes); (2) elongate phytoliths (grass phytoliths); (3) globular phytoliths (arboreal phytoliths), (4) other diagnostic, and (5) non-identified morphotypes. Phytoliths from panicoid grasses are the most common in all the strata sampled with frequencies of 32.76% (n=2,645) of the total phytolith count. Second are elongate phytoliths associated with grasses, with frequencies of 13.87% (n=1,120), followed by globular phytoliths with 10.59% (n=856); other diagnostic phytoliths with 29.84% (n=2,410); and non-identified phytoliths at 12.94% (n=1,045) (Figures 3 & 4).

Bilobates, polylobates, and quadra-lobates are morphotypes commonly associated with panicoid grasses (Piperno and Pearsall 1998). With an average length of 20 μm, bilobates are common in the genera *Aristida* (Arundinoideae), *Eragrostis* (Chloridoideae), and *Stipa* (Pooidae), all present in the soils of San Cristóbal Island. I classified bilobates according to the lobate shape and shaft size, after other studies that have indicated the possibility that these body features may indicate relative taxonomic and environmental sorting (Fahmy 2008; Barboni et al. 2007; Mercader et al. 2010).

### Table 2 Prominent phytolith morphotypes in soils from the Scalesia Zone of San Cristóbal Island, Galápagos.

<table>
<thead>
<tr>
<th>Morphotype</th>
<th>Source</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parallelepipedal bulliform cell</td>
<td>Madella et al. (2005:255)</td>
<td>1,214</td>
<td>15.03</td>
</tr>
<tr>
<td>Elongate cylindrical piscilate long cell</td>
<td>This study</td>
<td>785</td>
<td>9.72</td>
</tr>
<tr>
<td>Bilobate concave outer margin short shaft var. A</td>
<td>Fahmy (2008:15)</td>
<td>762</td>
<td>9.43</td>
</tr>
<tr>
<td>Globular sinuate</td>
<td>This study</td>
<td>699</td>
<td>8.65</td>
</tr>
<tr>
<td>Scutiform lanceolate</td>
<td>This study</td>
<td>587</td>
<td>7.26</td>
</tr>
<tr>
<td>Elongate Echinate long cell</td>
<td>Madella et al. (2005:255)</td>
<td>335</td>
<td>4.40</td>
</tr>
<tr>
<td>Fusiform equal</td>
<td>This study</td>
<td>319</td>
<td>3.95</td>
</tr>
<tr>
<td>Saddle</td>
<td>Madella et al. (2005:255)</td>
<td>209</td>
<td>2.59</td>
</tr>
<tr>
<td>Bilobate concave outer margin long shaft var. B</td>
<td>This study</td>
<td>204</td>
<td>2.53</td>
</tr>
</tbody>
</table>
In CLM_1, biogenic silica averages 2.261% of the dry mass. The total number of phytoliths counted was 2,332. Parallelepipedal bulliform cells are the dominant type found in all the strata excavated with frequencies of 16.69% (n=389), followed by elongate cylindrical piscilulate long cells at 11.53% (n=269), globular piscilates at 8.02% (n=187), scutiform lanceolates at 7.25% (n=169), and saddle epidermal short cells at 5.58% (n=130) of the total assemblage (Figure 4). In CLM_2, biogenic silica averages 0.209% of the dry mass. A total of 1,539 phytoliths were counted in this column. Globular piscilates were the dominant morphotype encountered in all strata excavated at 17.74% (n=273); followed by parallelepipedal bulliform cells at 11.70% (n=180), elongate cylindrical piscilulate long cells at 9.81% (n=151), hair bases at 7.73% (n=119), and scutiform lanceolates at 5.78% (n=89) of the total assemblage (Figure 5).

In CLM_3 biogenic silica averages 19.371% of the dry mass. A total of 759 phytoliths were counted in this column. Phytoliths of arboreal/dicotyledonous origin are dominant. The scutiform lanceolate morphotype is the most common morphotype in all the strata excavated at 19.63% (n=149), followed by ovates at 10.40% (n=79), elongate echinate long cells/stomatal epidermis cells at 9.88% (n=75), parallelepipedal bulliform cells at 9.88% (n=75), and globular piscilates at 3.29% (n=25) (Figure 6).

Finally, in CLM_4, biogenic silica averages 2.286% of the dry mass. A total of 3,446 phytoliths were counted in this column and grass phytoliths are most common. Bilobate concave outer margin short shaft var. A dominates in all the strata excavated at 18.57% (n=649), followed by parallelepipedal bulliform cells at 16.54% (n=570), elongate cylindrical piscilulate long cells at 9.72% (n=335), scutiform lanceolates at 5.22% (n=180), and Bilobate concave outer margin short shaft var. C at 5.19% (n=179) (Figure 7).
Figure 3. Common arboreal phytoliths in soils of San Cristóbal Island, Galápagos: (A,B) globular sinuate; (C) fusiform equal; (D) ovate equal; (E) tissue platelet asteraceae (Photos: OLYMPUS Stream Basic 1.8 software with DIC microscopy).
Figure 4 Common grass phytoliths in soils of San Cristóbal Island, Galápagos: (A) scutiform lanceolate; (B,C,D,E,F) variations of bilobate concave outer margin short shaft; (G,H,I) variations of cuneiform bulliform cell; (J) elongate cylindrical long cell; (K) elongate echinate long cell; (L) papillae cell; (M) parallelepipedal bulliform cell; (N) polylobate epidermal short cell; (O) quadra-lobate epidermal short cell; (P) rondel tall pyramidal ovate top; (Q) saddle epidermal short cell; (R) glume phytoliths; (S,T) stomatal phytoliths (Photos: OLYMPUS Stream Basic 1.8 software with DIC microscopy).
Figure 5 Stratigraphic diagram representing final counts of phytoliths in CLM_1 VILLAGE (C2 Software).
Figure 6 Stratigraphic diagrams representing counts of phytoliths in CLM_2 ABANDONED FIELD, and CLM_3 FOREST (C2 Software).
Figure 7. Stratigraphic diagram representing counts of phytoliths in CLM_4 CULTIVATED FIELD (C2 Software).
D/P indices were calculated from final concentrations of phytoliths to discriminate vegetation composition. D/P indexes vary from 42.00 in the lowest levels to 0.00 at the surface. The results show that concentrations of phytoliths formed in arboreal and dicotyledonous taxa grew rare through time, and were replaced by open habitat indicators. (Figure 8).

In CLM_1 VILLAGE, the index changes from 5.54 to 0.21 between 35 and 40 cm below surface. In this level, the concentration of phytoliths associated with arboreal vegetation suddenly changed. Three morphotypes are not present in levels closer to the surface: (a) fusiform equal, associated with the native tree *Piscidia carthagenensis* (Matazarno); (b) globular sinuate, produced in the majority of trees and shrubs such as native *Piscidia carthagenensis*, *Psidium galapageium* (guayabillo), *Scalesia pedunculata*, and *Prosopis juliflora* (mesquite or algarrobo), as well as introduced *Syzygium jambos* and *Persea americana* (avocado); and (c) hair base, found in the native trees and herbs *Piscidia carthagenensis*, *Psidium galapageium*, *Scalesia pedunculata*, *Tournefortia pubescens* (white haired tournefortia), *Zanthoxylum fagara* (cat's claw), *Tournefortia rufo-sericea* (red haired tournefortia), and *Laportea aestuans* (west Indian woodnettle). On the other hand, concentrations of diagnostic grass phytoliths increase significantly in contexts closer to the surface.

Phytoliths such as: 1) saddle, produced by the introduced *Cynodon nlemfuensis* (African bermudagrass), *Pennisetum purpureum* (elephant grass), *Brachiaria decumbens* (bracharia grass), and *Bambusa vulgaris* (bamboo); 2) scutiform lanceolate, common in all the tested native and introduced grasses except in *Saccharum officinarum* (sugar cane), *Cynodon nlemfuensis* (african bermudagrass), *Panicum maximum* Jacq (saboya grass), *Bambusa vulgaris*, and *Guadua* sp. (bamboo); 3) bilobate morphotype produced by the native grasses *Scleria melaleuca* (cortadera grass) and *Stenotaphrum secundatum* (buffalo grass), and by all the introduced grasses; 4) parallelepipedal bulliform cell, produced by the native *Rynchospora nervosa* and also by the introduced *Panicum* maximum and *Eragrostis amabilis* (japanese lovegrass); 5) cuneiform bulliform cell, observable in the introduced grasses, *Cynodon nlemfuensis*, *Panicum* maximum, *Brachiaria decumbens*, and *Bambusa vulgaris*; and 6) polylobate short cell, present in the introduced *Eragrostis amabilis*. 

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8 Phytoliths such as; 1) saddle, produced by the introduced *Cynodon nlemfuensis* (African bermudagrass), *Pennisetum purpureum* (elephant grass), *Brachiaria decumbens* (bracharia grass), and *Bambusa vulgaris* (bamboo); 2) scutiform lanceolate, common in all the tested native and introduced grasses except in *Saccharum officinarum* (sugar cane), *Cynodon nlemfuensis* (african bermudagrass), *Panicum maximum* Jacq (saboya grass), *Bambusa vulgaris*, and *Guadua* sp. (bamboo); 3) bilobate morphotype produced by the native grasses *Scleria melaleuca* (cortadera grass) and *Stenotaphrum secundatum* (buffalo grass), and by all the introduced grasses; 4) parallelepipedal bulliform cell, produced by the native *Rynchospora nervosa* and also by the introduced *Panicum* maximum and *Eragrostis amabilis* (japanese lovegrass); 5) cuneiform bulliform cell, observable in the introduced grasses, *Cynodon nlemfuensis*, *Panicum* maximum, *Brachiaria decumbens*, and *Bambusa vulgaris*; and 6) polylobate short cell, present in the introduced *Eragrostis amabilis*. 

Figure 8. Concentrations of arboreal vs grass phytoliths and D/P ratio signals in soil phytoliths from San Cristóbal Island, Galápagos. Note the sudden change from arboreal to open habitat.

CLM_3 FOREST shows a similar pattern. D/P index changes from 3.27 to 0.29 between 20 and 25 cm below surface levels. The diagnostic arboreal phytoliths that gradually disappeared through time are: (a) globular sinuate; (b) ovate equal, produced by the native *Psidium galapageium* (guayabillo); (c) acicular hair cell, observed in the native *Laportea aestuans* and *Gossypium darwinii* (Galápagos cotton), and in the introduced *Ceiba pentandra* (silk cotton tree) and *Artocarpus altilis* (bread tree). Morphotypes from grasses that increase in this level are: elongate psilate long cell; elongate echinate long cell/stomatal epidermis phytoliths produced in the native *Rynchospora nervosa*, *Scleria melaleuca*, and in the introduced grasses *Pennisetum*
purpureum, Eleusine indica (crowfoot grass), Eragrostis amabilis; and parallelepipedal bulliform cells. In addition, CLM_3 shows a stable presence of the scutiform lanceolate morphotype, common in native Scleria melaleuca and Stenotaphrum secundatum.

CLM_4 AGRICULTURAL FIELD shows the same pattern. The D/P index changes from 2.92 to 0.64 between 20 and 25 cm below surface. The diagnostic arboreal morphotypes that gradually disappear through time are: (a) orbicular hair cell morphotype, associated with Scalesia pedunculata; and (b) ovate equal morphotype, associated with Psidium guajava (guava). In this level morphotypes from grasses also increase through time.\textsuperscript{9}

In CLM_2 ABANDONED FIELD, a different pattern is observed. There is an incremental increase in the presence of grasses through time, but the presence of arboreal morphotypes is stable, contrary to the patterns observed in the other three columns. The D/P index changes from 2.00 to 0.33 between the levels 20 and 25 cm below surface. Arboreal phytoliths which decrease are: (a) globular sinuate; (b) hair base, and (c) tissue platelet Asteraceae. Phytoliths from grasses increases through time. One diagnostic phytolith that disappears in recent levels is the papillae cell, associated with Rynchospora nervosa (a native Cyperaceae).

2.6. Discussion

The phytolith record from the soils of San Cristóbal Island suggest that the vegetation composition of the Scalesia Zone has changed from arboreal to open habitat during the past century. The phytolith analysis and Tree Cover Index show that arboreal vegetation dominated the landscape in the period preceding human arrival. This tree cover was partially replaced by grasses during the second half of the 19\textsuperscript{th} century. The

\textsuperscript{9} Grass phytoliths that increase through time in this column are: 1) Saddle morphotype; rondel short flat top associated to Eragrostis amabilis; 2) rondel tall pyramidal ovate top associated to Stenotaphrum secundatum and Saccharum officinarum; 3) bilobate short cell; 4) quadra-lobate epidermal short cell associated to Panicum maximum, Eleusine indica (Crowfoot grass), and Eragrostis amabilis; 5) cuneiform bulliform cell associated exclusively to the introduced grasses; 6) elongate psilate long cell; 7) elongate echinate long cell/Stomatal epidermis phytoliths; and 8) parallelepipedal bulliform cell.
results show higher concentrations of globular phytoliths and other arboreal-derived phytoliths in earlier contexts, and large concentrations of grasses after human arrival on the island.

Globular phytoliths are formed in most tree and shrub taxa in tropical zones (Piperno 2006). Even though they are not diagnostic morphotypes at the level of genus or species, globular phytoliths in soils are indicators of the existence of arboreal vegetation. My research shows that globular and ovate phytoliths are formed in leaves and stems of native taxa in the Galápagos, including *Piscidia carthagenensis*, *Psidium galapageium*, *Prosopis juliflora*, and *Scalesia pedunculata*. These trees were described as an important component of the local landscape by early travellers during the first scientific expeditions to the Galápagos Islands (California Academy of Sciences 1907; Compañía "Guía del Ecuador 1909; Mann 1909; Stewart 1911). Several other morphotypes such as fusiform equal, hair base, and acicular hair cells were also observed. Changes in concentrations of these morphotypes support the premise that arboreal vegetation was preponderant in the area prior to human arrival.

After human arrival, grasses became a primary component of the local landscape around the first settlements. The concentrations of diagnostic grass phytoliths such as bilobate, cuneiform bulliform cell, saddle, elongate epidermal long cells, and parallelepipedal bulliform cells, all formed in Poaceae grasses, noticeably increase in contexts associated with human activities; especially the industrial-scale agriculture of El Progreso plantation. These phytoliths are formed in leaves of some members of the Panicoideae subfamily of grasses such as the *Andrapogon*, *Aristida*, *Eragrostis*, *Panicum* and *Zea* (Mulholland 1989). Today, these genera are categorized as introduced and invasive taxa in the entire archipelago and dominate the modern local ecology.

The alteration in vegetation composition is supported by the D/P indexes from all the columns analyzed. D/P indexes from CLM_1 VILLAGE, for instance, go from 5.54 to 0.21 in the context associated with the plantation, considered to be the initial human permanent occupation of the island. The indexes are similar in all columns analyzed supporting the assumption of a change in vegetation composition. This variation in phytolith concentrations suggest a transformation in vegetation composition began about
150 years ago as consequence of human colonization and agriculture in the areas near El Progreso village, the central core of the plantation.

2.6.1. Human impact

Deforestation and intensive agriculture are the most likely reasons for the alteration in the vegetation cover observed in the phytolith record. Deforestation brings ecological effects such as the migration of invasive plants, erosion, and disease. Similar effects of human disturbance on Islands have been reported to have happened after the colonization of Nevis Island in the Caribbean, where in the 60 years after first settlement aggressive land clearing and planting by the English radically changed the local rainforest into an agro-industrial landscape (Meniketti 2015).

The information present in documents regarding the colonization of the Galápagos Islands suggest three periods of ecological transformation in the highlands of San Cristóbal caused mainly by agriculture. First, deforestation started in the 1860s when Manuel J. Cobos and José Monroy, the owners of Hacienda El Progreso, obtained an agricultural concession for the Island. During this decade, they started to recruit workers in mainland Ecuador and transported them to the island to prepare the land for agricultural activities (for more details about colonization of San Cristóbal Island see Chapter 5 of this dissertation). According to Bognoly and Espinoza (1905), by 1869 about ten people were living and working in San Cristóbal. They also wanted to maintain the concession status following 1885 legal changes that created incentives for the colonization of the islands through tax exemptions, land grants, and exemption from military service for colonizers (Guia Comercial 1909:1319). Workers were recruited in several coastal cities of Ecuador and were transported to the island with families, domestic animals, fruits, and vegetables to create small gardens and farms; this increased the rates of introduction of new plant species. Undoubtedly, the first settlers deforested the land around El Progreso village to create agricultural parcels and to obtain wood for construction materials, timber, or to manufacture agricultural tools.

Alexander Mann, who visited San Cristóbal Island (formerly known as Chatham Island) and El Progreso in 1906, described a “wide extent of pasture land, almost devoid
of trees and brush estimated at over ten thousand acres” (Mann 1909). Nicolas
Martinez, after a visit to Hacienda El Progreso in the same year expressed his concern
about the disappearance of native forest and the expansion of grasslands caused by
deforestation. In his description of the local vegetation on San Cristóbal Island he
pointed out the impacts of deforestation and the necessity to plant wood species to
replace the already few sources of firewood and timber. In this regard, he suggests the
immediate introduction of pine and oak trees; species that could grow quickly to replace
the disappearing forest (Martínez 1915). Another estimate of grasslands around El
Progreso village by this time suggested 1200 hectares had been put into pasture
(Compañía "Guía del Ecuador 1909).

An intensive agricultural and farming period began in the 1870s at Hacienda El
Progreso. During the initial years of plantation operation people deforested large areas
to create suitable parcels for monocrop production close to the hacienda core. Activity
further intensified after 1879 when Manuel J. Cobos decided to live permanently at El
Progreso. In 1889 there were about 210 cuadras10 of sugarcane, which increase to
approximately 400 cuadras in 1904 (Latorre 1991). These fields were carefully
controlled, irrigated, and constantly cleared of weeds to maintain high productivity levels.
In 1906, the hacienda was reported to have 1,000 cuadras of natural grass and 210 of
Janeiro grass (Guia commercial: 1324); which in modern measurement units represent
approximately 1,200 hectares.

Leather production was also one of the main activities of El Progreso during the
last decade of the 19th century. In this regard, extensive rangeland had to have been
created. Apparently, areas at higher elevations close to El Junco Lake were selected for
this activity, which gradually increased deforestation outwards from the urban core of El
Progreso to the east. Trees, bushes, or trenches were used as fencing in the
pastureland since early colonial times in Ecuador. Fences made with the agave plant
(Agave americana) were common in the Ecuadorian highlands until imports of barbed

10 In Spanish America, one cuadra measured approximately 10,000 m² (1 hectare); in Argentina
during the 19th Century one square cuadra was equivalent to 16,874 m² (1.6874 hectares)
(Amaral 2002); and in modern times according to the official measuring units of Ecuador, one
cuadra is equivalent to 6,987 m² (0.69873 hectares) (INEN 47:1973).
wire began after its invention in 1879. Excavated trenches were also commonly used to demarcate land use boundaries. Natural fences made with trees can be observed in the historical photographs of El Progreso and two species of agave (Agave americana and Agave angustifolia var. marginata) were introduced to San Cristóbal Island during colonization. Considering the unlimited access to land and the lack of state control, it seems likely that pasture rotation was the method used for beef cattle raised at El Progreso (Figure 9).

Figure 9. The village of El Progreso in 1888 on San Cristóbal Island, Galápagos. This is one of the earliest known photos of the island (National Archives photo no. 22-FA-87).
These activities described in archival data corroborates the sudden increase of grass derived phytoliths in the soil samples analyzed and support the paleoecological records that suggest an increase of Poaceae pollen grains during the first decade of the 20th century (Bush et al. 2014; Collins and Bush 2011; Leeuwen et al. 2008; van der Knaap et al. 2012; Vargas et al. 2012). The increase in pollen from Poaceae was also observed in a recent soil core from El Junco Lake, 7 km north-east from the study area (Restrepo et al. 2012). This seems to be the time when the introduced grasses start to become part of the local landscape; especially *Penisetum* and *Bracharia*, both recognized in the phytolith record from the presence of the cuneiform bulliform cells, polylobate, and saddle morphotypes. The high numbers of Panicoideae derived phytoliths in superficial levels of the Scalesia Zone could also be indicators of the presence of economically useful taxa such as sugar cane (*Sacharum officinarum*) or bamboo (*Guadua* sp.).

A third period of vegetation change resulted from the abandonment of agricultural land at El Progreso during the mid 20th century. During this time, agricultural activities declined at Hacienda El Progreso and most land parcels were abandoned. People returned to mainland Ecuador leaving behind the introduced flora and fauna. Consequently, the open habitat landscape once controlled and maintained for monocrop agriculture was overtaken by introduced grasses and arboreal taxa that are evident today. It took about 30 years after abandonment for invasive taxa to repopulate these open habitats. The vegetation of the original agricultural parcels was replaced by several grasses including *Panicum*, *Pennisetum*, and *Bracharia* and arboreal taxa such as *Psidium guajava*, *Rubus niveus*, and *Syzygium jambos*; all observable as topsoil phytoliths. This increase in the number of invasive taxa is corroborated by the records of the Charles Darwin Foundation, which report the existence of about 550 introduced plant species on the archipelago (Froyd et al. 2010; van der Knaap et al. 2012).

Relevant palaeoecological data show that colonization efforts in the 19th century had a huge impact on local island biota (Colinvaux and Schofield 1976a, 1976b; Eckhardt 1972; Leeuwen et al. 2008). The phytolith record at El Progreso partly supports a recent palynological record presented by Restrepo et al (2012) from El Junco Lake, which has demonstrated with high-resolution pollen analysis that the local vegetation has been stable during the past 2,600 years with an important vegetation change in the
period from AD 1930 to 2000, which is observed in influx reductions of *Acalypa* and *Alternanthera* and increases in Poaceae and Myrtaceae pollen. The phytolith record corroborates the increases in Poaceae pollen after the 1930s on the island due to more intensive farming and animal grazing around El Junco Lake occurring after the plantation operations. However, it is evident that the vegetation transformation of the Scalesia zone started at least five decades before with the first activities around El Progreso plantation. In this regard, I consider that the most important vegetation change happened during the late 1880s during the first agricultural activities on San Cristóbal Island.

### 2.6.2. Phytolith production and preservation

The phytolith record from San Cristóbal demonstrates low concentrations of phytoliths in soil contexts predating human presence. A low production of diagnostic phytoliths in endemic taxa is the best explanation. Leaves and stems of eight of the most important useful arboreal native taxa were tested for phytolith production; however, low concentrations of diagnostic phytoliths exist in taxa correspondent to this Zone other than the globular and ovate morphotypes. The comparative material processed indicates that the amount of silica extracted from leaves and stems of modern trees is approximately 0.001% of the plant tissue, which would explain the low concentrations of globular phytoliths in soils.

Early historical descriptions of the landscape of the Galápagos Islands mention the presence of arboreal taxa such as *Scalesia pedunculata* (Asteraceae), *Psidium galapageium* (Myrtaceae), *Zanthoxylum fagara* (Rutaceae), and *Piscidia carthaganensis* (Fabaceae) at El Progreso. These plant families are mentioned in three of Piperno’s (2006:7) categories for phytolith production: (a) pattern IV, where production varies substantially among different subfamilies and tribes and forms of taxonomic value appear to be limited (*Piscidia carthagenensis* (Fabaceae) and *Gossypium darwinii* (Malvaceae); native to Galápagos); (b) pattern V, where phytoliths have not been observed or where production is often uncommon to rare and is usually not of taxonomic significance (*Prosopis juliflora* (Mimosaceae), *Psidium galapageium* (Myrtaceae), *Psychotria rufipes* (Rubiaceae), and *Zanthoxylum fagara* (Rutaceae); native to San Cristóbal); and (c) pattern I, where production is usually high, phytoliths specific to family
are common; and subfamily and genus-specific forms occur, sometimes widely in the family. *Scalesia pedunculata* (Asteraceae) and *Tournefortia pubescens* (Boraginaceae) are native to San Cristóbal; however, the production of diagnostic phytoliths is limited to fruits and seeds that were unavailable at the time of modern plant collection for this study.

The clay sediments of San Cristóbal Island could be another factor causing the displacement of phytoliths. Water can wash down small phytoliths to deeper strata or strata at lower elevations. Once phytoliths are deposited in the sediments, they can also suffer from vertical movement, a process known as translocation or percolation (the smallest phytoliths are removed (eluviation) and accumulated (illuviation) in deeper strata) (Zurro et al. 2016). These two factors make the entire composition of the local forest virtually ‘invisible’ in the phytolith record.

### 2.6.3. Climate change

A recent vegetation change in Galápagos due to climate change has been proposed. Dumbar et al. (1996), based on isotopic signatures of corals, suggest that the early 1800s were cool, while the period between AD 1880-1940 had lower sea-surface temperature, resulting in warmer conditions. (Zhang et al. (2014, 2007) suggest wet conditions were present during the Little Ice Age (AD 1400-1800) followed by a dry event that peaked around 1870, before wetter conditions resumed during the 20th century. Conroy et al. (2008) have proposed that the main driver of Galápagos climate change through the Holocene appears to be “orbitally induced changes in seasonal insolation, changes in the tropical Pacific sea surface temperature (SST) gradient, changes in the position of the Inter-Tropical Convergence Zone (ITCZ), or the strength of the Asian Monsoon” (Conroy et al. 2008).

The climate history of the region is also known from historical documents. Environmental descriptions are available beginning in early colonial times in Spanish America, and include descriptions of landscape and climate by explorers and conquistadors who traveled on both the mainland and ocean (Garcia-Herrera et al. 2008; Quinn et al. 1987). Fluctuations in temperature, precipitation, and drought periods are
mentioned. The effects of El Niño southern oscillation (ENSO) are constantly mentioned by sailors and travelers in early documents, because the environmental effects of this current determined the movement of ships along the Pacific coast and impacted agriculture and fishing activities. A total of 59 ENSO events are identified with the 1620s, 1720s, 1810s, and 1870s being the most active decades. “These periods reveal non-stationary behaviour in warm ENSO occurrence with alternating periods of high and low activity lasting as long as 50 yr.” (Garcia-Herrera et al. 2008:1960). Quinn’s work initially proposed 93 events over the period AD 1500-1900. Several attempts to reinterpret Quinn’s data propose that the events previously considered strong could be from another source and not ENSO related (Hamilton and Garcia 1986; Ortlieb 2000; Ortlieb and Macharé 1993). Quinn associated higher precipitation in southern Peru to ENSO events; however, that seems to be a feature of La Niña events. In this sense, Ortlieb suggest that from the 93 cases proposed by Quinn, only 26 can be consider as clear ENSO events.

In summary, a total of 33 strong ENSO events can be defined since the 1500s along the Pacific coast of South America. Even though a paleoenvironmental reconstruction was not the aim of this study, it is likely that a combination of both deforestation and warmer conditions during the middle 19th century influenced the transition of vegetation cover from arboreal to grasslands in the area around El Progreso plantation.

2.7. Conclusions

This research demonstrates the potential of an interpretive model that combines historical documents and soil phytolith analysis for inferring vegetation change and disturbance. Results from soil phytolith analysis and tree cover index aid in demonstrating a rapid change in local vegetation due to deforestation and industrialized monocrop agriculture. In addition, the abandonment of original agricultural lands and the proliferation of feral animals increased the expansion of introduced plant species, creating the modern landscape.
This paper has provided the results of a study of phytoliths from the Scalesia Zone of San Cristóbal Island, Galápagos. The phytolith records allowed the partial reconstruction of vegetation dynamics in the area during the past 200 years. This work has put forward a model that illustrates the phytolith signal that grass and woody species are likely to leave behind in the fossil record of a volcanic island, favouring the human introduced Poaceae derived phytoliths. This study also proves the validity of the protocols used to differentiate phytoliths from grasses and woody species, and the importance of combining ecological data with historical information to explore past relationships between humans and landscapes.

The phytolith record suggests that the modern landscape of San Cristóbal is a human-created landscape that was mostly covered by arboreal vegetation before human colonization of the island during the middle 19th century. Phytoliths were not useful in discriminating specific taxa present on the Island before human arrival. However, it was useful in differentiating arboreal and grassland composition, which is a key element in understanding the ecological effects of initial human activities in previous unpopulated landscapes. The results show that humans have permanently modified the vegetation cover of the Scalesia Zone of San Cristóbal Island. The modern landscape of the southern areas of the highlands of San Cristóbal Island is the result of an introduction of alien species by humans starting in the mid 19th century, which rapidly adapted to the new environment creating the modern ecology.

My work supports the first postulate of the Historical Ecology program, which points out that practically all environments on Earth have been affected by humans and no pristine ecologies exist. In this scenario, this study aids in understanding the vegetation history of the study area but also challenges the misuse of the concept of pristine to define the Galápagos Islands as one of the last pristine places in the world. Researchers, governments, and the general public have long viewed the Galápagos Islands as the ultimate example of nature or wilderness; however, it is evident that the modern landscape of southern San Cristóbal Island it is the outcome or product of human presence. This work suggests that defining the Galápagos Islands as one of the last pristine paradises on earth is a myth that needs to be revised by researchers, local governments, and the local population.
2.8. Supporting material

2.8.1. Protocol for soils phytoliths extraction

Phytolith extraction consisted of four steps: (1) Pre-treatment and sterilization: Samples were dried for 6 hours at 130°C in a laboratory oven\textsuperscript{11}. Once dried, they were allowed to cool at room temperature and weighed\textsuperscript{12}. A sample aliquot weighing approximately 1 g was collected for processing.

(2) Acid Digestion: Each sample was placed in 140 ml beakers and received a 10 ml solution of equal parts of hydrochloric (HCl) and nitric (HNO\textsubscript{3}) acids at 3N. The beakers were placed on a hot plate for about \(\frac{1}{2}\) hour to accelerate acid reaction. The acid remainder was removed during three consecutive 5-minute wash and centrifugation cycles at 3000 rpm\textsuperscript{13}. Each sample was mixed prior to centrifugation for one minute. The samples were dried at \(~100^\circ\text{C}\) for 20 hours then reweighed to calculate phosphate and carbonate loss. Organic matter reduction was accomplished by using 10 ml of hydrogen peroxide (H\textsubscript{2}O\textsubscript{2} 30%) boiled at \(~70^\circ\text{C}\.). Upon its evaporation, the samples were dried in an oven at \(~100^\circ\text{C}\) for 20 hours and weighed again to establish the mass of the inorganic acid-insoluble fraction (A.I.F.).

(3) Heavy Liquid Separation: A.I.F. was placed in clean 15 ml test tubes to which 5 ml of Sodium Polytyngstate (S.P.T.)\textsuperscript{14} at a 2.4 specific gravity was added. The floating fraction was transferred with disposable pipettes to a second 15 ml tube. One ml of distilled water was added to the floating fraction in the new 15 ml tube using a precision pipette. Samples were centrifuged at 3000 rpm for 5 minutes. The floating fraction was separated and transferred again to a third 15 ml centrifuge tube and was filled with distilled water, mixed, and centrifuged 3 times at 3,000 rpm for 5 minutes to remove any residual S.P.T. The remnant was transferred to a clean 1.5 ml eppendorf tube, filled with

\textsuperscript{11} Barnstead-Thermolyne Oven/Incubator Type 19200
\textsuperscript{12} Ohaus ExplorerPro 413C.
\textsuperscript{13} Eppendorf Centrifuge 5810;
\textsuperscript{14} Sometu-Europe.
distilled water, mixed, and centrifuged for the last time at 4,500 r.p.m. for 3 minutes\textsuperscript{15}. This fraction (F.3) contains the majority of the opal silica bodies. Final drying in an oven at 100°C ensued for 24 hours.

(4) Mounting: A fixed aliquot of ~0.002 g was mounted after proper mixing. The medium consisted of four drops of slow drying resin “Entellan New”. The aliquot was well mixed and covered by a 22mm x 22mm slip.

\textsuperscript{15} Eppendorf MiniSpin.
Table 3. Biominerall content, relative contributions of Panicoid and globular phytolith types, and D/P index of phytoliths in soil samples from San Cristóbal Island, Galapagos.

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Depth cm</th>
<th>Prov.</th>
<th>Initial Mass (g)</th>
<th>Mass after Acid</th>
<th>A.I.F (g)</th>
<th>F,3</th>
<th>Total Phyt.</th>
<th>% D</th>
<th>% P</th>
<th>D/P</th>
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Chapter 3. Environmental Historical Archaeology of the Galápagos Islands: Paleoethnobotany of Hacienda El Progreso, 1870-1904

Paper submitted to: Vegetation History and Archaeobotany (https://link.springer.com/journal/334)

3.1. Abstract

The initial relationships between colonizers and the native vegetation of San Cristóbal Island were studied based on the analysis of wood charcoal, macro-remains, phytoliths, and historical records. Archaeological and modern botanical samples were collected from an archaeological midden, the mill, and former agricultural land of the 19th century Hacienda El Progreso. The archaeobotanical remains show the use of native wood, the introduction of crops and weeds, aspects of local diet, and evidence of deforestation. Ecological impact is observed in the alteration of native vegetation caused by the colonization of the Island and the expansion of agricultural land for the plantation enterprise. This paper provides a synthesis of the paleoethnobotanical study at El Progreso which forms a baseline for future palaeoenvironmental research in the Galápagos Islands.

Key words: Anthracology, Macroremains, Sugar plantation, Colonization, Ecuador.
3.2. Introduction

After independence from Spain in 1822 and separation from Gran Colombia in 1830, the new nation of Ecuador claimed sovereignty over the Galapagos Islands, an archipelago located a thousand kilometers to the west. By 1831 the government instigated the colonization of the islands, negotiating concessions with national and international private companies for extracting fur, leather, salt meat, fish, and turtle oil. Eventually industrial-scale quinine tree (Cinchona pubescens)\(^\text{16}\), sugarcane (Saccharum officinarum), and coffee (Coffea arabica) plantations were established. General Jose de Villamil set up the first Galápagos colonization plan, the Sociedad Colonizadora del Archipielago de Colón. Villamil travelled to Galápagos with independent workers from mainland Ecuador to create a small colony on King Charles Island—now Floreana. This was the first large permanent human population established in the Galápagos Archipelago.

People travelled to the islands looking for better working conditions and the possibility of land acquisition. They brought familiar plants and animals from highland and coastal Ecuador to start small-scale farming. Social conflict and violence undermined the first colonization attempt, but efforts spread to other islands. Beginning in the 1860s Ecuadorian businessmen Manuel J. Cobos, Angel Cobos, and José Monroy obtained a long-term concession for Chatham Island—now San Cristóbal where were able to create an industrial-scale plantation called El Progreso.

This paper explores the ecological impacts of the colonization of San Cristóbal Island. I present the first results of a paleoethnobotanical study of the 19\(^{\text{th}}\) century Hacienda El Progreso. The overall goal of this study is to explore the interactions between colonizers and the native vegetation of the island since the 1860s through the combined analysis of wood charcoal, macroremains, phytoliths, and historical records. The specific objectives of this work are: (1) To identify the woody taxa utilized at El

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\(^{16}\) The Quinine tree (Cinchona pubescens) was introduced to Santa Cruz Island, Galápagos during the 1850s to be the hosting plant for a moss where purple dye was extracted. The bark of Cinchona tree has been the source of the chemical quinine, effective against malaria. A large plantation of this tree was initially located on Santa Cruz Island. Today this plant is considered one of the worst invasive plant species in the entire archipelago.
Progreso plantation during its operational years (1860s-1920s); (2) to determine historic fuel wood collection and possible deforestation patterns; (3) to explore crop introduction and local diet; and (4) to understand the impact of colonization on the native vegetation of San Cristóbal Island.

3.2.1. Study area

The Galápagos are a group of volcanic islands located below the equator in the eastern Pacific Ocean. The archipelago comprises 19 named islands and more than 40 islets but only four are inhabited. San Cristóbal is the easternmost Island of the Archipelago located 1,000 km west of the Ecuadorian coast.

The Galápagos Archipelago does not have a tropical climate due to the influence of two interacting ocean currents: the Inter Tropical Convergence Zone (ITCZ) and the El Niño Southern Oscillation (ENSO). Local climate and weather is influenced by altitude; the local temperature oscillates from 20°C to 31°C and only two seasons are recognized: cool and dry between June and December, and warm-rainy between January and May. The islands are of volcanic origin formed about three million years ago and soils developed through decomposition of lava flow surfaces caused by moisture (Gromme et al. 2010; McBirney and Williams 1969; Simkin 1984). The modern landscape is covered with poorly developed Black soils, older soils are brown Andisols, and the oldest surfaces show eroded and highly cohesive Red soils (Franz 1980).

Approximately 600 plant taxa exist in the Galápagos, of which approximately 32% are endemic. The study area is located in the the Scalesia Zone, an environmental setting that extends from 200 to 400 m a.s.l. This zone, also known as the Humid, or Agricultural, Zone, is home to endemic and native tree taxa such as Scalesia pedunculata, Psidium galapageium, Pisonia floribunda, Cordia lutea, and Piscidia carthagenensis (Lee 2006; McMullen 1999; Wiggins et al. 1971). Today, the landscape is dominated by introduced and invasive trees, shrubs, and crops such as guava (Psidium guajava), blackberry (Rubus niveus), plum rose (Syzygium jambos), multicolored lantana (Lantana camara), orange (Citrus sinensis), banana (Musa
acuminata) and several grasses of the genera *Bracaria, Erasgrostis, Panicum,* and *Pennisetum.*

### 3.2.2. Hacienda El Progreso

The Galápagos Islands have a relatively short human history. It is believed that humans did not occupy the archipelago before the European arrival. Heyerdahl and Skjølsvold (1974) presented evidence suggesting that pre-Columbian groups from coastal Peru and Ecuador visited the islands, but this proposition is still in dispute (Anderson et al. 2016). The archipelago was first visited by Bishop Tomas de Berlanga in 1535 in the name of Spain. During the next three centuries the islands remained seasonally inhabited by pirates and whalers, and were finally incorporated into Ecuador in February 12, 1832, which marked the start of formal colonization efforts.

Starting in 1832 the Government of Ecuador incentivised the colonization of the Galápagos Islands. Ecuadorian businessmen Manuel J. Cobos and José Monroy saw an opportunity to plant quinine tree (*Cinchona pubescens*) for obtaining and exporting Orchila, a moss used to obtain high-value purple dye during the 19th century. In 1858, the Ecuadorian state approved the creation of the *Compañía Orchillera* to operate on Chatham Island. By 1870, ten workers lived and worked in Chatham. The first mill was built and several debt workers, deported people, poor families, and unemployed foreigners were moved to Chatham to live and work for the Cobos-Monroy enterprise (Bognoly and Espinosa 1905).

After the invention of synthetic purple dye in 1856 the Orchila business declined; consequently, Cobos and Monroy shifted their agricultural production to sugarcane, coffee, tobacco and expanded grasslands for grazing. Starting in the 1860s they were able to create a large agricultural enterprise called El Progreso in the humid highland interior of the island, which was meant to compete with the large plantation systems of coastal South America. This industrial-scale plantation occupied most of the southwestern portion of the island and was operated under the Cobos-Monroy administration from the 1870s to the 1920s (Figure 10). From a few hectares in 1879, El Progreso had grown to ~3000 ha by 1904, assisted by the Special Law of Galápagos
(Ley de Regimen de Galápagos), which was approved by the Ecuadorian congress in 1885, and provided benefits to colonizers including 5 years of tax exemption, free land, exemption from military service, duty-free imports of goods, and local state authority. Hacienda El Progreso fully operated until 1904, when Manuel J. Cobos was murdered by his convict laborers, causing the decline of the largest company in the Galápagos archipelago during the early 20th century.

![Map of Galápagos Islands showing the location of Hacienda El Progreso](image)

**Figure 10.** Hacienda El Progreso was located in the humid highlands of San Cristóbal Island, 6 km east of the modern port city of Puerto Baquerizo Moreno.

By 1904 the El Progreso enterprise was producing approximately 500 tons/yr. of sugar products and great quantities of alcohol. Water was extracted from small springs and one of the largest sources of fresh water in the entire archipelago, El Junco Lake, located 7 km away in the interior of the island. An irrigation system composed of metal pipes and canals was built to transport water to the fields. In addition, over 100 km of roads were constructed and a 10 km Decauville railroad transported sugar products, coffee, tortoise oil, lime, salted and dried fish, meat, and leather to a deep-water port.
built for a dedicated cargo fleet (Peter Stahl, personal communication 2014). More than 400 laborers lived and worked on the hacienda, many of them convicts and indigents from the mainland (Bognoly and Espinosa 1905; Carbo 1894; Latorre 2011, 2002, 1991) (Figure 11). In Chapter 5 of this dissertation, I present detailed aspects of the social landscape of El Progreso during the late 19th century.

Figure 11. The village of El Progreso in 1888. The plantation produced large quantities of refined sugar and coffee for the Ecuadorian market during the late 19th century (National Archives photo no. 22-FA-88).

The hacienda managed to continue after Cobos’ death but eventually ceased operations in the early 1920s. Since then smallholder farmers have occupied some of the original El Progreso lands. Weeds invaded the abandoned fields and the useable
machinery was sold, returned to the mainland, or removed by remaining workers and visitors. The original hacienda was divided into small parcels that are used for small-scale farming or completely abandoned. Today a park, a Catholic Church, state administrative buildings, and private houses comprise the modern parish of El Progreso.

3.2.3. Environmental Historical Archaeology and Garden Archaeology

Environmental historical archaeology is a research framework concerned with investigating the recursive relationships between people and their environments during the historic periods of the past (Deagan 2008). The aim is the investigation of human-environment interactions during historical times, integrating environmental data (animal, plant, geological, and chemical) with the archaeological record and historical information from documents and oral sources.

Environmental archaeology emerged during the late 1970s from the interest in the biological aspects of the archaeological record. This research framework refers to exploration of the interactions between humans and their environment, with the use of scientific techniques to study environmentally and biologically produced data (Reitz and Shackley 2012; Branch et al. 2005). The goal is to understand the combination of natural and cultural processes that have generated the environmental contexts for human populations. Topics of interest include climate, soil development, ecology, succession, adaptation of biotic communities, and human impact on landscapes. Environmental historical archaeology, in this context, is the exploration of the human-environmental relationships in the Modern World.

Since first proposed by Kathleen Deagan (1996), environmental historical archaeology has gained worldwide acceptance. The environmental approach in historical archaeology is based on the idea that the recent past has incorporated significant environmental change with lasting consequences for the planet (Landon 2005). Environmental data from historical sites have contributed to the exploration of topics such as global colonialism, urbanism, slavery, labor, class structures,
industrialization, and environmental degradation (e.g., Hardesty 2009; Mrozowski 2006; Orser 1996).

Garden Archaeology is the study of cultivated landscapes consciously planned to reflect the real or desired economic, social, or political status of their builders (Branton 2009). The archaeology of cultivated landscapes and gardens investigates the physical and symbolic construction process of these landscapes (Brown 1991; Currie 2005; Leone et al. 2005, Miller and Gleason 1994; Taylor 1983). Plantations, ornamental gardens, agricultural fields, or backyards are some examples of cultivated landscapes. These landscapes are living places used by social groups or individuals to communicate messages about social order and status. They are a hybrid representation of the natural and the cultural worlds in the same geographical setting. With the analysis of layouts and plans, material culture, and botanical remains archaeologists attempt to understand the function and meaning of these features. Following Crumley’s precepts that human actions over time are manifested in a landscape that retains physical evidence of cultural practices, decisions, and ideas (Crumley 1994); I consider past cultivated landscapes such as farms and plantations as examples of human-environment relationships in both a material and ideological sense.

Since the emergence of garden archaeology in the 1990s (Brown 1991; Cummings 1994; Yamin and Metheny 1996), paleoethnobotanical techniques have become a common approach to the study of modern world agriculture, horticulture, gardening, and diet. Macro and micro-botanical evidence in the form of charred seeds, wood charcoal, phytoliths, spherulites, diatoms, starch grains, and pollen grains are the proxies analyzed and complemented with information from historical documents (e.g., Becks 2012; Horrocks et al. 2008; Evett et al. 2012; Mrozowski et al. 2008; Seiter and Worthington 2013). The environmental consequences of industrialism have also been explored using environmental data (Cowie 2011; Gibb et al. 2009; Murphy and Wiltshire 2002). Is in this scenario that the integration of paleoethnobotany and historical records could provide important evidence to understand possible use of native plants and vegetation changes caused by the construction of El Progreso plantation.
3.3. Paleoethnobotany of Hacienda El Progreso

To investigate past human-plant relationships at Hacienda El Progreso, archaeological and modern botanical samples were analyzed. Collection of samples was limited to two sites inside the original perimeters of the Hacienda: Carpintero midden and El Progreso Mill. During the archaeological survey of the site in 2014, a midden was found in a construction trench a few meters south of the main plantation house (Figure 12). Charred and uncharred material culture, faunal remains, and wood charcoal constitute the midden. Recovered complete liquor bottles, porcelain fragments, nails, glass, metal fragments, and other pieces of domestic objects were associated with the time period AD 1880–1930. Bulk soil samples and soil samples for phytolith extraction were collected from this archaeological feature.

The soil profile exposed at Carpintero midden showed four distinct horizons: an active soil layer 12 cm thick (Munsell: 5YR 3/3); a thick clay-rich, spheroidal- to euhedral-clod A horizon (5YR 3/2) with some dead roots, some charcoal, and some cultural material; a cultural midden; and a mineral horizon composed of solid clay that grades from red (2.5YR 3/4) to orange (2.5YR 4/6) in color. The clay is extremely wet and has no evidence of organic matter. The pH of soils averages 7.7 (Percy 2015, personal communication). Three phases were defined: (1) pre-occupational phase, (2) plantation phase AD 1870-1920, and (3) post plantation phase from 1920s to modern times.

Three additional test units were excavated in the area between the main house and the exposed profile, an area known as Carcel. This area could have been the location of a communal kitchen run by the Hacienda and is likely that in this building food was cooked for both the plantation staff and workers. Soil samples for flotation were collected here and four horizons were observed: an active soil layer 8 cm thick (Munsell: 5YR 2.5/2); a 12 cm modern cultural layer (Munsell: 5YR 3/2); followed by a clay A horizon (Munsell: 5YR 3/3) with dead roots, charcoal, and cultural material possibly dating to hacienda times; and a mineral horizon composed of solid Red clay (Munsell: 2.5YR 3/4). This location was covered by mixed vegetation including ornamental plants, several types of grasses, herbs, and palms.
Figure 12. Top: the communal kitchen of Hacienda El Progreso in 1888. Below: Unit 2 at Carpintero midden with proveniences of the soil samples collected for analysis (Circles = phytoliths; rectangles = macroremains. The archaeological record is likely composed of discarded elements from the kitchen and the main house of the plantation. (Photos: top: Albatross 1888 expedition, National Archives photo no. 22-FA-96; bottom: Stahl 2014).
Finally, one test pit was excavated next to one of the standing buildings of the El Progreso sugar mill. Several layers of charcoal and ash were observed in this location. The modern surface was covered by grasses and banana trees. Thirteen soil samples for phytolith extraction were collected from the exposed profile.

3.3.1. Field procedures

Collection of wood charcoal, flotation samples, and columns for palaeoecological sampling on exposed profiles were the primary field techniques applied (Astudillo 2011; Pearsall 2000). Wood charcoal was hand collected from exposed profiles during excavation and from light fractions of flotation samples. The pieces of wood charcoal were first dried to room temperature and then placed in clean small plastic. Fourteen bags of charcoal were collected during excavation and a subsample of 288 fragments were analyzed (Supplementary material, Table 4). A maximum of 20 charcoal fragments were randomly collected from each bag. In addition, two fragments of wood were extracted from a tree trunk that remains underwater close to the modern city of Puerto Baquerizo Moreno, from one of the remaining original poles from the 19th century pier of the Hacienda.

Seven flotation samples of approximately 10 l were collected during archaeological survey and excavation, four from test pits and three from the midden layer. In the field, the samples were processed using bucket floatation in approximately 20 l of clean water. A sieve of 250 µm was used to collect the light fraction that was transferred to cloth bags. Light fractions were sieved in laboratory to separate components.

Soil samples for phytolith extraction were collected in columns from exposed profiles. The soil matrix was troweled into sterilized 15 ml plastic test tubes from the bottom up. The spacing unit was 5 cm and visible horizon boundaries were avoided. Each sample contained a maximum volume of 10 ml. The sampling tool was washed with distilled water to avoid cross-contamination. Altogether, 31 samples were collected; 18 from Carpintero loci and 13 from Mill loci.
3.3.2. Laboratory protocols

**Anthracology**: Usually attacked by fungi and bacteria, wood rarely survives unless carbonized (Dimbleby 1978; Figueiral and Mosbrugger 2000; Gale et al. 2000). Charring preserves many of the anatomical characteristics of wood fragments (Lee 2006:8). Variation in the cellular structure of wood is generally consistent within each species, and given sufficiently high levels of magnification, species-level identification is possible. Identification of wood can give insight into patterns of selection of firewood, timber for house construction, or material for tool manufacture (Pearsall 2000:144).

Charcoal identification followed the methodology of Leney and Casteel (1975). Fragments were split with a razor blade to obtain transverse, tangential, and radial sections and the transverse section was examined at 4X magnification\(^\text{17}\). Fragment size distribution categories used were: small (<4 mm diameter), medium (4–6 mm), large (<10 mm), and extra-large (>10 mm). For the purposes of this study the transverse or cross-section was adequate for identification.

Charred wood is usually identified by comparing the structure of unknown pieces to known comparative specimens or keys. A local reference collection of wood charcoal was created by the author in the Laboratories of Simon Fraser University and the Galapagos Science Centre based on the official checklists of native and introduced taxa of the Galápagos National Park (Bungartz et al. 2009; Guézou et al. 2016; Jaramillo Díaz and Guézou 2010). The anatomical descriptions and photographs presented by Froyd et al. (2010), Lee (2006), and in the InsideWood online wood anatomy database were used to identify native and introduced taxa. Anatomical characteristics were described for each species according to the International Association of Wood Anatomists (IAWA) standards (Wheeler et al. 1989). Examination of transverse sections was conducted on photographic frames using Leica Application Suite 3.5.0 image analysis software.

\(^{17}\) Microscope: Leica MZ6
**Macromains:** Light fractions from flotation samples were sieved to separate components. Three sieves were used: 2.80 mm, 1 mm, and 250 µm. The first two fractions were separated in seven components for analysis and taxa identification: wood charcoal, charred seeds, grass come, bone, shell, indeterminate charred plant remains, and uncharred plant remains. The Rapid Identification Guide of Galápagos Seeds was the main source for seed identification (Jaramillo and Guézou 2012).

**Phytolith extraction:** Phytolith analysis has been successfully employed to explore ecological history and to identify plant communities and environments of the recent past (Evett et al. 2007; Fernández Honaine et al. 2009; Kerns et al. 2001; Morris et al. 2009; Thorn 2004). In El Progreso, phytoliths were extracted from soils with a combination of two protocols: wet oxidation (Piperno 2006; Zhao and Pearsall 1998) and dry ashing (Albert et al. 1999; Albert and Weiner 2001; Mercader et al. 2011, 2010) with minor modifications (Supplementary material 3.7.1). This combined process destroys calcium, phosphate, and organic based compounds in order to isolate the biogenic silica through flotation in heavy liquid at the specific gravity of ~2.4 (Jones and Beavers 1963).

Classifying criteria follow those presented by the International Code for Phytolith Nomenclature 1.0 (Madella et al. 2005) and comparison with a local reference collection created for this project (Astudillo 2016a) and other collections from tropical south America (Ezell et al. 2006; Fernández Honaine et al. 2009, 2006; Iriarte et al. 2004; Iriarte and Paz 2009; Korstanje and Babot 2007; Korstanje and Cuenya 2010; Morcote-Ríos et al. 2015; Pearsall 2000; Pearsall et al. 2003; Perry et al. 2007; Piperno 2009, 2006; Piperno and Pearsall 1998). Morphological features scrutinized were size, bi-dimensional outline, and surface texture. Counting took place at 400X magnification in ten adjacent but not overlapping lines across the cover slip. All samples were analysed under differential interference contrast (DIC) microscopy. Examination of phytolith morphology was conducted on photographic frames using OLYMPUS Stream Basic 1.8 image analysis software.
3.4. Results

3.4.1. Wood Charcoal

A total of 289 wood charcoal fragments were examined. 249 fragments were positively identified, 18 with non-confirmed identifications, and 22 remained unidentified (Tables 4 & 6). Ten distinct wood anatomical types are proposed: six positive, two provisional species identifications, and two distinct types remained unidentified (Figures 13 & 14). Size distribution and anatomical features observed in the charcoal samples for each identified taxon are summarised in Tables 7 & 8 (Supplementary material).

The wood charcoal assemblage shows the presence of both native and introduced taxa to San Cristóbal Island since the decade of 1860s. Three charcoal types were identified to be woody material derived from species of the native trees *Piscidia carthagenensis*, *Psidium galapageium*, and *Scalesia pedunculata*; two charcoal types have been categorized as the possible native trees *Bursera graveolens* and *Croton scouleri*; and three charcoal types were identified as the introduced plants *Guadua angustifolia* or *Bambusa* sp., *Pinus* sp., and *Quercus* sp. The assemblage is completed with two unidentified species.

Ranks of the wood charcoal assemblage are: (1) *Piscidia carthagenensis* $(n = 176; 60.90\%$ of the total assemblage); (2) *Scalesia pedunculata* $(n = 27; 9.34\%$); (3) *Psidium galapageium* $(n = 20; 6.92\%$); (4) *Pinus* sp. $(n = 17; 5.88\%$); (5) Unidentified species 2 $(n = 12; 4.15 \%)$; (6) cf. *Croton scouleri* $(n = 11; 3.81\%)$; (7) Unidentified species 1 $(n = 10; 3.46\%)$; (8) *Guadua angustifolia/Bambusa* sp. $(n = 8; 2.77\%)$; (9) cf. *Bursera graveolens* $(n = 6; 2.08\%)$; and (10) *Quercus* sp. $(n = 2; 0.69\%)$. 


Figure 13. Wood charcoal of native tree taxa present in the archaeological midden of El Progreso (Pictures on the right are modern fragments): (A) *Psidium galapageium* at 3.2X.; (B) *Pscidia carthagenensis*; and (C) *Scalesia* sp., right: *Scalesia pedunculata* (Photos: Leica application suite v3.5.0).
Figure 14. Wood charcoal of introduced tree taxa present in the archaeological midden of El Progreso (Pictures on the right are modern fragments): (D) *Guadua angustifolia*/Bambusa sp., right: *Guadua angustifolia*; (E) *Pinus* sp., right: *Pinus strobus*; and (F) *Quercus* sp., right: *Quercus rubra* (Photos: Leica application suite v3.5.0).
Table 4. Totals of wood charcoal fragments from Hacienda El Progreso, 1870-1904.

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3.4.2. Macromains

A total of 80 charred seeds and seed fragments were extracted from the soil samples associated to the plantation phase (AD 1870-1920). Edible plants and weeds were identified. The most prominent taxa found was *Zea mays* (*n* = 35) and charred seeds of other edible plants such as *Lens culinaris*, *Coffea Arabica*, and *Psidium guajava* were also identified. Possible charred remains of the *Phaseolus*, *Vicia*, and *Inga* genus of the Fabaceae family are also present. Weeds from the Malvaceae family; specifically, the *Sida* genus complete the macroremains assemblage from El Progreso (Figures 15 & 16; tables 5 & 9).

![Figure 15. Charred macroremains from the archaeological midden of El Progreso, 1870-1920: (A) Asteraceae sp.; (B) Coffea arabica; (C) Phaseolus vulgaris; (D) Psidium guajava (Photos: Leica application suite v3.5.0).](image-url)
Figure 16 Charred macroremains from the archaeological midden of El Progreso, 1870-1920: (E) *Inga edulis*; (F) *Lens culinaris*; (G) *Sida* sp.; (H, I) *Zea mays* (Photos: Leica application suite v3.5.0).
Table 5. Totals of charred seeds recovered from El Progreso midden

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### 3.4.3. Phytoliths

A total of 32.61 g of soil were processed for phytolith extraction. Biogenic silica averages 3.39% of the total dry mass and the total number of phytoliths counted was 8,066 (Supplementary material, Table 10). Five main groups of phytolith morphotypes were identified: panicoid phytoliths (scutiform lanceolate, bilobate, polylobate, cuneiform bulliform, and quadra-lobate); elongate phytoliths (grass phytoliths); globular phytoliths (arboreal phytoliths), other diagnostic, and non-identified. Prominent morphotypes in the soils of El progreso are: (1) elongate cylindrical piscilate long cell \((n = 1,520)\); (2) parallelepipedal bulliform cell \((n = 1,040)\); (3) saddle short cell \((n = 899)\); (4) bilobate concave outer margin short shaft \((n = 621)\); (5) rondel short cell \((n = 538)\); (6) globular...
sinuate \((n = 406)\); and (7) elongate echinate long cell \((n = 307)\) (Figures 17 & 18). Bilobate, polylobate, and quadra-lobate morphotypes are associated to Panicoid grasses (Piperno and Pearsall 1998). With an average length of 20 μm, bilobates are common in the genera *Aristida* (Arundinoideae), *Eragrostis* (Chloridoideae), and *Stipa* (Pooideae) (Fahmy 2008; Barboni et al. 2007; Mercader et al. 2010).

In the Carpintero midden biogenic silica averaged 2.70% of the dry mass. The total number of phytoliths counted in this column was 3,853. Elongate cylindrical piscilate long cell morphotype is the most prominent contributor in all excavated strata with frequencies of 20.85% \((n = 803)\); followed by parallelepipedal bulliform cell with 20.21% \((n = 779)\), saddle epidermal short cell with 12.88% \((n = 496)\), globular piscilate morphotype with 6.30% \((n = 243)\), rondel short cell 3.76% \((n = 145)\), elongate echinate long cell with 3.53% \((n = 136)\), and bilobate concave outer margin short shaft with 3.11% \((n = 120)\).

In El Progreso Mill biogenic silica averages 3.95% of the dry mass. The total number of phytoliths counted in this column was 4,213. Elongate cylindrical piscilate long cell morphotype is the most prominent contributor with frequencies of 17.02% \((n = 717)\); followed by saddle epidermal short cell with 9.56% \((n = 403)\), rondel short cell with 9.33% \((n=393)\), bilobate concave outer margin short shaft morphology with 8.52% \((n = 359)\), parallelepipedal bulliform cell with 6.19% \((n = 261)\), charred phytoliths with 4.48% \((n=189)\), elongate echinate long cell with 4.05% \((n = 171)\), and globular piscilate morphotype with 3.86% \((n = 163)\) (Figure 19).
Figure 17. Common phytoliths in the archaeological midden of Hacienda El Progreso: (A) Achene phytoliths (Cyperaceae); (B) bilobate concave outer margin short shaft; (C) elongate echinate long cell; (D) elongate cylindrical long cell; (E) globular piscilatte phytoliths; (F) parallelepipedal bulliform cell; (G) quadra-lobate short cell; (H) wavy-top rondel; (I) saddle epidermal short cell; (J) stomatal phytolith; (K) perforated platelet (Asteraceae); and (L) charred epidermal tissue (Photos: OLYMPUS Stream Basic 1.8 software with D.I.C. microscopy).
Figure 18 Common phytoliths extracted from soils near the old mill of Hacienda El Progreso: (A-D) variants of bilobate concave outer margin short shaft; (E) elongate cylindrical long cell; (F) elongate echinate long cell; (G) globular echinate; (H,I) globular sinuate; (J) phytoliths from *Musa* genus; (K) parallelepipedal bulliform cell; (L) polylolate epidermal short cell; (M) quadra-lobate epidermal short cell; (N-R) variants of rondel phytoliths; (S) saddle epidermal short cell; and (T) stomate phytoliths (Photos: OLYMPUS Stream Basic 1.8 software with D.I.C. microscopy).
Carpintero midden

El Progreso mill

Figure 19. Stratigraphic diagrams representing final counts of phytoliths in soil samples from El Progreso plantation (1870-1920) (Software: C2 1.7.4)
3.5. Discussion

In this work, I have aimed to demonstrate that an environmental oriented historical archaeology can contribute to a more complete understanding of the biological dimensions of cultural processes. Colonization spread plants, animals, and diseases around the planet on a massive scale, with immense and sometimes devastating consequences (Crosby 1986); including conflict with indigenous peoples and the institution of new subsistence, economic, and resource-use patterns. With industrialization, the scale of resource exploitation increased and human-land interactions were amplified, shaping the world that we live today.

In this regard, the archaeobotanical remains from El Progreso plantation provide evidence of the ecological effects of human colonization on a previous unpopulated island. The results presented here shows aspects of the initial relationships between colonizers and native vegetation in the highlands of San Cristóbal Island and demonstrate the introduction of crops to support industrial-scale agriculture and farming, which allowed first colonizers to continue dietary traditions from the Ecuadorian mainland. The interpretation of the archaeobotanical data has been complemented with environmental and landscape descriptions of the plantation during the 1880s.

Native trees were described as an important component of the local landscape by early travellers during the first scientific expeditions to the Galápagos Islands (e.g., California Academy of Sciences 1907; Compañía "Guía del Ecuador 1909; Mann 1909; Stewart 1911), which apparently were removed in order to create agricultural parcels around the first settlements. Deforestation started in the 1860s when Manuel J. Cobos and José Monroy, the owners of Hacienda El Progreso, obtained the agricultural concession for the Island. During this decade, they started to recruit workers in mainland Ecuador and transported them to the island to prepare the land for agricultural activities. According to Bognoly and Espinoza (1905), by 1869 about ten people were living and working in San Cristóbal.

The wood charcoal assemblage from El Progreso midden, for instance, is mostly composed of charred fragments of native tree species. Fragments of *Piscidia*
carthagenensis dominate the assemblage. This tree, locally known as Matazarno, is a native tree or shrub to ca. 15 m tall that grows from the arid lowlands to moist uplands of San Cristóbal and the other islands on the archipelago. This member of the Fabaceae is a hardwood tree highly valued for its hardness and preservation properties. It is likely that the extremely hard inner wood of this tree was used from the early years of colonization of the Galápagos Islands as the main source of wood for timber and construction materials. Photographs of Hacienda El Progreso in 1888 taken by personnel of the USS Albatross scientific expedition during its visit to the Galápagos, show large pieces of Matazarno trunks forming the structures of some plantation facilities, the main house, and parts of the worker's houses (Figure 2)18. The analysis of wood charcoal presented here confirms, for instance, that the foundations of the pier were almost entirely built with large trunks of this tree.

The high numbers of charred fragments of Piscidia carthagenensis found in the archaeological assemblage reflects the excellent preservation of this wood after burning. It seems that wood of this species preserves better dry or charred than other native taxa. Most the large and extra-large charcoal pieces analyzed are Matazarno fragments, which demonstrates a preservation issue and not necessarily an indicator of abundance of this tree in the landscape.

Two other native trees were identified in the wood charcoal assemblage: Psidium galapageium and Scalesia pedunculata. Psidium galapageium, locally known as Galapagos guava or Guayabillo, is an endemic small tree or shrub that grows up to 8 m tall in the Myrtaceae. The variety howellii D. M. Porter is present on San Cristóbal Island today (McMullen 1999:83). Medium charcoal fragments of <6 mm diameter of this tree are present in the wood charcoal assemblage. The wood of this tree has been, and is still used for firewood, fencing, and small tool making. Galapagos guava is still preferred for firewood but native stands of this tree have been replaced by the introduced and invasive related tree species Psidium guajava (Guava). Psidium galapageium was tested for phytolith production but no diagnostic phytoliths were observed in the comparative material or in the soil phytoliths (Astudillo 2016a).

18 The original photos of the USS Albatross Expedition are owned by the National Archives and Record Administration.
**Scalesia pedunculata** is a species endemic to the Galápagos Archipelago. This member of the Asteraceae is a tree that grows up to 20 m tall and possess soft wood and gummy sap (McMullen 1999:45). It is found in the humid uplands of San Cristobal forming small stands and forming extensive forest on Santa Cruz and Isabela islands. The trunk and branches of this taxa can be used as firewood. Because of its soft wood, *Scalesia* stems are not a common source for construction materials or tool making. Only a few small and medium fragments of this tree were found in the charcoal assemblage which suggests its rapid combustion in an open fire. *Scalesia* trees could have formed sizable forests before permanent population of the highlands of San Cristóbal Island, similar to the ones visible today on other islands. It is likely that these forests were reduced on the southern side San Cristóbal after of the intense deforestation and agriculture of El Progreso enterprise starting during the 1860s.

Two additional native trees are possibly present in the wood charcoal assemblage: *Croton scouleri* and *Bursera graveolens*. *Croton scouleri*, locally known as Chala, is an endemic species to the Galapagos. It is a small tree or shrub 2-6 m tall mostly present at lower elevations and it is mainly used as firewood. *Bursera graveolens*, commonly known as *palo santo*, is a native tree or shrub 3-12 m tall mostly found in the arid lowlands of the islands. This plant has an aromatic resin that produces a distinguishable odor when is broken or burned. *Bursera* branches are often burned for incense in churches throughout Latin America. This tree species can be found along the South American coast and is used as an incense and natural insect repellent (Jørgensen et al. 1999). The main use of these two species could have been firewood, small tool making, gardening, fencing, and incense. Few non-confirmed fragments of these two trees were present in the wood charcoal assemblage.

Deforestation caused intensive ecological changes around the plantation. Alexander Mann, who visited San Cristobal Island and El Progreso in 1906, described a “wide extent of pasture land, almost devoid of trees and brush estimated at over ten thousand acres” (Mann 1909). Nicolas Martinez also expressed his concern about the disappearance of native forest and the expansion of grasslands caused by deforestation. In his description of the local vegetation on San Cristóbal Island he pointed out the impacts of deforestation and the necessity to plant wood species to replace the already few sources of firewood and timber. In this regard, he suggests the immediate
introduction of pine and oak trees; species that could grow quickly to replace the disappearing forest (Martínez 1915). Another estimate of grasslands around El Progreso village by this time suggested 1200 hectares had been put into pasture (Compañía "Guía del Ecuador 1909). The indiscriminate use of the native wood led to the near-extinction of *Piscidia carthagenensis* on San Cristóbal island (León-Yánez et al. 2011).

Introduced taxa to San Cristóbal Island are also present in the wood charcoal assemblage. Fragments of bamboo (*Guadua angustifolia* or *Bambusa* sp.), pine (*Pinus* sp.), and oak (*Quercus* sp.) were identified. Bamboos are giant fast-growing grasses with woody and hollow stems (culms) that can attain heights to more than 40 m in the larger species forming patches in humid and warm environments. Used mainly as a construction material for house frames and fences, bamboo can also be used for a variety of purposes such as agricultural tools, water canals, fencing, kitchen utensils, weapons, etc. A common construction material for houses in Ecuador during the 19th century was called *bahareque*, which refers to the mixture of clay with grass or ash over a bamboo frame to form walls. This construction material was a common and inexpensive method for house construction in both the Ecuadorian coast and highlands. Houses with bahareque walls were observable in the local architecture of El Progreso during the late 19th century (Figure 20). Only small fragments of charred bamboo were found in the wood charcoal assemblage of El Progreso suggesting high combustion and poor preservation of this plant in the archaeological record.
Bamboo is distributed worldwide and is one of the most commonly used plants in tropical environments. Bamboo belongs to the subfamily Bambusoideae of the grass family Poaceae (or Graminaceae). There are about 75 genera and approximately 1,300 species. The culm (stem) is mostly hollow and characterized by nodes with internodes in between that give the plant its strength. “The culms arise from buds at the underground shoot–root system, the so-called rhizome. Shoots emerge with the rainy season and expand within a few months to their final length of 10–30 m and diameters from 5 to 30 cm” (Liese and Köhl 2015:v).
*Guadua angustifolia* is the native genus of bamboo and is widely distributed in the neotropics. It is mainly used for construction, scaffolding, fencing, small-scale irrigation systems, and furniture. It is likely that this species was introduced to the Galápagos Islands during colonization due to its popularity as cheap and reliable construction material, rapid adaptation, and fast low-maintenance growth. The few pieces of bamboo charcoal found in the midden are too small for identification at the level of species. However, considering that the *Guadua* genus exist today in Galápagos and is categorized as introduced/escaped species by the Galápagos National Park, it is likely that *Guadua angustifolia* was the species used by people at Hacienda El Progreso and is the type of bamboo observable in the photographs taken by the USS Albatross expedition in 1888 and the Alexander Agassiz expedition in 1891.

A few medium fragments of <10 mm diameter of pine (*Pinus* sp.) and oak (*Quercus* sp.), were identified. These two trees are not native to the Galápagos Islands or northern South-America. Nicolas Martinez during his visit to El Progreso plantation in 1906, reported two specimens of these trees existing on San Cristóbal that apparently were ornamental trees not used for wood (Martínez 1915:32). Presence of oak is also mentioned in other early descriptions of the plantation such as the 1904 Bilbao´s visit in 1904 (Bilbao 1904) and Alexander Man´s visit in 1909 (Mann 1909). The most plausible explanation for its presence in the hacienda midden is that they are burned fragments of furniture or other objects manufactured elsewhere. Delicate household items of porcelain and crystal, liquor bottles, or tableware were commonly transported in wooden boxes. The large numbers of wine, champagne, and whiskey bottles found in the Carpintero midden suggest that these could have been transported to El Progreso in wood cases, which once broken were discarded and burned as firewood or common garbage.

Pine is a soft wood commonly used for making small pieces of furniture and crates due to its light weight. Oak, on the other hand, is a hardwood used in larger furniture items such as dinner tables, cabinets, closets, or dressers. The two small charcoal fragments of oak found at El Progreso could have had their origin in broken furniture discarded and burned in the midden. Several imported materials from both Europe and North America manufactured during the late 19th century were found in the archaeological record. The other possibility is that they were barrel fragments. Oak barrels were commonly used at the time to transport and store wine, beer, or other
liquids. Some barrels are observable in the 1888 pictures of the Hacienda (Figure 3). Rusted and broken pieces of metal hoops for barrels were also found in the midden.

The charcoal assemblage analyzed suggests that wood fragments from firewood, timber, house frames, water canals, tools, or furniture were discarded and burned with other trash. In this regard, the wood identified from the midden does not necessarily show the entire spectrum of woody plants that existed around the old village; however, it probably represents both discarded wooden objects and firewood. The wood charcoal assemblage suggests that during hacienda times, wood for construction was locally acquired, which is the opposite of today’s importation of construction materials from the mainland. The wood charcoal assemblage also suggests a deforestation pattern favouring the acquisition of wood from forest stands close to the Hacienda urban centre with a possible preference for the *Piscidia* genus.

On the other side, the macro-remains present evidence of consumed crops and provides limited information about the local vegetation. Charred seeds found in the archaeological midden show the early importation of crops and fruit trees common in mainland Ecuador. It is likely that the first colonizers of Galápagos imported known crops to maintain a conventional dietary pattern from both the coast and the highlands. Charred kernels of maize (*Zea mays*), for instance, demonstrate the existence of this crop on San Cristóbal Island since the 1870s. Maize is a member of the Panicoideae subfamily of grasses. This plant is an economic crop that had its origins in Mesoamerica and has been cultivated in the Andean region since 6,000 BC. Maize can grow from sea level to an altitude of about 3000 m.a.s.l. in most tropical latitudes and temperate climates (Smith et al. 2004).

Several of the first colonizers to the archipelago were farmers from the highlands and coastal Ecuador who travelled to this new ecological setting with known plants and animals to create small farms and gardens. It is probable that maize was one of the first crops introduced to the Galápagos Islands during the 1860s. José A. Bognoly and José Moises Espinoza mentioned the existence of big corn fields near the plantation in 1905 (Bognoly and Espinosa 1905), which was also noticed by Nicolas Martínez who mentions “sizeable parcels of corn cultivated at El Progreso” in 1906 (Martínez 1915:30).
Maize can be consumed in a variety of forms, the cob can be boiled or roasted and the kernels eaten directly; maize starch can be transformed in flour to prepare dishes, corn beer (chicha), or pies; small, immature, or damaged corncobs are usually used to feed domestic corral animals such as pigs and goats, both introduced to the Galápagos as domestic animals during colonization. Complete bones and bone fragments of these animal species were also identified in the midden (Stahl 2016 personal communication). The charred kernels and cob fragments found at Carpintero midden may have been refuse from human or animal food burned in the garbage pit. The fragmented kernels found do not allow identification at the variety level.

Other charred seeds of edible plants present are coffee beans (*Coffea arabica*), lentils (*Lens culinaris*), and seeds of common guava (*Psidium guajava*). These species were introduced to the Caribbean and inter-Andean valleys of South America during the middle 18th century as economic crops. Coffee production was an important activity at Hacienda El Progreso during the 1890s. By 1906, 172 cuadras¹⁹ (about 170 hectares) were reported to be dedicated to coffee at El Progreso (Compañía "Guía del Ecuador 1909). Some of these parcels of land are still used for growing coffee today. The coffee bean in the midden shows local consumption of this plant, likely by the people living in the main house.

Lentils (*Lens culinaris*) are a popular edible legume in the Andean region. It is nutritious, easily transported, and quick to prepare. This species was introduced to the Americas in the colonial period from Europe. The Charles Darwin Foundation categorizes lentil as a cultivated introduced species only on Isabela Island, but it can be found in local markets on the other Islands (Guézou et al. 2016). It is possible that the charred remains found at El Progreso came from lentil imported for local consumption. Dry lentils are easy transportable and can be stored for long periods of time. It is also a quick and healthy source of proteins and was, and is still a popular component of the food culture in mainland Ecuador.

¹⁹ In Spanish America, one cuadra measured approximately 10,000 m² (1 hectare); in Argentina during the 19th Century one square cuadra was equivalent to 16,874 m² (1.6874 hectares) (Amaral 2002); and in modern times according to the official measuring units of Ecuador, one cuadra is equivalent to 6,987 m² (0.698 73 hectares) (INEN 47:1973).
The common guava (*Psidium guajava*) is a tree to 8 m tall, leaves opposite with blade elliptic shape and axillary flowers in clusters of 2 or 3. The fruit is an edible berry, pale yellow in color to ca. 5 cm diameter with numerous seeds (McMullen 1999:84). The pulp of the fruit is sweet in flavor and used to make juice or jam. Commonly eaten by domestic animals and native birds, its seeds are easily dispersed. This plant was introduced to the Galápagos during colonization and after abandonment of El Progreso and the other first colonies on Isabela and Floreana islands, became an invasive taxon in the entire archipelago (Guézou et al. 2010). Today, guava is one of the major threats to native vegetation. Dense patches of guava trees can be observed in San Cristóbal. Seeds of this plant were found at Carpintero midden.

Charred remains of the *Phaseolus* and *Vicia* genera of the Fabaceae are also present in the midden. Small plants of the common brown bean (*Phaseolus vulgaris*) are still grown on modern farms in Galápagos, which suggests that this species has been permanently cultivated in the archipelago since colonization. The common fava bean (*Vicia faba*) is also an important component of Ecuadorian food culture, especially in the highlands. This plant could also have been locally cultivated or the dry beans were imported. *Inga edulis* (ice cream bean tree or guabo) is a fruit tree native to South America. This tree grows pods that contain black seeds covered by a white pulp of sweet flavor and smooth texture. The pulp can be consumed directly from the bean or used to prepare sweet dishes. Other uses of this tall tree are timber and forage. The seeds are not consumed and normally discarded (McMullen 1999; Wiggins et al. 1971). This is the likely scenario for the presence of this seed in the midden assemblage. Although this species is used for wood no charcoal fragments were found in the archaeological record.

Some small charred seeds present in the macroremain assemblage provide insight into the vegetation existing around El Progreso Village during the late 19th century. Seeds of members of the Malvaceae suggest the presence of weeds associated with crops. Plants of the *Sida* genus, for example, are small shrubs that are common weeds that are troublesome in pastures, plantation crops, cereals, root crops, and vegetables in at least 30 countries (Holm et al. 1977:426). Six species of the *Sida* genus exist on San Cristóbal Island; three native (*S. hederifolia*, *S. salviifolia*, and *S. spinosa*), and three are accidentally introduced taxa (*S. ciliaris*, *S. rhombifolia*, and *S.
paniculatum) (Bungartz et al. 2009). The taxa seem to be introduced as weeds of the main crops of El Progreso plantation. *Sida acuata*, for instance, is known to be a common weed in plantations of corn, onions, sugarcane, coffee, and pastures in the tropical Americas (Holm et al. 1977). It seems likely that the charred seeds found at El Progreso midden are evidence of weeds growing in the agricultural parcels, pastures, or the local gardens of El Progreso plantation.

The soil phytolith assemblages analyzed from the midden and mill of Hacienda El Progreso also provide extra evidence of introduced plants, crops, and some indications of the original landscape of the area prior to permanent human occupation. In Carpintero midden, the soil phytoliths from the pre-occupational phase show the existence of mixed vegetation. Grass is represented by large concentrations of the parallelepipedal bulliform cell; a phytolith formed in the leaves of most C3 and C4 grasses. This morphotype is also observed in the native species *Rhynchospora nervosa*, a grass-like plant member of the Cyperaceae. Other grass phytoliths such as scutiform lanceolate and elongate cells are also present in this phase. These two morphotypes were observed in the natives *Scleria melaleuca* Rchb. Ex Schltll. & Cham, another grass-like plant member of the Cyperaceae and in *Stenotaphrum secundatum*, a native grass (see: Astudillo 2016). Arboreal vegetation is recognized by concentrations of globular sinuate morphotype and phytoliths from the Asteraceae. Globular phytoliths are produced by the majority of native trees and shrubs. Large trees such as *Piscidia carthagenensis*, *Psidium galapageium*, *Scalesia pedunculata*, and *Prosopis juliflora* are native to this ecological zone and globular morphotypes were observed in the comparative material of these species. In this regard, the phytolithic record supports the wood-charcoal record in suggesting that the local landscape prior to human occupation was covered by tall trees possibly of the *Scalesia*, *Psidium*, and *Prosopis* genus, and with short native sedges.

Soil phytoliths were extracted directly from the midden layer (AD 1870-1920). They show the presence of crops and possible consumption of introduced plant species. Concentrations of quadra-lobate and saddle morphotypes increased in this phase suggesting the presence of two important crops: corn and sugar cane. Quadra-lobate phytoliths are commonly formed in maize (*Zea mays*) and saddle phytoliths were observed in leaves of sugarcane (*Saccharum officinarum*); both stable crops introduced to the Galápagos Islands during the first colonization projects started in 1832. These two
morphotypes were not observed in the levels prior to human occupation. In addition, concentrations of bilobate phytoliths shows the first appearance of introduced species of grasses possible to expand grasslands for grazing. This change in vegetation coverage was also observed in the soil phytolith record of the area (Astudillo 2016b). In this phase, a low presence of the parallelepipedal bulliform cell and globular phytoliths suggest a vegetation change from a native to human-formed landscape after deforestation. Low numbers of globular phytoliths exist in the midden, which could be evidence of deforestation, poor preservation, or melting of phytoliths due garbage burning.

The post-hacienda phase is represented by the disturbed soil layers covering the midden. These layers are the result of periods of abandonment, plowing, or modern construction which present challenges for interpretation of phytolith concentrations. In order words, the record from this phase does not represent a stable input of phytoliths from the vegetation cover. However, introduced species are present in this phase. For instance, the record shows an increase in saddle and rondel phytoliths, which are possible indicators of sugar cane; phytoliths from the genus Musa (banana tree); globular echinate phytoliths associated with palms; and a re-emergence of globular phytoliths that may represent abandonment periods and invasive vegetation resilience.

The phytolith record from the Mill shows a permanent presence of grass species represented in large concentrations of short bodies. It is probable that the ash and charcoal layers analyzed are a direct result of grasses being used as fuel for the steam powered machinery of El Progreso. It is likely that the grass phytoliths come from sugar cane leaves and stems that were burned after crushing (a fuel known as “bagasse”), which is a common practice in sugar plantations and was mentioned by the visitors to Hacienda El Progreso (Mann 1909:30-32). It is likely that the mill boilers were cleaned regularly and the resulting ash and charcoal was deposited outside the buildings. The modern vegetation is represented by high concentrations of phytoliths from Musa sp., palms, and globular phytoliths in the superficial layers. These plants were growing on the surface when the soil samples were collected.
3.6. Conclusions

This work presents new evidence of human-plant relationships on San Cristóbal Island, Galápagos during the second half of the 19th century. The combined data from macro and micro-botanical remains with historical descriptions of the plantation demonstrate the use of native plant species, the effects of human activities on a previously unpopulated landscape, and the consumption of introduced plants during the last decade of the 19th century.

The analysis of wood charcoal reveals a diverse assemblage with up to six taxa present and shows the preferred use of tree species native to San Cristóbal Island by first colonizers. The results suggest that the native trees, locally known as matazarno, guayabillo, scalesia, and palo santo, were the main sources of firewood, timber, and construction materials starting in the 1860s. Most the native taxa identified could have proceeded from patches of forest close to the plantation facilities in both the arid and humid zones. Introduced bamboo was an additional plant used for construction material. Pine and oak could have been imported as furniture, barrels, or packing crates.

The macroremain assemblage shows several plant species introduced to the island in the 19th century. Maize, lentils, and beans were probably important ingredients of the local diet at El Progreso, complemented by consumption of introduced fruits from mainland Ecuador such as guabo and guayaba. Some native weeds present in the flotation samples reveal the existence of open landscapes and vegetation clearing by the time that Hacienda El Progreso was in full operation during the late 19th century.

The phytolith record shows aspects of the native vegetation prior to permanent occupation and provides evidence of crops introduced to the site. The record shows the introduction of several varieties of grasses for grazing and agriculture. It also shows the possible existence of mixed vegetation composed of trees and grass-like plants covering the site prior to human population. Introduced crops such as maize and sugarcane are evident in the large concentrations of grass phytoliths. Fossilized cells from the Musa genus shows the early presence of banana trees. In addition, the record suggests that leaves and stems of sugarcane were one of the main fuel sources for the steam-
powered machinery of the plantation. Large concentrations of short phytoliths such as saddle, bilobate, and rondel associated with sugarcane were extracted from soils next to the ruins of the old mill.

In sum, this work has proved the validity of an environmental archaeology framework to explore the historic use of plants, and aspects of the adaptation strategies implemented by people to start a permanent colony in a previously unpopulated landscape.
### 3.7. Supplementary material

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Table 7. Charcoal fragment number and size distribution by collection site in El Progreso, Galápagos

<table>
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<th>Sampling Area</th>
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<td>S  M  L  XL  Total</td>
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<tr>
<td>Carpintero</td>
<td>Midden</td>
<td>80</td>
<td>5 5 5 5 20</td>
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<td></td>
<td>Unit2 Midden</td>
<td>80</td>
<td>10 11 6 8 35</td>
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<td></td>
<td>Unit1 level2</td>
<td>20</td>
<td>0 0 5 0 5</td>
</tr>
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<td></td>
<td>Unit1 level5</td>
<td>60-80</td>
<td>0 0 4 3 7</td>
</tr>
<tr>
<td></td>
<td>Unit1 level7</td>
<td>70</td>
<td>15 15 15 15 60</td>
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<td>Unit2 level3</td>
<td>30</td>
<td>0 0 1 1 2</td>
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<td>Unit2 level4</td>
<td>70-90</td>
<td>6 5 5 5 21</td>
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<td>Unit2 level5</td>
<td>50</td>
<td>0 4 8 9 23</td>
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<td>Unit3 level2</td>
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<td>5 3 7 5 20</td>
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<td>Unit1 level8</td>
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<td>Unit2 level6</td>
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<td>Unit2 level7</td>
<td>30-40</td>
<td>10 10 10 10 40</td>
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<td>Pier</td>
<td>2 m b.s.l.</td>
<td>0 0 0 2 2</td>
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Fragment size distribution categories: small ‘S’ (<4 mm diameter), medium ‘M’ (4–6 mm), large ‘L’ (<10 mm), extra-large XL (> 10 mm)
Table 8. Anatomical features of identified charcoal types

<table>
<thead>
<tr>
<th>Family</th>
<th>Species</th>
<th>Anatomical features (Transect view)</th>
<th>References</th>
</tr>
</thead>
</table>
| Asteraceae  | *Scalesia pedunculata*   | • Growth ring boundaries indistinct or absent;  
• Wood diffuse porous;  
• Vessel-ray pits with distinct border;  
• Vascular/vasicentric tracheids present.                                    | (Froyd et al. 2010; Lee 2006) |
| Burseraceae | cf. *Bursera graveolens* | • Growth ring boundaries indistinct or absent;  
• Wood diffuse porous;  
• 20-40- vessels per square millimetre;  
• Tyloses common;  
• Vessels: 100–150 lm, typically single or in pairs.                          | (Froyd et al. 2010; Lee 2006) |
| Euphorbiaceae | cf. *Croton scouleri*     | • Wood diffuse-porous;  
• Vessels in radial multiples pf 4 or more common.                                                | (Froyd et al. 2010; Lee 2006) |
| Fabaceae    | *Piscidia carthagenensis* | • Growth ring boundaries distinct;  
• Intervessel pits alternate;  
• Numerous (40–100 per mm2) small vessels (<50 lm);  
• Axial parenchyma bands more than three cells wide;  
• Vessel rays with distinct borders;  
• Ray width 1 to 3 cells  
• Tyloses common;  
• Prominent storied parenchyma.                                                | (Froyd et al. 2010; Lee 2006) |
| Fagaceae    | *Quercus* sp.            | • Growth ring boundaries distinct;  
• Ring porous;  
• Flame-like, radial                                                            | (Hoadley 1990; Schweingruber 1978; Carlquist 2001) |
<table>
<thead>
<tr>
<th>Family</th>
<th>Species</th>
<th>Anatomical features (Transect view)</th>
<th>References</th>
</tr>
</thead>
</table>
| Myrtaceae    | *Psidium galapageium*            | • Growth ring boundaries distinct  
• Wood diffuse porous  
• Vessels in diagonal and/or radial patterns  
• Simple perforation plates  
• vessels mostly solitary  
• vessel-ray pits with distinct borders  
• ≥100 vessels per square millimeter  
• Ray width 1 to 3 cells                                                                                                                                 | (Froyd et al. 2010; Lee 2006)                                              |
| Pinaceae     | *Pinus sp.*                      | • Resin canals with large, thin-walled epithelial cells;  
• Large, numerous, mostly solitary resin canals;  
• Earlywood/latewood gradual transition.                                                                                                                                                                                      | (Hoadley 1990; Schweingruber 1978; Carlquist 2001)                        |
| Poaceae      | *Guadua/Bambusa sp.*            | Closed, collateral, vascular bundles within the parenchyma                                                                                                                                                                         | (Liese and Tang 2015; Liese 1998; Schweingruber et al. 2006)              |
Table 9. Macrobotanical seed remains recovered from El Progreso plantation, San Cristóbal Island (Galápagos, Ecuador)

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<th>Loci</th>
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<th>Family</th>
<th>Genus species</th>
<th>Common name</th>
<th>Charr.</th>
<th>Unch.</th>
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<td>level 7</td>
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<td></td>
<td></td>
<td>Poaceae</td>
<td>cf. Zea mays</td>
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<td></td>
<td>Rubiaceae</td>
<td>Cф. Psychotria rufipes</td>
<td>Cafetillo</td>
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<td>Rubiaceae</td>
<td>cf. Psychotria rufipes</td>
<td>Cafetillo</td>
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<td>cf. Fabaceae</td>
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<td>Frejol</td>
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Table 10. Biomineral content and relative contributions of prominent phytolith types in soil samples from El Progreso plantation.

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<th>Initial Mass (g)</th>
<th>Mass after acid (g)</th>
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<th>F.3 (g)</th>
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<td>0.55</td>
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<td>0.68</td>
<td>0.62</td>
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<td>227</td>
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<td>Initial Mass (g)</td>
<td>Mass after acid (g)</td>
<td>A.I.F (g)</td>
<td>F.3 (g)</td>
<td>Total Phytoliths</td>
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<td>----------</td>
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<td>-----------</td>
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</table>
3.7.1. Protocol for phytoliths extraction from modern plants

(1) Pre-treatment and sterilization: Samples were dried for 6 hours at 130°C in a laboratory oven\textsuperscript{20}. Once dried, they were allowed to cool at room temperature and weighed\textsuperscript{21}. A sample aliquot weighing approximately 1g was collected for processing.

(2) Acid Digestion: Each sample was placed in 140 ml beakers and received a 10 ml solution of equal parts of hydrochloric (HCl) and nitric (HNO\textsubscript{3}) acids at 3N. The beakers were placed on a hot plate for about ½ hour to accelerate acid reaction. The acid remainder was removed during three consecutive 5-minute wash and centrifugation cycles at 3000 rpm\textsuperscript{22}. Each sample was mixed prior to centrifugation. The samples were dried at ~100°C for 20 hours then reweighed to calculate phosphate and carbonate loss. Organic matter reduction was accomplished by using 10 ml of hydrogen peroxide (H\textsubscript{2}O\textsubscript{2} 30%) boiled at ~70°C. Upon its evaporation, the samples were dried in an oven at ~100°C for 20 hours and weighed again to establish the mass of the inorganic acid-insoluble fraction (A.I.F.).

(3) Heavy Liquid Separation: A.I.F. was placed in clean 15 ml test tubes to which 5 ml of Sodium Polytungstate (S.P.T.)\textsuperscript{23} at a 2.4 specific gravity was added. The floating fraction was transferred with disposable pipettes to a second 15 ml tube. One ml of distilled water was added to the floating fraction in the new 15 ml tube using a precision pipette. Samples were centrifuged at 3000 rpm for 5 minutes. The floating fraction was separated and transferred again to a third 15 ml centrifuge tube and was filled with distilled water, mixed, and centrifuged 3 times at 3,000 rpm for 5 minutes to remove any residual S.P.T. The remnant was transferred to a clean 1.5 ml eppendorf tube, filled with distilled water, mixed, and centrifuged for the last time at 4,500 r.p.m for 3 minutes\textsuperscript{24}. This fraction (F.3) contains the majority of the opal silica bodies. Final drying in an oven at 100°C ensued for 24 hours.

\textsuperscript{20} Barnstead-Thermolyne Oven/Incubator Type 19200
\textsuperscript{21} Ohaus ExplorerPro 413C
\textsuperscript{22} Eppendorf Centrifuge 5810
\textsuperscript{23} By: Sometu-Europe
\textsuperscript{24} Eppendorf MiniSpin
(4) Mounting: A fixed aliquot of ~0.002 g was mounted after proper mixing. The medium consisted of four drops of slow drying resin “Entellan New”. The aliquot was well mixed and covered by a 22mm×22mm slip.
Chapter 4. Illustrated Catalogue of Phytoliths from Modern Useful Plants. San Cristóbal Island, Galápagos

4.1. Introduction

For comparative purposes, a set of 43 plant samples representing 18 families and 42 species of vascular plants was processed for phytolith extraction. Based on published sources, a pre-selection of prominent local taxa to be sampled in the field was used (Bungartz et al. 2009; Guézou et al. 2016; Jaramillo Díaz et al. 2014; Jaramillo Díaz and Guézou 2010; McMullen 1999). Nine endemic, eleven native, and twenty-two introduced modern plant species were collected considering the possible uses of these plant species during the first years of colonization of San Cristóbal Island (Table 11). The comparative illustrated catalog presented here is limited to test the production of phytoliths in useful endemic, native, and introduced plant taxa.

The overall goal of this work was to initiate a comparative collection of phytoliths from endemic, native, and introduced plant species existing in the highlands of San Cristóbal. The specific objectives were: (1) diagnose the production of diagnostic phytoliths; and (2) catalog the existing diagnostic phytolith morphotypes.

The plant specimens were collected during the summers of 2014 and 2015 in the proximity of El Progreso village in the Scalesia zone of San Cristóbal Island. Sections of leaves, stem, and wood were used to explore the presence and production of diagnostic
phytoliths. The samples were processed in the laboratories of the Galapagos Science Centre (UNC-Chapel Hill) and Simon Fraser University.

4.2. Protocols

Phytolith extraction from modern samples followed “dry ashing” protocols outlined by Albert and Weiner (2001), with minor modifications from Mercader et al. (2011, 2010, 2009) and Astudillo (2011). The protocol is ordered in four steps.

1. The plant tissue was cleaned by immersion in a soap solution to eliminate residues of soil or other kinds of impurities. Specimens were then dried overnight at ~100°C in an incubator oven. After cooling, plant mass was weighed on a precision balance.

2. The dry samples then went into a muffle furnace for combustion over the course of 36 hours at 500°C. Ceramic crucibles of 30 and 50 ml with lids were used. (3) The mass of the resulting ash was weighed in a precision balance and received a 10 ml 50:50 solution made of hydrochloric (HCl) and nitric (HNO3) acids at 3N. After acid reactions the samples were placed to boil at ~70°C until a gelatin matrix was formed. After cooling, successive washing cycles removed acids from the sample by 5 minutes centrifugation cycles at 3,000 r.p.m. When acid elimination was complete the remainder of a sample was dried overnight at ~100°C and weighed. Phosphate and carbonate loss was estimated by calculating mass differential. After this, approximately 10 ml of hydrogen peroxide (H2O2) at 30% was added to the sample to tear down organic matter. The sample was dried at ~100°C overnight.

This study was conducted with permits from the Galapagos National Park N° PC-93-14 and N° PC-61-15; National Institute of Cultural Heritage of Ecuador (INPC) N°. 006-2014 and N° 004-DR4-INPC-2015. Export of soil samples and dried plant material was conducted with the Authorization No.10, INPC’BC’EC’00705. The research was funded by the Government of Ecuador/SEnescyt with a scholarship for doctoral studies to Fernando Astudillo (Beca Convocatoria Abierta 2012 II Fase); a SSHRC Partnership Development Grant No. 890-2013-0013; and the Department of Archaeology of Simon Fraser University (SFU). I am grateful to Dr. Carlos Mena, MA. Juan Pablo Muñoz, Ing. Leandro Vaca, and Ing. Luis Tasipanta at the Galápagos Science Centre; Dr. Catherine D’Andrea, Shannon Wood, and Peter Locher at SFU; and to all the people of El Progreso, specially Paulina Cango Eddie Becerra, and Jeffres Malaga.
(4) The resulting biominerals form the acid-insoluble fraction (A.I.F.) where phytoliths, among other biogenic precipitates, are present. An aliquot of ~0.001 g was taken for mounting, after proper mixing. The mounting medium was made up of two droplets of resin solution ‘Entellan new’. The aliquot was well mixed, and the microscopic inspection and counting took place within 48 hours of mounting before media were able to dry (3-D shifting of phytoliths was necessary to carry out identification).


Morphological features scrutinized were size, bi-dimensional outline, three-dimensional classification, and surface texture. All samples were analyzed under differential interference contrast (D.I.C.) microscopy at 40X magnification in ten adjacent but not overlapping lines across the cover slip. Close examination of phytolith morphology was conducted on photographic frames using the image analysis software OLYMPUS Stream Basic 1.8. in a research microscope Olympus BX53 D.I.C.

4.3. **Biogenic production**

Biogenic content is the total percentage of phytoliths, silica, and diatoms produced by plants. The biogenic content of the comparative material from San Cristobal Island are expressed in table 2 where higher values in the Acid Insoluble Fraction (A.I.F.) indicate greater silica production.
In native and endemic woody plants in San Cristóbal Island biogenic silica production averages from 0.13% to 2.93% of the plant's dry mass; the highest amount of silica was produced by *Tournefortia pubescens* (Boraginaceae). In native/endemic grasses and members of the Cyperaceae family the silica presence variates from 0.79% to 2.97%.

Typical ash production is between 0.95% and 6.78% of the original mass on introduced grass species, and between 0.10% and 1.23% on introduced woody plants. The absolute highest biogenic content (>6%) has been recorded among introduced members of C3 grasses from the Poaceae family: *Bambusa vulgaris* and *Panicum maximum*; while the lowest silica production (<0.09%) is noticed in members of the Asrestaceae (*Scalesia pedunculata*), Bombaceae (*Ceiba petandra*), Cupressaceae (*Cupressus macrocarpa*), Euphorbiaceae (*Croton scouleri* and *Hippomane mancinella*), Malvaceae (*Gossypium darwinii* and *Miconia robinsoniana*), Mimoseae (*Prosopis juliflora*), Myrtaceae (*Psidium guajava*), and Rubiaceae (*Coffea arabica*).
Table 11 Plants collected in San Cristóbal Island for phytoliths extraction

Key: L= leaves; S= stem; W= wood/bark; F = flowers

<table>
<thead>
<tr>
<th>Family</th>
<th>Species</th>
<th>Parts</th>
<th>Category</th>
<th>TAL No.</th>
</tr>
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<td>Rubiaceae</td>
<td><em>Psychotria rufipes</em> Hook. f.</td>
<td>L, S</td>
<td>Endemic</td>
<td>GLP-PRG-PLB-REF 30</td>
</tr>
<tr>
<td>Rutaceae</td>
<td><em>Citrus paradisi</em> Macfadd.</td>
<td>L, S, W</td>
<td>Introduced</td>
<td>GLP-PRG-PLB-REF 31</td>
</tr>
<tr>
<td>Rutaceae</td>
<td><em>Zanthoxylum fagara</em> (L.) Sarg.</td>
<td>L, S, W</td>
<td>Native</td>
<td>GLP-PRG-PLB-REF 37</td>
</tr>
<tr>
<td>Rutaceae</td>
<td><em>Citrus sinensis</em> (L.) Osbeck</td>
<td>W</td>
<td>Introduced</td>
<td>GLP-PRG-PLB-REF 38</td>
</tr>
<tr>
<td>Solanaceae</td>
<td><em>Solanum cheesmaniae f.</em> <em>cheesmaniae</em> (Riley) Fosberg</td>
<td>L, S</td>
<td>Endemic</td>
<td>GLP-PRG-PLB-REF 24</td>
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<tr>
<td>Urticaceae</td>
<td><em>Laportea aestuans</em> (L.) Chew</td>
<td>L, S</td>
<td>Native</td>
<td>GLP-PRG-PLB-REF 26 &amp; 27</td>
</tr>
</tbody>
</table>


Morphotypes: (a) Globular sinuate; (b) hair base; (c) mesophyll epidermal phytoliths; (d) orbicular hair cell.

![Phytolith images](image_url)
4.4.2. **Bombaceae. *Ceiba pentandra* (L.) Gaertn.**


Morphotypes: (a) Clavate columellate hair cell, (b) acicular hair cell, (c) globular phytolith.
4.4.3. **Boraginaceae. *Tournefortia pubescens* Hook. f.**


Morphotypes: (a) Cylindrical striate long cell; (b) hair base; (c & d) polyhedral epidermal phytoliths.
4.4.4. **Boraginaceae. *Cordia lutea* Lam.**


Morphotypes: (a-e) Clavate columnellate hair cell.
Morphotypes continue: (f) stellate bulliform cell.


Morphotypes: Hair base.
4.4.6. **Burseraceae. *Bursera graveolens* (Kunth) Triana & Planch.**


Morphotypes: Mesophyll epidermal phytoliths.

Origin: Native (Indigenous taxon).

Morphotypes: (a) Glum phytoliths; (b) globular phytoliths; (c) papillae cell; (d) parallelepipedal bulliform cell.
Morphotypes continue: (e) parallelepedal granulate bulliform cell; (f) polyhedral epidermal phytoliths.
4.4.8. **Cyperaceae. *Scleria melaleuca* Rchb. Ex Schltdl. & Cham.**


Morphotypes (a) Acicular equal prickle; (b) bilobate concave outer margin short shaft; (c) elongate echinate long cell; (d) epidermal phytoliths.
Morphotypes continue: (e) ovate phytoliths; (f & g) papillae cell.
4.4.9. **Euphorbiaceae. *Aleurites moluccana* (L.) Willd.**


Morphotypes: Mesophyll epidermal phytoliths.
4.4.10. *Euphorbiaceae*. *Hippomane mancinella* L.


Morphotypes: Mesophyll epidermal phytoliths
4.4.11. **Fabaceae. Piscidia carthagenensis Jacq.**


Morphotypes: (a) Fusiform equal; (b) globular sinuate; (c) hair base; (d) irregular equal.
Morphotypes continue: (e) mesophyll phytoliths; (f) polyhedral phytoliths.


Morphotypes: (a) Cylindrical sulcate tracheid; (b-d) globular sinuate phytoliths.
Morphotypes continue: (e & f) mesophyll epidermal phytoliths.


Morphotypes: Acicular hair cell.
4.4.14. **Malvaceae. Miconia robinsoniana Cogn.**

Common name: Miconia. Origin: Endemic

Morphotypes: Globular piscilate phytoliths from flowers
4.4.15. Moraceae. *Artocarpus altilis* (Parkinson) Fosberg


Morphotypes: (a) Acicular columnellate hair cell; (b) acicular hair cell; (c) cylindrical sulcate tracheid; (d & e) hair base.
Morphotypes continue: (f) mesophyll epidermal phytoliths.
4.4.16. Myrtaceae. Psidium galapageium var. howellii Porter


Morphotypes: (a) Elliptical rugulate; (b) globular sinuate; (c) hair base; (d) ovate equal.
Morphotypes continue: (e) polyhedral phytoliths; (f) stellate linear.


Morphotypes: (a) Carinate facetate bulliform; (b) clavate facetate; (c) cylindric sulcate tracheid; (d) globular sinuate.
Morphotypes continue: (e) polyhedral phytoliths; (f) stellate psilate bulliform cell.
4.4.18. **Myrtaceae. Psidium guajava L.**


Morphotypes: (a) Elongate cylindrical; (b - d) polyhedral phytoliths.
4.4.19. Poaceae. *Bambusa vulgaris var. vittata* Rivière & C. Rivière


Morphotypes: (a) Cuneiform bulliform cell, (b & c) parallelepipedal bulliform cell, (d) saddle epidermal short cells.
Morphotypes continue: (e) saddle short cell and stomatal phytoliths.
4.4.20. Poaceae. *Bambusa vulgaris* var. *vulgaris* Schrad ex Wendle

Common name: Bamboo / Caña verde. Origin: Introduced (Cultivated)

Morphotypes: (a) cuneiform bulliform cell, (b & c) parallelepipedal bulliform cell, (d-f) saddle epidermal short cells.
Morphotypes continue: (e & f) saddle epidermal short cells.
4.4.21. **Poaceae. Brachiaria decumbens Stapf.**


Morphotypes: (a) Scutiform lanceolate; (b-e) variants of bilobate concave outer margins short shaft.
Morphotypes continued: (f) cuneiform bulliform cell; (g) glum phytoliths; (h) polylobate epidermal short cell; (i) saddle short cell (j) stomatal phytoliths.


Morphotypes: (a) Cuneiform bulliform cell; (b) elongate cylindrical psilate; (c) polyhedral epidermal phytoliths; (d & e) saddle epidermal short cell.
Morphotypes continue: saddle epidermal short cell.
4.4.23. Poaceae. *Digitaria* sp.

Origin: Introduced (Accidentally).

Morphotypes: (a) Scutiform lanceolate; (b) bilobate concave outer margins long shaft; (c-f) variants of bilobate concave outer margins short shaft.
Morphotypes continued: (g) bilobate concave outer margins short shaft; (h) epidermal aggregation, (i) papillae cells.


Morphotypes: (a) Scutiform lanceolate; (b) elongate echinate long cell; (c) epidermal tissue; (d) quadra-lobate short cell.
Morphotypes continue: (e) saddle epidermal short cell; (f) stomatal phytoliths.


Morphotypes: (a) Scutiform lanceolate; (b) bilobate concave outer margins short shaft; (c) elongate echinate long cell; (d) parallelepipedal bulliform cell.
Morphotypes continued: (e) polylobate epidermal short cell; (f) quadra-lobate epidermal short cell; (g) rondel tall pyramidal ovate top; (h) collapsed saddle; (i) stomatal and rondel short cells.
Morphotypes continued: (i) stomatal and rondel short cells.

Common name: Guinea grass / Pasto Sabolla. Origin: Introduced (Escaped)

Morphotypes: (a-e) variants of Bilobate concave outer margin short shaft.
Morphotypes continued: (f) cuneiform bulliform cell; (g) glum phytoliths; (h) parallelepipedal bulliform cell; (i) polylobate epidermal short cell; (j) stomate phytoliths.
4.4.27. **Poaceae. Panicum maximum Jacq.**


Morphotypes: (a) acicular hair cell; (b-d) variants of bilobate concave outer margins short shaft.
Morphotypes continued: (e) glum phytoliths; (f) parallepipidal bulliform cell; (g) Polylobate epidermal short cell; (h) quadra-lobate epidermal short cell; (i & j) stomate phytoliths.
4.4.28. **Poaceae. Pennisetum purpureum Schum.**


Morphotypes: (a) Scutiform lanceolate; (b & c) variants of bilobate concave outer margin short shaft; (d) collapsed saddle.
Morphotypes continued: (e) elongate echinate; (f) glum phytoliths; (g) rondel tall pyramidal ovate top; (h) stomatal phytoliths
4.4.29. **Poaceae. Saccharum officinarum L.**


Morphotypes: (a-c) variants of bilobate concave outer margin short shaft; (d) elongate cylindrical psilate.
Morphotypes continue: (e) glum phytoliths; (f) mesophyll & stomatal phytoliths; (g) polyhedral phytoliths; (h) rondel tall narrow flat top.
Morphotypes continue: (i) rondel tall pyramidal ovate top; (j) rondel wavy-top; (k) saddle phytoliths; (l) stomate phytoliths.

Common name: Buffalo grass. Origin: Native.

Morphotypes: (a & b) Bilobate concave outer margins short shaft; (c-f) variants of polylobate epidermal short cell.
Morphotypes continued: (g & h) polylobate epidermal short cell; (i & j) rondel tall narrow flat top; (k) rondel tall pyramidal ovate top; (l) scutiform lanceolate.
Morphotypes continued: (i & j) rondel tall narrow flat top; (k) rondel tall pyramidal ovate top; (l) scutiform lanceolate.
4.4.31. Rubiaceae. Coffea Arabica L.


Morphotypes: Cylindrical sulcate tracheid phytoliths.


Morphotypes: (a) Globular phytolith; (b) trapeziform epidermal phytolith


Morphotypes: (a) Cylindrical sulcate tracheid; (b & c) hair base; (d) mesophyll epidermal phytoliths.
4.4.34. **Solanaceae. Solanum cheesmaniae f. cheesmaniae (Riley) Fosberg.**


Morphotypes: Mesophyll epidermal phytoliths
4.4.35. Urticaceae. *Laportea aestuans* (L.) Chew


Morphotypes: (a-c) Acicular hair cell; (d) hair base.
Morphotypes continued: (e & f) oblong columellate epidermal cell.
Table 12 Biogenic production of phytoliths of modern plants of San Cristobal Island.

<table>
<thead>
<tr>
<th>Family</th>
<th>Species</th>
<th>Part</th>
<th>Dry mass (g)</th>
<th>Ash (g)</th>
<th>A.I.F. (g)</th>
<th>A.I.F. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asteraceae</td>
<td><em>Scalesia pedunculata</em> Hook. f.</td>
<td>L, S</td>
<td>1.976</td>
<td>0.192</td>
<td>0.001</td>
<td>0.051</td>
</tr>
<tr>
<td>Bombaceae</td>
<td><em>Ceiba pentandra</em> (L.) Gaertn.</td>
<td>L, S, W</td>
<td>3.644</td>
<td>0.598</td>
<td>0.001</td>
<td>0.027</td>
</tr>
<tr>
<td>Boraginaceae</td>
<td><em>Tournefortia pubescens</em> Hook. f.</td>
<td>L, S</td>
<td>1.360</td>
<td>0.159</td>
<td>0.041</td>
<td>3.015</td>
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<tr>
<td></td>
<td><em>Cordia lutea</em> Lam.</td>
<td>L, S</td>
<td>2.885</td>
<td>0.351</td>
<td>0.007</td>
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<tr>
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<td><em>Tournefortia rufo-sericea</em> Hook. f.</td>
<td>L, S, W</td>
<td>3.180</td>
<td>0.309</td>
<td>0.004</td>
<td>0.126</td>
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<td>Burseraceae</td>
<td><em>Bursera graveolens</em> (Kunth) Triana &amp; Planch.</td>
<td>L, S, W</td>
<td>3.189</td>
<td>0.170</td>
<td>0.011</td>
<td>0.345</td>
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<td>Cupressaceae</td>
<td><em>Cupressus macrocarpa</em> Hartw.</td>
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<td>7.878</td>
<td>0.424</td>
<td>0.001</td>
<td>0.013</td>
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<td>Cyperaceae</td>
<td><em>Rhynchospora nervosa</em> ssp. <em>Ciliate</em> (G. Mey.) T. Koyama</td>
<td>L, F</td>
<td>0.538</td>
<td>0.061</td>
<td>0.002</td>
<td>0.372</td>
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<tr>
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<td><em>Scleria melaleuca</em> Rchb. Ex Schltdl. &amp; Cham.</td>
<td>L, F</td>
<td>2.084</td>
<td>0.393</td>
<td>0.061</td>
<td>2.927</td>
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<td>Euphorbiaceae</td>
<td><em>Aleurites moluccana</em> (L.) Willd.</td>
<td>L, S, W</td>
<td>1.902</td>
<td>0.198</td>
<td>0.002</td>
<td>0.105</td>
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<td></td>
<td><em>Croton scouleri</em> var. <em>scouleri</em> Hook. f.</td>
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<td>1.753</td>
<td>0.250</td>
<td>0.001</td>
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<td><em>Hippomane mancinella</em> L.</td>
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<td>4.205</td>
<td>0.410</td>
<td>0.003</td>
<td>0.071</td>
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<td>Fabaceae</td>
<td><em>Piscidia carthagenensis</em> Jacq.</td>
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<td>0.133</td>
<td>0.003</td>
<td>0.150</td>
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<td>Lauraceae</td>
<td><em>Persea americana</em> Mill.</td>
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<td>2.474</td>
<td>0.099</td>
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<td>0.162</td>
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<tr>
<td>Malvaceae</td>
<td><em>Gossypium darwinii</em> G. Watt.</td>
<td>L, S, W</td>
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<td><em>Miconia robinsoniana</em> Cogn.</td>
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<td>0.198</td>
<td>0.002</td>
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<td><em>Miconia robinsoniana</em> Cogn.</td>
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<td>Family</td>
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<td>Part</td>
<td>Dry mass (g)</td>
<td>Ash (g)</td>
<td>A.I.F. (g)</td>
<td>A.I.F (%)</td>
</tr>
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<td>Mimosaseae</td>
<td><em>Inga insignis</em> Knuth.</td>
<td>W</td>
<td>N/A</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
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<td><em>Prosopis juliflora</em> (Sw.)</td>
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<td><em>Artocarpus altillis</em> (Parkinson) Fosberg</td>
<td>L, S</td>
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<td>0.856</td>
<td>0.048</td>
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<td>Myrtaceae</td>
<td><em>Psidium galapageium</em> var. <em>howellii</em> Porter</td>
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<td><em>Psidium guajava</em> L.</td>
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<td>0.167</td>
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<td><em>Syzygium jambos</em> (L.) Alston</td>
<td>L, S</td>
<td>2.842</td>
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<td>0.023</td>
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<td>Poaceae</td>
<td><em>Bambusa vulgaris</em> var. <em>vittata</em> Rivière &amp; C. Rivière</td>
<td>L, S, W</td>
<td>2.630</td>
<td>0.232</td>
<td>0.175</td>
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<td><em>Bambusa vulgaris</em> var. <em>vulgaris</em> Schrad ex Wendle</td>
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<td>0.146</td>
<td>0.081</td>
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<td><em>Brachiaria decumbens</em> Stapf.</td>
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<td><em>Cynodon niemfuensis</em> Vandyerst.</td>
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<td>0.192</td>
<td>0.030</td>
<td>1.720</td>
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<td><em>Digitaria sp.</em></td>
<td>L, F</td>
<td>3.521</td>
<td>0.193</td>
<td>0.020</td>
<td>0.568</td>
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<td><em>Eleusine indica</em> (L.) Gaertn.</td>
<td>L, F</td>
<td>2.206</td>
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<td>0.021</td>
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<td><em>Eragrostis amabilis</em> (L.) Wight &amp; Arn. Ex Nees.</td>
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<td><em>Panicum maximum</em> Jacq.</td>
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<td><em>Saccharum officinarum</em> L.</td>
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<td><em>Stenotaphrum secundatum</em> (Walter) Kuntze</td>
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<td><em>Psychotria rufipes</em> Hook. f.</td>
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<td>0.005</td>
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<td>Family</td>
<td>Species</td>
<td>Part</td>
<td>Dry mass (g)</td>
<td>Ash (g)</td>
<td>A.I.F. (g)</td>
<td>A.I.F (%)</td>
</tr>
<tr>
<td>--------------</td>
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<td>--------------</td>
<td>---------</td>
<td>------------</td>
<td>-----------</td>
</tr>
<tr>
<td>Rutaceae</td>
<td><em>Zanthoxylum fagara</em> (L.) Sarg.</td>
<td>L, S, W</td>
<td>1.878</td>
<td>0.164</td>
<td>0.005</td>
<td>0.266</td>
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<tr>
<td>Rutaceae</td>
<td><em>Citrus sinensis</em> (L.) Osbeck</td>
<td>W</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Solanaceae</td>
<td><em>Solanum cheesmaniae f. cheesmaniae</em> (Riley)</td>
<td>L, S</td>
<td>0.961</td>
<td>0.172</td>
<td>0.001</td>
<td>0.104</td>
</tr>
<tr>
<td></td>
<td><em>Fosberg</em></td>
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<td>Urticaceae</td>
<td><em>Laportea aestuans</em> (L.) Chew</td>
<td>L, S</td>
<td>0.496</td>
<td>0.118</td>
<td>0.007</td>
<td>1.411</td>
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<td><em>Laportea aestuans</em> (L.) Chew</td>
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<td>0.742</td>
<td>0.204</td>
<td>0.012</td>
<td>1.617</td>
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</table>
Chapter 5.  *Hacienda El Progreso: Criminals, peons, and industrial sugar on the 19th century Galápagos frontier*

Fernando J. Astudillo and Ross W. Jamieson (For submission to Journal of Latin American Studies)

5.1. Manuel J. Cobos

In 1866 Manuel J. Cobos, a merchant born in Cuenca, Ecuador, but running an import/export business from the port of Chanduy on the Ecuadorian coast, created a private company to harvest *orchilla* (orchil/archil) lichen (used for creating dye for cloth) from the Galápagos Islands (Kok 1966). The *Empresa Industrial de Orchilla y Pesca*, created by Cobos, his brother Angel, and José Monroy; was one of several companies initially given such licences. They soon found that the orchilla was not profitable, and turned the company’s efforts to harvesting sea lions and feral cattle from the islands for the hide trade (Latorre 2011: 17-25). Selling these hides in Panama fit into Cobos’ already shady reputation as someone who avoided taxes, set up multiple business schemes that involved bringing contraband goods between Mexico, Panama, and Ecuador, and occasionally pirated other peoples’ ships (De Kay 1872; Latorre 2011:18-19).

Three years later Cobos set up a base of operations on Chatham Island (today San Cristóbal), one of the most fertile islands in the archipelago, with a good port, plentiful fresh water and excellent agricultural potential. He left a crew of workers on the island to clear the forest, capture feral cattle for breeding, and otherwise begin preparations for a large agricultural operation (Epler 2013:94; Salvin 1876).
Manuel J. Cobos called his new operation the *Hacienda El Progreso*, and from 1878 or so, he lived on the property full time, and built it into a large sugar, coffee, and fruit plantation run by up to 400 labourers. The question for us is over the definition of what *El Progreso* was, and how it fits into the history of Ecuador. Cobos’ labourers came at least partly from the jails of Guayaquil, in an arrangement with the local municipality and the police there. The land *El Progreso* sat on appears to have been granted to him as a colonization concession from the government of Ecuador. The agricultural installations appear to have been funded out of his own pocket, and all profits returned to him and his business partners. Thus, at a time when the Republic of Ecuador was modernizing, and the Liberal Revolution changed a lot about how Ecuadorians interacted with their government, Cobos ran an operation on Galápagos that was a complex mix of agricultural plantation, government colonization concession, and penal colony.

5.2. The Galápagos and Ecuador

The Galápagos Islands were accidentally encountered by Bishop Tomàs de Berlanga in 1535, when his ship went off course sailing from Panama to Lima, Peru (Berlanga 1884 [1535]). There is no clear evidence that humans had settled on the islands before this date (Anderson et al. 2016). From Berlanga’s first report, through to Ecuador’s formal ceremony to claim the islands in 1832, they remained an extra-national space, 1000 km from the South American coast, used by pirates, sealers, whalers and other ships from many nations to restock provisions and water, and particularly to take on board live tortoises for consumption during long sea voyages in the Pacific. The islands were ecologically impacted by accidental and deliberate introduction of invasive species of plants and animals, as well as the destruction of some resources through human predation over this 300-year period, but without any sizeable permanent human settlements (Epler 2013; Idrovo 2005; Latorre 2011).

As the wars of independence came to an end, and the new Andean republics solidified their boundaries, the republic of Ecuador asserted its territorial claim to the Galápagos. General José Villamil, a hero of Ecuadorian Independence, lobbied the
government to incorporate the Galapagos as a province of the new republic, and it became officially recognized as the “Archipiélago del Ecuador.” Villamil dispatched Colonel Ignacio Hernández on the schooner Mercedes, and Hernández took possession of the archipelago in a ceremony on the newly christened island of Floreana in February of 1832. The ceremony was witnessed by the crews of two American whaling vessels that happened to be there (the Richmond and the Levanthian), and by John Johnston, a man who was living on the island at the time (Coulter 1845; Epler 2013:87; Latorre 2011:7). From that day forward the Galápagos became a frontier for Ecuadorian colonization, but one which, because of its very remote location and difficult living conditions, was not an easy region to convert to human habitation.

5.3. Agricultural Penal Colonies on the Galápagos: The Asylum of Peace, Progress, and the Future

Thus began a period of over 100 years in which the Galapagos were colonized with a set of privately-run agricultural penal colonies. The first was Villamil’s Asilo de la Paz (Asylum of Peace) colony on Floreana Island. Villamil had arranged for Ecuador’s president, Juan José Flores, to commute the death sentences of 80 soldiers who had colluded to revolt against Flores. Instead they were exiled to the Galápagos under Villamil’s supervision, and formed the first wave of colonists at Asilo de la Paz. Villamil continued to receive various categories of people deemed worthy of exile by the government, including political dissidents, thieves, murderers, debtors, vagrants and prostitutes (Bognoly and Espinosa 1905:48; Epler 2013:88-89). An 1833 decree by the government of Ecuador declared the Island of Floreana an official location “for the deportation of those sentenced to exile” (Idrovo 2005:49). About 300 people lived at Asilo de la Paz at its peak. The colony produced agricultural products, and extracted oil from tortoises, selling their products to passing ships, particularly the whaling ships that visited frequently in this period. After several violent incidents, Villamil ended his role as administrator of the province in 1846, leaving the islands to a period of largely ungoverned chaos (Latorre 2011:8).
In the latter half of the 19th century the hunt for orchilla lichen, for use in the industrial dying of cloth, had become a global trade. Orchilla was known to grow on the Galapagos, and in 1869 President Gabriel García Moreno gave the licence for the orchilla harvest of the entire Galápagos to the Spanish businessman José Valdizán, who took over the colony on Floreana. The orchilla business failed, and he instead set up a farming operation on Floreana, again with a mix of convict and debt labourers. He was killed by the convicts in 1878, and the colony collapsed (Latorre 2011:8; Mann 1909:15). Many of his workers escaped to Chatham Island, where they were taken up by the newly founded El Progreso operation of Manuel Cobos and José Monroy, Valdizan’s business rivals. From 1878 to 1904 Cobos lived at El Progreso, and de facto controlled the entire small population of the Galápagos, most of whom lived at his plantation. His death at the hands of his own workers in 1904 was the end of an era, but not the end of the unique mix of penal colony and private business on the islands.

The use of the Galápagos for criminal exile continued until the mid-20th century. The 1906 Penal Code restated that deportation to the Galápagos was an important tool for the control of criminality in Ecuador (Salvatore and Aguirre 1996:11). In the 1920s the idea of the Galápagos as agricultural penal colony was revived. The government proposed sending large numbers of minor offenders to San Cristóbal Island, mainly to reduce overcrowding in mainland penitentiaries. Hundreds of criminals were deported to San Cristóbal and other islands in the 1920s and 1930s, apparently to live as colonists without much supervision, in an atmosphere described as beyond the control of the government of Ecuador (Larco Chacón 2011:253).

The Second World War brought American military bases to the islands, and curtailed the transport of criminals. With the end of the war, though, Ecuadorian President Velasco Ibarra ordered the conversion of an American radar station on Isabella Island into a new prison colony, El Porvenir (“The Future”). Criminals from public jails were condemned to forced labour here from 1946 onwards, including the construction of the “Wall of Tears,” a long wall of lava cobbles built simply to keep the prisoners working. In 1959, after a rebellion and many reports of violence and abuse, the prison colonies on Isabela finally closed, in the same year that most of the Galápagos were declared a national park (Idrovo 2005:175-177).
5.4. Plantation Labour

The *Hacienda El Progreso* was the first industrial-scale plantation that existed in the Galápagos Islands. Several commodities were produced at *El Progreso* during its active years (1878-1920), with a focus on refined sugar and coffee. By 1904 *El Progreso* produced and refined about 500 tons of sugar for the Ecuadorian market annually, and several other products such as coffee and leather for international markets. The plantation occupied most of the southwestern portion of the island, and from a few hectares in 1879, El Progreso had grown to about 3000 ha by the time Cobos was killed in 1904 (Latorre 1991; 2011). But what was it?

In many senses *El Progreso* was a plantation. Philip Curtin (1998:11-13) provides a list of six criteria for the definition of an agricultural plantation, and *El Progreso* meets these. The first is the use of forced labour, often enslaved. The second is a population that is not self-sustaining, needing constant in-migration to maintain population levels.

With a long history of colonial production under slavery in the Caribbean, in the second half of the 19th century sugar became an export commodity produced in many tropical regions on large-scale industrial plantations, including Java (Knight 2014), Hawaii (Takaki 1983), Cuba (Dye 1998) and a host of other regions. Throughout the tropical world, wherever sugar was grown, the end of African slavery in the 19th century brought challenges to landowners in finding labour. Sugar plantation work was exhausting, dirty and dangerous. The solution in many cases was contract, or indentured, labour. Hundreds of thousands of the poorest rural labourers in Africa, India, China, Japan, and the Pacific Islands were contracted, tricked, kidnapped, or otherwise encouraged to move to sugar plantations (Engerman 1983). The growing 19th century sugar industry in Queensland, Australia, for example, relied on the kidnap, or coercion, of Pacific Islander “Kanaka” labourers, mainly men from Melanesia, brought in by labour contractors and made to work under very harsh conditions (Graves 1993; Munro 1995). In Peru, the coastal sugar plantations relied on a massive migration of Chinese indentured labourers from the 1840s to the 1870s (Gonzales 1985, 1989).
On most Latin American plantations, however, the solution to labour shortages was the debt peonage of local populations. Plantation owners would hire labour contractors to travel to areas where the labour pool resided, and offer cash advances in return for a commitment to travel and do labour. Such a cash advance was often used to pay off existing debts, or for sponsoring a festival, buying a small plot of land, etcetera. The worker then became a debt peon, owing the owner of the enterprise for the cash advance (Carnes 2014; Monteón 1979).

Slavery had been abolished in Ecuador in 1851, and the large population of enslaved Afro-Ecuadorians were manumitted on coastal cacao plantations and other agricultural operations, where they had little choice but to transition into becoming conciertos, or debt peons (Chiriboga 2013:35). In Ecuador, this mid-19th century system was known as conciertaje, and the workers as jornaleros or conciertos. The system had emerged with the decline of tribute-based mita labour with independence. It relied on the idea that debt to a landlord put the debtor into a state of servitude, and tiny wages and excessive expenses kept them there. Day labourers on coastal Ecuadorian cacao plantations made on average 6/10 of a peso per day in the 1830s (Chiriboga 2013:34). This was a very low wage, and thus the conciertaje system became intertwined with laws against vagrancy enforced by the Policía Rural, to ensure that workers stayed on the plantations (Chiriboga 2013:34). Technically this was a simple debt peonage relationship, but through race relations, the illiteracy of workers, coercion, and violence, concierto relationships were often without written contract, had no clear time or work limits, and were based more on coercion, and the threat of debt imprisonment or violence on the part of the landowner, than on any real written labour contract with clear legal limits (Foote 2004:46-48).

This began to change with the Ley de Indígenas of the Urbina government in 1854. This made concierto labourers more legally mobile, while at the same time maintaining the system of criminal arrest for unpaid debts. The key change that this law brought in was to allow debt peons to legally move to a new estate if their debt to the old landlord was paid, freeing them from a system which had kept them from moving for the duration of multi-year labour contracts, even if they were not indebted to their employer. One of the major results of this change in the 1860s and 1870s was the increasing flow of debt peons from southern highland haciendas to coastal regions where cacao and
sugar operations could offer them better wage and working conditions, or at least the promise of those things (Williams 2003:715). Liberal coastal landowners were the beneficiaries of this new freedom.

Workers were attracted by coastal landowners through the process of *enganche* ("hooking") the workers; this involved payment either directly to highland hacienda owners, or to middlemen, who then offered cash advances to pay off the church, state, or private debts of peons on the highland haciendas. The money could also go to pay for feasts, land purchases, or other community obligations of these highland workers. Once cash was advanced, the peon’s debts were transferred to the coastal plantation owner, and the worker was obligated to move to the coast to work to pay it off, creating flow of labour from highlands to coast (Chiriboga 2013:193). By 1900 coastal daily agricultural wages had risen to between 80 centavos and $1.50 (Chiriboga 2013:220).

In 1885 Ecuador created the *Ley de Regimen de Galápagos* (The Galapagos Act), which provided benefits to colonizers such as 5 years of tax exemption, free land, exemption from military service, and the ability to import goods to the Galapagos without paying duties. These rules did attract colonizers, some of whom brought enough capital to create independent agricultural smallholdings; others came as indentured labourers for Cobos in hopes of eventually being able to buy their own land. By 1889 there were 287 people living at *El Progreso*. These workers were from several mainland regions with different backgrounds. Among them were foreign and undocumented workers from Colombia and Peru. The census of 188926 showed six Colombians, five Peruvians, four Mexicans, one Chinese, and three Norwegian workers (technicians for the sugar mill) living at *El Progreso*. A number of these people were free labourers, who saw the opportunity of getting land and work on the Islands. An important number of the workers were, however, convicts and indigents from the mainland; specially from the main port city of Guayaquil.

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26 Archivo Nacional del Ecuador (Quito), 31 de marzo de 1889,. Informe y censo del jefe Territorial.
5.5. Crime and Labour

In the late 18th century the city of Quito was the second largest in what is now Ecuador. There were three jails: the Cabildo (city council), the Audiencia (region), and the women’s (Recogimiento of Santa Marta). The number of people annually detained in them ranged from about 300 to 500 in total, and these numbers were evenly split between men and women (Black 2011:80). The idea of such detentions was different from that of the penitentiary – these were buildings for securely holding people awaiting trial, or awaiting punishment. In late 18th and early 19th century, Quito and Guayaquil criminal punishment could be several things other than jail, including banishment from the city, or a sentence of several years’ labour, whether in the Royal Tobacco Factory (which existed in both cities), or, for men, the Navy. Whipping and execution were the final recourse for serious crimes (Black 2011:110-120).

In the 1830s, as Ecuador became an independent republic, ideas about crime and punishment began to change. This reflected a widespread Latin American change, in which growing labour mobility, and capitalist wage labour, made the authorities nervous. Those who were criminal, or simply idle (vago), rowdy, or immoral (vicioso) could find themselves brought in by the police. A wide range of punishments, or forms of social control, could then be implemented, including drafting into the military, labour gangs for public works, or being assigned as a labourer on a private plantation (Ruggiero 2004; Schaefer 2014) (Ruggiero 2004; Schaefer 2014). Exile, or banishment, to an agricultural colony on the frontier was another common fate.

There was a clear racial element to the Galápagos penal colonies, as evidenced by the account of John Coulter, the surgeon on the English ship Stratford, who visited Villamil’s Asilo de la Paz colony in 1833. Coulter emphasized race in his description, calling the settlement “a set of sanguinary black Spaniards;” “his sable subjects;” and Villamil’s appointed magistrates as “being nearly as black as a coal, and without either shoe or stocking” (Coulter 1845:53-56). He described Villamil organizing evening entertainments in which a drum, guitar and fifes would play music, a few of the workers would dance a “fandango” for them, and Villamil would sit and watch (Coulter 1845:56-57). Although the racial make-up of the colony is not made specific, it would seem that
most of the workers were Afro-Ecuadorians, or others whose dark skin colour differentiated them from the white elite.

The Galápagos agricultural colonies were tied into the labour market in Guayaquil – the coastal port that supplied the islands. With a growing urban population, the manumission of enslaved Ecuadorians in 1851, and increasing labour mobility as cacao plantations boomed, coastal Ecuador’s view of vagrancy, idleness, and poverty was changing. The 1847 Guayaquil Reglamento de Policía (Police Regulations) stated that anyone without land, or a profession, could be rounded up and jailed, and should be returned to their previous landowner as a concierto. These regulations were mirrored in the Guayaquil Ley de Régimen Municipal (Municipal Regulations) of 1863, which obligated the Rural Police to regulate servants, apprentices, and jornaleros, ensuring they were not vagrant, and ensuring that those deemed vagrants were returned to the property they were attached to.

In sum, in the second half of the 19th century on the Ecuadorian coast any man without his own employment or home was subject to vagrancy laws, as were women found to be immoral, or without a proper home. The men could be assigned to public works, such as road building, put into concertaje at a local plantation, or sent as colonos conciertos to build new roads in areas of coastal forest being cleared for agriculture. Women, although not sent to field labour, construction, or military labour, could be put into a house of reform, or sent to a private home to become a servant (Chiriboga 2013:35, 113-115; Clark 1998:47).

By 1890 criminal convictions in Guayaquil had reached 8000 men and 1000 women annually (Pineo 1996:84). Many were young, single men, picked up for petty theft or vagrancy. At the turn of the 20th century the Guayaquil jail housed only petty criminals, as serious offenders were sent to the national prison in Quito. The Guayaquil jail was described as overcrowded and filthy; prisoners were not fed, but received 10 cents per day to feed themselves; unless family brought food, they had to beg the guards for scraps (Pineo 1996:82). The combination of an overcrowded municipal jail, and overwhelming numbers of convictions, led police chief R.T. Caamaño to advocate for 3-5 year exile of “habitual drunks and vagrants” to the Galapagos (Pineo 1996:85).
At this date, the only location these exiles could have been sent was *El Progreso* plantation.

It is evident that the *El Progreso* administration used criminals as cheap labour, and thus the colony was, in some sense, a penal institution. Nicolas Vidal in 1894 described the inhabitants of El Progreso as “…people mostly relegated from Ecuador, for various offenses, which are used in the farm and who are paid with little wages and food provided by Mr. Cobos” (Vidal 1890). Latorre (1991:54) proposes the existence of a secret agreement between the Cobos-Monroy company and local officers and police authorities to send convicts to Galápagos. Little documentation for this exists, and the civil authorities at *El Progreso* constantly complained of the lack of documentation for criminals transported to Chatham in the 1880s. The cases of Rosa Terán, Aurelio Pérez, Pedro Negrete, Marcelino Tapia, Narciso Cadena, and Adolfo Rojas are described by Latorre (1991:55). Another important piece of evidence that unofficial exile of undesirables was happening is that when the commission sent to investigate Cobos’ murder arrived in Galapagos in 1904, they mention the existence of thirty offenders being deported to Albermale island in the government ship *Cotopaxi* (El Telegrafo 1904:117).

5.6. The Plantation Frontiers of 19th century Ecuador

The plantation has been an integral part of both the expansion of European colonies globally, and the expansion of state power into new territory. Involving both the modification of the environment to suit the requirements of capitalist agricultural commodity production, and the explicit control over the agency and mobility of a labour force, the plantation has been a key part of the expansion of capitalism into new territories (Duncan et al. 1977; Meniketti 2015; Mintz 1985). In 19th century Ecuador cacao and rubber were the commodities that changed the tropical forest landscape.

Two main strategies were applied in incorporating Ecuador into globalized markets in the 19th century. First, the existing large haciendas on the coast and in the highlands were improved with technology to support monocrops. Second, agricultural zones were expanded through colonization of previously ‘unoccupied’ territories or
frontiers. Thousands of hectares of tropical forest were deforested for installing monocrop plantations. McCook (2002:28) has proposed two phases for cacao production in Ecuador. From the late 18th century to about 1890 the first large plantations were created. When cacao exports began, Ecuador was still under Spanish control, and thus cacao sales were limited by mercantilist policies.

With Ecuadorian independence, free market capitalism entered the picture, and by 1887 Ecuador was the global leader in cacao production. At the end of the 19th century large pieces of land around the Gulf of Guayaquil and the Guayas basin were converted to cacao agriculture. Most of the cacao exported was produced on large private plantations or as Bromley defined them, semi-feudal estates (Bromley 1981:20). The production was focused on a local variety called national, cultivated using traditional methods. By the mid-nineteenth century the main cultivated zones were in the modern provinces of Guayas and Los Ríos and around the alluvial zones of the Guayas basin. Cacao cultivation spread north and east from the Guayaquil area to Babahoyo, Vinces and Catarama, and the expansion of cultivation over the southern and central Guayas Basin continued until the 1920s (Bromley 1981). By 1923 about 95 million cacao trees were planted in coastal Ecuador, occupying about 85000 hectares. In the 1920s the expansion of agricultural zones and the introduction of non-native varieties caused the appearance of plagues triggering the crisis and collapse of this business. After the collapse of cacao production in Ecuador many plantations were subdivided or abandoned (McCook 2002:234).

On the other side of the Andes, in Amazonia, the Ecuadorian government officially created the Region Oriental (Eastern Region) in 1879. Quinine trees, gold, and tagua nuts were all targets of late 19th century commercial extraction, but it was rubber trees which turned the region into an infamously exploitative zone, beyond the law of state governance over labour relations. With the Liberal government of Eloy Alfaro road-building also expanded the settled farming zones of the region, colonized by diverse groups of people from Guayaquil, Manabí, and the Andean highlands (Bromley 1981; Wasserstrom 2014).

During the rubber boom (1885-1930) labour was arranged in a variety of ways, from armed violence to unequal and/or semi voluntary trade relations. The rubber
business in the Upper Amazon was based on local indigenous labourers, who were put into debt relations with rubber collectors through “gifts” of trade goods, such as machetes, clothes, and blankets. With little government control in this tropical forest frontier, debt peonage merged with kidnapping and illegal slavery, as many indigenous people were taken from the region to work in denser rubber zones in Colombia and Peru (Muratorio 1998; Taussig 1986; Wasserstrom 2014).

Thus, at the time Manuel J. Cobos and José Monroy set up their sugar operation on the Galápagos, Ecuador had two other plantation frontiers – the cacao zone on the coast, and the rubber zone in the Upper Amazon. Each had its own version of labour relations, extractive technologies, and economics. The Cobos-Monroy enterprise had strong ties to Guayaquil, and must have based their operation partly on knowledge gained from the experience of plantation owners on the south coast, but their operation was different, mostly because of its location.

5.7. Prison Islands

Rikers Island. Elba. Alcatraz. New Caledonia. Devil’s Island. Tasmania. Islands have been used by societies to abandon, exile, or warehouse those deemed unworthy for a very long time. In the 19th and 20th centuries they have been used to detain migrants, criminals, the mentally ill, and a host of others, using the islands’ ambiguous sovereign status and geographic remoteness to allow the state to do things to people they would not otherwise do. The geography of the frontier could be used to hide, or minimize, societal problems, people, and practices. These were remote places, but the common dynamic of island exile has been an important part of how many states operate (Mountz 2011). In a seminal contribution, Peter Redfield (2005) discusses Foucault’s panopticon, and its relationship to British transportation to Australia, and French transportation to French Guiana, as alternate ways of seeing punishment. “Transportation”, or exile, to a remote location allowed a spatial change to change the prisoner, as opposed to the constant monitoring of the panopticon doing that job. Unfortunately, as Redfield lays out, this mixing of punishment, redemption, and frontier settlement is in many senses a failure of modernity.
In Latin America, the exile of criminals to islands, and the creation of both agricultural colonies, and panoptic prisons, in remote island locations, was an important part of the carceral technologies of the state from the independence period through to the mid-20th century, but with widely varying policies, geographies, and results. From 1822-1899 the island of Fernando de Noronha in Brazil was an agricultural penal colony with convicts who came from all over the Brazilian Empire, with 1500 “inmates” by the 1870s. This was a large operation run by military officers. The main town on the island had a village with government buildings, and a large aldeia, or barracks, where many of the criminals slept in “cells”. Many convicts, however, also lived outside the aldeia, in huts they built themselves (Beattie 2015).

In the former colonies of Spain prison islands were also common in the 19th century. In 1830 Santa Cruz, one of the Channel Islands off Santa Barbara in Alta California, briefly became a penal colony when an American ship captain contracted to deliver criminals to the Alta California frontier dumped them on the island. They only survived a few years before building rafts and escaping (Gherini et al. 2015:44). In Costa Rica, the islands of San Lucas (in Nicoya Bay) and Coco (500 km offshore in the Pacific) both became penal colonies for serious offenders in the 1870s (Palmer 1996). From the 1860s to 1880s Argentina created a prison colony in Ushuaia, in the remote southern region of Tierra del Fuego. The colony was intended to purge Buenos Aires of delinquents while the prisoners’ souls would be purified by an exile at a remote frontier 2500 km from the capital (Edwards 2014; García Basalo 1988). The Juan Fernández Islands, 700 km off the coast of Chile, have a very similar history, having had small human settlements since the 16th century, but a formal colonization process that began in 1749. Convicts, as well as free labourers, were transported here, but in the 1850s the government of Chile recognized the corruption and brutality of the colony, and stopped the transportation of prisoners to the islands (Orellano 1975; Woodward 1969).

The 1000 km that separates San Cristobal Island from the mainland created a strong feeling of isolation. During the late 19th century, Cobos owned two sailing ships, the Manuel J. Cobos and the Josefina Cobos, which were the only regular form of transportation between Guayaquil and the Galápagos Archipelago. The sporadic visits of the government steamer Cotopaxi meant that everyone, including the territorial governor, was dependant on Cobos for transport on or off the archipelago. (Martinez
This isolation is interesting to consider when framing Cobos’ operation as a plantation worked by debt peons. In the late 19th century in Latin America debt peons who worked on agricultural operations within a day’s walk of their home often left on weekends, going home to see family, tend their own fields and animals, and to participate in the social life of their community of origin. Those in more remote locations were completely dependent on the plantation owner, but also formed stronger bonds with other workers on the plantation. In the early 20th century labour reform demands from radicalized workers in Latin American agriculture often came from these more remote places (Carnes 2014:98).

The Galápagos islands in the late 19th century were both prison islands and a remote agricultural frontier for the expanding Ecuadorian state. The Cobos-Monroy operation was the manifestation of this combination. The plantation frontier in 19th century Ecuador was tied to areas accessible to national and international markets, whether by road, river, or ocean. Government programs to settle people on such frontiers were much less important than large operations where private citizens created commodity plantations largely beyond government control. Effective control over Ecuadorian state territory was thus expanded based on extractive plantations looking for the best soils, water, and transport to markets (Bromley 1981: 25). Cobos’ El Progreso plantation was different from this. Government control, and his access to markets, were challenged by the 1000 km of water between El Progreso and Guayaquil. Such distance also meant he had dictatorial control over the territory in, and surrounding, his plantation in a way that magnified the usual patriarchal role of the patron or hacendado in Ecuadorian 19th century agriculture. This emphasized Curtin’s (1990: 11-13) third criterion for defining the plantation – a lack of strong government control over the activities on the property.

From Cobos’ first orchilla harvests on the Galapagos in the 1860s, up until the time he began setting up a plantation agricultural system at El Progreso, the government of Ecuador had very little presence in the Galápagos. It was once Cobos’ operation began to grow in size that the government took more notice. In 1885 Ecuador brought in the Ley de Régimen del Archipiélago de Galapagos, which created the title of Jefe Territorial (the sheriff), and a system of perks for people choosing to settle in the archipelago (Bognoly and Espinosa 1905:67). A small lighthouse was delivered to
Puerto Chico (the port for Cobos' operation, now Puerto Baquerizo Moreno), and in 1886 a government building was built for the offices of the Territorial government (Bognoly and Espinosa 1905:67-69).

5.8. Authority and Architecture at *El Progreso*

The fourth of Curtin's (1998:11-13) plantation characteristics was the maintenance of “feudal” features, with planters controlling labourers both during and outside of regular working hours. The architecture of *El Progreso* included, most prominently, Cobos’ house (Figure 21), located on a hill in the centre of the property, with balconies and a central watchtower to allow his gaze to rest on most of the nearby plantation operations without ever leaving his home (Browne 2015; Delle 2014; Epperson 1990). Manuel J. Cobos moved to San Cristobal Island in 1879. He was married to Adelaida Monroy, the sister of his business partner, and they had two children, Josefina and Manuel Julian (Latorre 1991:144).

Contemporary photographs show that workers lived in a village downslope from Cobos’ house to the NE, in huts made of wooden or bamboo frames, woven walls, and thatched roofs (Figure 25). The atmosphere seems entirely unlike a prison, with huts in rough rows along “streets”, completely enclosed. There would have been little opportunity for overseers, or Cobos, to see what workers were doing inside the huts. The worker's housing at *La Clementina* cacao plantation on the coast of Ecuador in 1907 looks very similar to the architecture of the *El Progreso* worker housing (frames, wattle and daub, thatch) (Chiriboga 2013:187). Social control seems more obvious outside of their homes, where Cobos and his *majordomos* were armed with repeating rifles and pistols, and Cobos was the only source of material goods, transport, or assistance for the workers, with the remoteness of the island serving as an effective barrier to escape. The worker's housing of El Progreso looks very similar to the housing on cacao plantations on the Ecuadorian coast in this time period, both in architecture and layout (Chiriboga 2013:187).
If Cobos’ investment in material goods and architecture at the *El Progreso* operation were any indication, this was a plantation rather than a prison. The architectural arrangement mirrors many classic plantations and haciendas in Latin America (Figure 22). There is little attempt at a panoptic architecture of social control, and instead, money, effort and foreign employees were used to create one of the most modern steam-powered sugar milling operations on the Pacific coast of South America.

One important aspect of Cobos’ control over the workers at *El Progreso* was the company store, or *tienda*. This was described as carrying “everything people might
need,” including wine, liquor, and preserves (Martinez 1915:39). Cobos controlled all goods being shipped to or from the island, so his monopoly over sales of consumer goods and foodstuffs to his workers was complete. Company stores were a common aspect of plantations under debt peonage in Latin America, but were more effective if the plantation was in a remote location. If workers could easily walk to other stores, they would often take advantage of that access, whereas in remote locations the plantation owner had to provide access to goods for workers, and could take advantage of this situation to create a monopoly (Carnes 2014:98).

Figure 22 “Plantation Chatham Island.” The worker’s village at El Progreso in 1888, viewed from the balcony of Cobos’ house (National Archives photo no. 22-FA-88).
Cobos used a variety of fichas, or tokens, at his store over the period of El Progreso’s operation. He is reputed to have used leather fichas, and illustrations exist of paper scrip, lead tokens, and vulcanite tokens with values of 5 and 20 cents (El Telegrafo 1904:142). We have also recovered examples of the vulcanite tokens archaeologically (Figure 23). Although often described as a system to ensure workers did not take their purchasing power elsewhere, this seems unlikely in Cobos’ case. The plantation’s store was the only place to buy anything on the island. Instead, it seems likely that these tokens served a practical purpose, allowing small “cash” transactions in an economy where national coinage may not have been easily available. Company stores were common on Peruvian and Ecuadorian plantations in this time period, but there is no mention of the use of scrip/fichas/tokens for payment (Chiriboga 2013; Gonzales 1985). Presumably workers on these operations were simply given store credit through recording debts in an account book. Not so far away, however, companies running remote Chilean nitrate mining operations used tokens extensively (Calvo 2009). They were also common in this period in agricultural plantations in other parts of Latin America (Romano 1998; Rulau 2000). Did Cobos see the use of tokens as a “modern,” practice, putting El Progreso on a par with other globalizing commodity producers?
Figure 23 Black vulcanite 5 centavos tokens used at El Progreso plantation during the late 19th century (photo by the authors, 2014).

5.9. Modernity

The agricultural penal colonies on the Galápagos are an example of the type of prison colony that embodies a failed modernity (Redfield 2005). The colonization of the Galápagos took place in the same time frame as the birth of the modern penitentiary system in Latin America. The earliest Latin American penitentiary is generally taken to be the Casa de Correção in Rio de Janeiro, which was completed in 1834. Designed to make prisons more healthful and humane, and designed for rehabilitation, these large-scale structures began to be built in major cities across the region over the next century (Salvatore and Aguirre 1996:3). In many regions of Latin America agricultural penal colonies were seen not to be working, in the sense that they did not produce
agriculturally, and therefore lost money. Instead, the urban panoptic penitentiary was taken on as a new global ideal in the management of criminals (Palmer 1996:232).

The first penitentiary in Ecuador was built in Quito under Gabriel García Moreno, and was completed in 1874. Its panoptic design, with the walls of cells painted black, and a rule of silence for inmates at all times, mixed ideas of reform and terror (Argüello 1991; Salvatore and Aguirre 1996:35). In Guayaquil, which was a growing city and the source of many of Cobos' colonists, a modern penitentiary, the Carcel Municipal de Guayaquil, was begun in 1886, and was still under construction in 1896 when partially destroyed in a fire that consumed the city. Work continued until it finally opened in 1907, four years after Cobos' death. It served as the main prison for Guayaquil until 1950 (Baleato 1983:53-54; Sánchez 2007). The jail that it replaced housed only petty criminals, as serious offenders were sent to the national prison in Quito from the 1870s up to 1907.

The final two criteria in defining a plantation system, according to Curtin (1998:11-13), are the production of crops at a large scale, and the export of most of this production. El Progreso fulfilled these criteria. The highland agricultural zone produced a wide variety of fruits and vegetables, for local consumption and to supply passing ships. The main economic engines of the operation were, however, sugar and coffee for commodity export. In 1900, 80% of sugar production in Ecuador was from 7 mills surrounding the town of Yaguachi, just across the river from the city of Guayaquil (Pineo 1996:11). Ecuadorian sugar, as an export product, was dwarfed by cacao in this period. The Cobos-Monroy operation in Galápagos was, however, an important contributor to these sugar exports. It has been estimated that at its peak El Progreso produced 500 tons of sugar annually, along with cane alcohol, rum, and coffee from 100,000 coffee trees (Mann 1909:29).

Directly below Cobos' house, on a terrace to the west, was the ingenio (sugar mill). A complex of wood framed buildings, with walls of cane matting and corrugated tin roofs, housed Cobos' greatest investment in modernity – sugar milling equipment from around the world. A visitor a couple of years after Cobos' death described the sugar mill: "The machinery is principally of Glasgow manufacture and quite up-to-date, there being a large cane mill, triple effects, vacuum pan, centrifugal separators, and a number
of other accessories” (Mann 1909:29). Our survey of remaining Cobos artefacts in private collections on the island has revealed marked industrial objects from McOnie, Harvey and Co. of Glasgow (the triple effects separator), a steam boiler marked “The Walsh and Weidner Boiler Co., Chattanooga, Tennessee” and a cane crushing mill from the George L. Squier Company of Buffalo, New York. The milling operation included a system of movable Decauville railway tracks and cars imported from France, to move cane more efficiently from the fields to the mill. Thus Cobos’ operation, far from being an example of a penitentiary, was in fact one of the most modern industrialized plantations in Ecuador while in operation.

5.10. Discipline and Punish: The Death of Cobos

On February 15, 1904 Manuel J. Cobos was shot and killed by his own workers, along with the territorial sheriff, Leonardo Reina. Newspaper reports stated that since the founding of El Progreso there had been rumours that Cobos thought of himself as a feudal lord, whipping, torturing and shooting the criminals sent there at his own whim. The workers reported that Cobos had put a Colombian worker in the hacienda jail overnight, and threatened to whip him 500 times the next day. In the morning, a majordomo, Elias Puertas, asked Cobos if he would really go through with the punishment, and when Cobos affirmed this, Puertas shot him three times with a revolver. Cobos was injured but dragged himself to get his Mauser rifle, and fired on the crowd of workers assembled below his balcony. He then fell into the crowd, who beat him to death. Others had already shot Reina (El Comercio, Lima, March 5, 1904, p.1). Immediately after Cobos’ murder, the company stores were ransacked, and all the account books and ledgers were burned. A large group of workers then took the company boat and escaped to the mainland, where they were arrested and stood trial (Latorre 2002).

Was Cobos a tyrant? In their declaration letter of 1904 the rebel workers recounted a history of Cobos’ tyranny. They claimed that he had had six workers shot, six workers had died after being whipped excessively, and 15 had been exiled to desert islands in the archipelago to await certain death (El Telégrafo 1904). There were
numerous reports of rape, and coercive sexual relations with female workers by Cobos and his *majordomos*, but the authorities seemed never to respond (Latorre 1991:50-62). Sheriff Pedro Jaramillo, when first assigned to the colony, requested more state and police presence to reduce and stop internal social conflict, violence, and the despotism of Cobos. This seemed an endless refrain, as Sheriff Juan Piño again denounced the “monopoly and authoritarianism” in *El Progreso* in 1904, its last year of operation (El Telégrafo 1904; Latorre 1991). During the 1904 trial the workers repeated the claim that local authorities were completely dependent on Cobos’ authority, and thus felt free to break both local and national law (El Telégrafo 1904:113). The cases of two workers, Geronimo Beltran and Manuel Olaya, were highlighted during the trial. As mentioned, the Hacienda controlled transportation and communication between the island and the continent; therefore, local civil authorities were subject to Cobos’ conditions.

Cobos’ death was part of a pattern on the isolated agricultural penal colonies on Galápagos. In 1841 the *Asilo de la Paz* workers revolted against the tyranny of José Williams, their brutal leader, beating him with sticks and machetes until he fled the colony in a company boat (Parks and Rippy 1940:38). In 1878 Lucas Alvarado and a gang of other convict workers on Santa Maria Island stabbed the colony’s leader, José Valdizán, to death. Loyal workers then killed all the rebels and abandoned the colony (Epler 2013:93).

Cobos had thrown the Colombian worker in to the *El Progreso* jail overnight. The presence of a jail on the property blurs the line further between plantation and prison. Many plantations in the 19th century New World had small jails, or holding cells, for their workers, and certainly not just in cases of plantations using criminal labourers (Birch and Buchanan 2013), whether in South Carolina (Hollis and Stokes 2012), the Yucatan (Wells and Joseph 1996:258), Peru (Gonzales 1991:69) or elsewhere. At Villamil’s *Asilo de la Paz* settlement on Floreana in the 1840s behind his house was “a natural cave of about twenty feet long, with an entrance of about eight feet high. To this entrance, a strong door, or, more properly speaking, gate, well secured, was fitted; this was the jail” (Coulter 1845:55-56). Elizabeth Newman (2014) has documented the correspondence between hacienda owners and the government in Puebla, Mexico, in the first half of the 19th century. Admitting they already had jails on their property, the landowners in the first half of the 19th century formally got permission from the government to continue their
practice of jailing indigenous tribute and debt workers who refused to work on the haciendas, in order to force them to remain on the property and not go home to tend their own fields.

On Peruvian sugar plantations in the 1870s and 1880s the labour force was almost entirely indentured Chinese. Each estate had a jail, and some workers were locked up for several years in these jails. More common were whippings, and in the case of murder, execution of the killer, usually by gunshot. The political instability of Peru in the late 19th century meant plantation owners relied on their own majordomos for law enforcement, whereas after 1890 they began to turn more towards police, reporting crimes and allowing the state to apprehend and punish (Gonzales 1985:106-111). What happened to Cobos was not, however, common. In Peru in the 1870s and 1880s there is one recorded case of a sugar plantation owner being killed by his workers. He was beaten to death in his house with agricultural tools by workers pushed over the edge by his repeated harsh corporal punishments (Gonzales 1985:111).

The El Progreso plantation existed at a time when relations between plantation owners and workers were changing in Ecuador. This had begun with the Urbina Ley de Indígenas of 1854. Rather than assuming that the goals of landlords were necessarily the same as the goals of the state, the Urbina government began to take seriously the idea that landlords could be abusive, and debt peons, rather than being seen as in perpetual servitude to the landlord, instead could end a contract if their debt was paid and they found the situation abusive (Williams 2003:708).

In the 1880s on the Ecuadorian coast montonera militias began to form, including both small landholders and debt peons, agitating for changes in the law and their lives. Worries of revolution began (Chiriboga 2013:132). In the late 19th century the vote was restricted to males with property, who were literate, and not dependant on anyone (Carnes 2014:100). These explicit or implicit voting restrictions did not begin to change until the early 20th century, when suffrage for workers resulted in the emergence of the first modern labour laws in Latin America, many of them applying to agricultural peons (Carnes 2014:100).
5.11. Conclusions

Landowners, *hacendados*, and slave owners had been the powerful class in Latin America since before independence from Spain, and continued to be into the 20th century. In the late 19th century they saw their personal ability to jail, whip, or execute workers as a key right, maintaining both class and racial order. Police agencies in Latin America agreed with this social order, and would often send, or return, escaped workers, as well as orphans, delinquents, the mentally ill, and other undesirable classes to a nearby private landowner to “take care” of the “problem” (Salvatore and Aguirre 1996:16). The opposite was also true, however. The workers on Andean haciendas saw the patriarchal role of the *hacendado* as a role of responsibility to be fair and just, rather than corrupt and abusive. If abuses grew large enough the *hacendado* risked death at the hands of his own workers (Langer 1990).

The agricultural penal colony was a variation on this theme. The idea of many Republican-era Liberal regimes in Latin America was that frontier zones could not be colonized because of rural labour shortages. Thus, if the government could give land grants with a source of labour guaranteed, the nation would benefit. Anyone seen as problematic by agents of the state could be rounded up and sent to these zones. The rural work would rehabilitate them, teach them the value of daily routines, and in the end the government would grant them small plots of land as *colonos* to live out their lives (Palmer 1996:231). Republican governments throughout Latin America saw agricultural penal colonies as a way of bringing wild frontier lands into agricultural production, and establishing sovereignty in zones previously without a government presence (Rausch 2002; Palmer 1996).

In industrialized nations, the panoptic penitentiary was taken on in the early 19th century, a reflection of a reform ethic that intended to create disciplined subjects appropriate to work in an emerging industrialized factory economy (Melossi and Pavarini 1981). In Latin America, the situation was different. Cobos’ operation at *El Progreso* embodied the modern 19th century Latin American export commodity agricultural zone, with the latest in industrial equipment. At the same time, it reflected an enduring Latin American idea of sending criminals to the frontier to become reformed, both through
exposure to rural work, and exposure to the firm hand of the *patron*, the patriarchal private landowner who knew best how to handle the broken, the intransigent, and the racially suspect.
Chapter 6. Synthesis and Discussion

In this dissertation, I have presented the results of paleoethnobotanical research at El Progreso plantation, Galápagos. The results demonstrate the ecological impacts of colonization on the highlands of San Cristóbal Island during the late 19th century. Several aspects of the relationship between people and plants have been revealed including deforestation, the use of native and endemic plants, plant introductions, local ecological dynamics, the perception of nature by the initial colonizers, and some insights into the conflictive landscape of El Progreso plantation and the socio-political context of Ecuador during the late 19th century.

This study offers methodological contributions to the field of Environmental Historical Archaeology in South America and on island ecosystems. In this work, I have reviewed historical information and added original environmental data to our understanding of past perceptions of landscapes in 19th century Ecuador. The incorporation of environmental variables in the exploration of colonization contributes to our understanding of the repercussions of first human activities in unoccupied spaces. The addition of biological data to the study of the recent past opens up the possibility of understanding social landscapes in a holistic perspective. This involves combining the analysis of written records, the socio-political context, and the physical properties of historical locations as an appropriate approach to study the human colonization of the Galápagos Islands.

This research shows that the use and application of an archaeobotanical framework is a suitable method for investigating human-environment relationships in the recent past. I have presented what I believe are the main contributions of paleoethnobotany in investigating colonization of islands. The combination of an archaeological framework with environmental/biological data in the exploration of power structures, gender relationships, and inequality were used to investigate colonial socio-political structures.
The isolation of the Galapagos Islands provided an ideal scenario to study initial anthropogenic effects over nature from both physical and ideological perspectives. The multidisciplinary nature of this work contributes to our understanding of the introduction of Eurasian crops to a previously unpopulated landscape, and to obtain insights into 19th century worldview; specifically, the adoption of the ideology of capitalism and the concomitant perceptions of place and space during the Republican Era in Ecuador.

6.1. Main Contributions

First, the phytolith results exposed general characteristics of the native vegetation that existed on San Cristóbal Island prior to human arrival in the 1860s. The analysis of the local soil phytolith assemblage and the signatures of tree cover index suggest the existence of a forested landscape in the Scalesia zone before human arrival that was transformed by the colonizers into open landscapes covered by grasses. The results suggest deforestation soon after colonization resulting from the expansion of agriculture on the El Progreso plantation. Deforestation and expansion of grasslands were probably associated with grazing activities. The change in local landscape is evident in the high concentrations of grass phytoliths in the landscape after human arrival, due to the introduction of grass species. The local soil phytolith assemblages also demonstrate the use of sugarcane stems as a fuel source for the steam-powered mill and the introduction of edible and ornamental plants such as bananas and palms.

The analysis of phytoliths in the modern plants of San Cristóbal do not show significant numbers of diagnostic morphotypes of native and endemic plant species. This fact limited the interpretation of the soil phytolith record to defining the spectrum of plant species used by humans during the first years of colonization. The use of phytoliths as a paleoenvironmental proxy has proved limited in exploring details of the native vegetation of the highlands of San Cristóbal Island. Further work will contribute to understanding the complete spectrum of phytolith production in the native and endemic vegetation of the Island. The comparative collection presented here was limited to detecting the production of phytoliths in useful plants for humans. In this regard, some of the unidentified phytoliths could be from species for which we do not yet have comparative samples.
Second, the analysis of wood charcoal shows the first archaeological evidence of the use of native plant taxa during the operational years of the El Progreso plantation. Three important native plant species are present in the archaeological record: *Pisidia carthagenensis* (Matazarno), *Piscidum galapageium* (Guayabillo), and *Scalesia pedunculata*; these suggest the use of native wood species as sources of timber, firewood, and construction materials since the 1860s. The charcoal assemblage also shows the use of three wood species introduced to the island: *Bambusa* sp. (Bamboo), *Pinus* sp. (Pine), and *Quercus* (Oak); which indicate either the existence of this taxa in the island or the use of objects created with these wood species. Historic photographs indicate the use of bamboo as an important source of construction material.

The analysis of wood charcoal was limited to the wood fragments found in the archaeological midden associated with the main house of the plantation. In this regard, the wood charcoal assemblage does not represent the entire spectrum of wood use by the first colonizers of San Cristobal Island; it only shows the use of wood in the administrative centre of the plantation. Future research will include the analysis of wood charcoal in other contexts such as the worker’s houses, the pier area, and former agricultural parcels. Unfortunately, access was not permitted to the land where the remains of the mill are located, which limited the interpretations of the use of wood in the industrial zone of the plantation.

Third, the macroremains provide some insights into plant consumption starting in the 1860s in El Progreso. The analysis of charred seeds shows the consumption of introduced plant species to the Galápagos Islands. The record shows the existence of one stable crop: corn (*Zea mays*). Other Andean grains and legumes such as lentil (*Lens culinaris*) and the common bean (*Phaseolus vulgaris*) have also been found. The tropical fruits guava (*Pscidium guajava*) and the ice cream bean tree (*Inga edulis*); and seeds of the weed *Sida* sp., were also found in the charred seed assemblage.

Once again, the charred seeds analyzed were found in contexts associated with the archaeological midden of El Progreso, which is not evidence of plant consumption in domestic contexts such as the workers’ houses, the common saloon, or the port. Future research could incorporate the macroremains after excavation of domestic contexts.
Fourth, the social landscapes of El Progreso were also discussed in this dissertation. One of the aims of this work was answering one question about El Progreso, what was it? It is not evident if Cobo’s organization was a Hacienda or a modern industrial-scale plantation. The discussion regarding the main differences between the colonial Spanish Hacienda and the modern plantation has been of interest since the late 1950s. Wolf and Mintz (1957:380), presented broad descriptions in order to define these two types of social organization and production systems: “Hacienda is an agricultural estate, operated by a dominant land-owner and a dependent labour force, organized to supply a small-scale market by means of scarce capital, in which the factors of production are employed not only for capital accumulation but also to support the status aspirations of the owner. On the other side, a plantation stand for an agricultural estate, operated by dominant owners (usually organized into a corporation) and a dependent labor force, organized to supply a large-scale market by means of abundant capital, in which the factors of production are employed primarily to further capital accumulation without reference to the status needs of the owner”.

The archaeology of plantations includes the investigation of internal social configurations. It is normally accepted that capitalism has been a central theme in the archaeology of plantations (Bell 2005, Delle 1998). Plantations were fundamentally part of an economic formation which always already precedes that of industrial capitalism. As Mintz (1985) has pointed out, plantations are bound up with the development of capitalism, seen to be the forerunner of modernity. The development of plantation systems is deeply embedded within specific colonial histories, highlighting the intertwined nature of the plantation with contexts of colonial rule (Croucher 2014).

Considering the political context of post-independent Ecuador created around the idea of liberalism, it seems that the El Progreso operation was a plantation organization; especially, considering Curtin’s six categories to define the plantation (Curtin 1998). However, it is evident that El Progreso was more complex than that. El Progreso enterprise was in operation during the transition years between a mercantilist economy dependent Spain and the autonomous economies of the recently formed republics in South America. Ecuador, during the late 19th century was dealing with new ideas of progress and industrialization to build the new nation but at the same time keeping the power relationships and the labor systems formed during the colonial Spanish era. In
addition, debt caused by the wars of independence wars shaped the economy for decades after the 1830s.

Given these factors, the lack of state control in the Galápagos and the logic of preserving the traditional power dynamics between races, producers, and labor; El Progreso appears as a hybrid production system between a Hacienda and a plantation. This local agricultural operation was thus in a transitional time between a production system focused on power relationships and social control, and a Republican emphasis on producing tropical commodities for the global market with the exploitation of natural resources from national frontiers.

According to the primary and secondary sources investigated here, it is evident that a capitalist ideology shaped the social landscape of El Progreso during the Cobos-Monroy administration (1870-1904), and was also what brought social conflict. It seems that the internal social conflict in the plantation was the result of a combination of factors such as authoritarianism, strict social control, geographical isolation, and the background of the workers with the final goal of maintaining a profit oriented business to contribute to the new global markets of Pacific south America.

This combination of factors combined with the isolation of San Cristóbal Island created the social landscapes of El Progreso. I believe that El Progreso plantation was a “de facto” prison; a hybrid system that combined the main precepts of capitalist ideology, while reinforcing the previous social stratification of the Spanish colonial system in the Americas. Hacienda El Progreso was created a few decades after the independence of the South American republics. Incorporation of the Galápagos Islands into Ecuador through colonization projects happened in a time soon after Ecuadorian independence from Spain.

This study of the social landscape of El Progreso fits into a literature on social control, internment, detention, conflict, and violence from an archaeological perspective. Social control plays a fundamental role in shaping modern experience. This is one of the central concepts in the study of plantations, institutions, and confinement camps (Brownlow 2006; Myers and Moshenska 2013b; Myers 2009; Lenik 2012). The focus is an examination of how planters manipulated plantation layouts to control people and
space. Brownlow (2006) argues that the absence or decline of control has profound implications for how public ecological space is used, perceived, and accessed. It is proposed that modern capitalist ecologies are politically inscribed and manipulated in a manner that reflects and reproduces social relations of power and inequality.

The archaeology of confinement and detention is part of a growing field studying the material remains of modern power and structural violence on a global scale (Myers and Moshenska 2013a). The materiality of these places has been studied to expose histories not written in documents. Food remains are today considered important sources of information to understand the prisoners daily life (Puseman et al. 2013). In these contexts, landscapes have been considered as artefacts of contestation when peoples are removed from or have abandoned their homes and homelands (Smith and Gazin-Schwartz 2008). The broad spectrum of memories associated with particular places, buildings, prisons, etc. is one of the main interests of this research focus (Funari et al. 2010).

Fifth, during my research I have tried to challenge the concept of “pristine” as a way to describe the ecology of the Galápagos Islands. During the 19th century, the Galapagos and the Amazon rainforest were considered the Ecuadorian frontiers. Much of the modern concepts about conservancy, nature, and pristine nature were not applicable during the colonization period. In this regard, the use of pristine by the tourism industry and local authorities to describe the local landscape and ecology needs to be reconsidered.

The results of this research show that the modern landscape of the area around the village of El Progreso is an anthropogenic landscape resulting from almost two centuries of human activity. The results of the phytolith analysis suggest at least three periods of vegetation change caused by human presence on San Cristobal. The modern landscape and ecology are the result of deforestation, the introduction of plants and animals, the abandonment of the landscape, and the adaptation of new plant species. Historical Ecology has proved to be a useful framework to investigate the human history of San Cristóbal Island. I consider that the colonization period brought irreversible consequences to the local ecology of the Galápagos; a fact that is not yet understood in detail. Most modern botanical and paleoecological research in the Galapagos is focused
on understanding the movement and introduction of plants and animals to reduce the effects of invasive species on the islands. However, it is important to understand the historical context of when these were introduced to the archipelago, to understand the potential of a new introduction of species associated with the tourism. It is essential to understand the socio-political context of 19th century Galápagos colonization to understand the history of invasive species on the Islands. An important number of naturalized plants were intentionally introduced to the Galápagos by colonizers to maintain dietary patterns and cultural traditions. People travelled with known plant species with the physical specimens but also carrying a pre-conceived meaning and a use of this species. Other plant taxa were transported to support agriculture and grazing, and some invasive plants were hosted by pests of other animals such as insects or rats.

6.2. Further work

The results of the paleoethnobotany component of the Historical Ecology and Archaeology of the Galápagos Islands project have created new research questions regarding the early interactions between colonizers and plants. A second phase of the research will include:

1) Excavation and sampling of domestic contexts of El Progreso plantation including the worker’s houses and the midden of the village. Soil samples for flotation will be collected for the analysis of charcoal and charred seeds. The goal is to obtain insights regarding the differences in plant use by different the members of the internal hierarchical structure of El Progreso plantation;

2) Excavation and sampling of El Progreso mill. The goal is obtaining archaeobotanical samples to expand our understanding regarding the use of plants in the machinery of the plantation. This will contribute to our current understanding about the technology used during the Cobos-Monroy period. I would like to explore the plants used as fuel or construction materials in the mill complex;
3) The expansion of phytolith analysis for paleoecological research beyond the agricultural zone of San Cristóbal Island. The aim will be testing the application of phytolith analysis in understanding local ecological dynamics and human impact on non-cultivated and non-populated areas in the National Park Area (Natural Reserve), to compare with the phytolith signatures in this dissertation;

4) A second phase of phytolith comparative collecting focused on cataloguing non-useful native, endemic, and introduced plants from the highlands of San Cristóbal Island. Modern plant specimens will be collected in the National Park Area (Natural Reserve);

5) An exploration of the activities of the El Progreso enterprise in mainland Ecuador. A second phase of historical archival research will be focused on investigating transaction & register inventories; manuscripts of acquisition and inheritance of lands; and republican maps or plans. The goal is to obtain more information about the trade between San Cristóbal and the continent; specifically, the transport of crops, live plants, animals, and people to the Galapagos.

6.3. Relevance

A popular use of environmental derived data from historical sites is for ecological restoration. The aim is to understand the effects of industrial and colonial practices in the environment as reference material for future restoration practices such as reforestation or sustainable agriculture. For instance, understanding the effects of the use of chemical fertilizers in plantations, use of chemicals such as led in cannery, or knowing the past methods of deforestation, could provide clues for future ecological restoration and health policies. The environmental derived data from historical sites provide a wide range of information to study the recent past but also to think about the possible effects of colonial practices in the future. The importance of environmental historical archaeology is that modern communities can learn from the lessons learned in the recent past in
shaping their own future regarding food production, urbanization, land planning, and more important, class relationships.

I expect that the results of this research contribute to a better understanding of the effects of capitalism in both the social and physical spheres of the Neotropics. Understanding the social and the ecological impacts of colonization and the introduction of European economic systems, plants, and animal species can help to improve local environmental policies and propose more equitable and environmentally sensitive economic strategies. The relationships between nature and capital can be more equal, using removable and non-invasive practices, favouring the use and consumption of local products, which could also have international demand.

It is recognizable that the formation of landscapes is a constant negotiation act between culture and environment. How to define the conceptual margin between a colonial dynamic in the landscape and separate it from the present? It is noticeable then, that different types of colonialism are still active and are constantly recreated in the present. In this sense, is it possible to conceptually separate the landscapes of colonialism and the present landscape? Are the landscapes of colonialism in the past or do they still exist and are they fully active in the present? I believe that this is a fundamental question of the landscape archaeology of colonialism.

I consider that one of the main contributions of the Historical Ecology of the Galapagos Islands Project is to educate the local people about the human history of the Islands. They need to realize that despite the past was painful and sad, it is something that needs to be understood. Colonizers were the ones who shaped the modern landscapes and knowing the reasons and consequences of their acts will allow local people to a better understanding of the modern society and local identities. Modern conflicts could or not could be traced to conflicts in the past, in this regard, they could be better treated. As an attempt to socialise our research with the public, the YouTube channel created (Anexus B) was meant to share visual information and the main goals of each component of the project.

Finally, the conceptual change between the concept of the island as a frontier in early Republican times, and today’s concept of an “untouched paradise” is important.
The same landscapes that once held the notion of frontier and the place to send undesirable people is today one of the most in-demand tourist zones because of the perception of the landscape as pristine. In this sense, pretending to eradicate the previous notions of place and space could bring terrible effects such as the repetition of similar practices of oppression and inequality in this region of Ecuador.
References

Ahassi, Cristina


Albert, Rosa M., and S. Weiner

Albuquerque, Elaine Santiago Brilhante de, João Marcelo Alvarenga Braga, and Ricardo Cardoso Vieira

Alexandre, A., J. -D. Meunier, A. -M. Lézine, A. Vincens, and D. Schwartz


Astudillo, Fernando J.  


2016b Soil Phytoliths as Indicators of Initial Human Impact on San Cristóbal Island, Galápagos. Burnaby, BC.

Baleato, Andrés  

Balée, William  

Balée, William L  

Balée, William L., and Clark L. Erickson  

Barboni, Doris, Laurent Bremond, and Raymonde Bonnefille  

Bassett, Carol Ann  
Baugher, Sherene

Beattie, Peter M

Becks, Fanya

Bell, Alison

Benton, Ted

Berlanga, Tomás de
1884 *Letter to His Majesty ... describing his Voyage from Panamá to Puerto Viejo*. In *Coleccion de Documentos Ineditos relativos al Descubrimiento, Conquista y Organizacion de las Antiguas Posesiones Españolas de América y Oceania*. Tomo XLI, Cuaderno II. Imprenta de Manuel G. Hernandez, Madrid.

Bilbao, Manuel
Birch, Kelly, and Thomas C. Buchanan  

Black, Chad T  

Blinnikov, Mikhail S., Chelsey M. Bagent, and Paul E. Reyerson  

Bognoly, José A, and José Moisés Espinosa  

Bowdery, Doreen  

Bowen, Joanne  

Bowser, Brenda J., and Maria Nieves Zedeño  
2009  *The archaeology of meaningful places*. University of Utah Press, Salt Lake City.

213
Branch, Nick, Mathew Canti, Peter Clark, and Chris Turney
2005 Environmental archaeology: theoretical and practical approaches. Key

Brannon, Nick

Branton, Nicole

Brattstrom, Bayard H.

Bremond, Laurent, Anne Alexandre, Christelle Hély, and Joël Guiot

Bromley, Ray

Brown, A. E.
Brown, Dwight A.  

Browne, Simone  
2015 *Dark matters: on the surveillance of blackness.*

Brownlow, Alec  


Bush, Mark B., Alejandra Restrepo, and Aaron F. Collins  

Cabanes, Dan, Yuval Gadot, Maite Cabanes, Israel Finkelstein, Steve Weiner, and Ruth Shahack-Gross  
Cáceres, Iván, and Miguel A. Saavedra  

California Academy of Sciences  

Calvo, Miguel  

Campbell, Judy  

Camus, Pablo, and María Eugenia Solari  

Carbo, L. F  

Carlquist, Sherwin John  

Carnes, Matthew E.  
Carroll, Maureen  

Chiriboga, Manuel  
2013 *Jornaleros, grandes propietarios y exportación cacaotera, 1790-1925*.

1992 Drowned islands downstream from the Galapagos hotspot imply extended speciation times.

Clark, A. Kim  

Cody, Martin L  

Coe, Heloisa H. G., Anne Alexandre, Cacilda N. Carvalho, Guaciara M. Santos, Antonio S. da Silva, Leandro O. F. Sousa, and Igo F. Lepsch  

Coe, Heloisa H. G., Kita Macario, Jenifer G. Gomes, Karina F. Chueng, Fabiana Oliveira, Paulo R. S. Gomes, Carla Carvalho, Roberto Linares, Eduardo Alves, and Guaciara M. Santos  
Coe, Heloisa Helena Gomes, Yame Bronze Medina Ramos, Cátia Pereira dos Santos, André Luiz Carvalho da Silva, Carolina Pereira Silvestre, Natalia Borrelli, and Leandro de Oliveira Furtado de Sousa
2015 Dynamics of production and accumulation of phytolith assemblages in the Restinga of Maricá, Rio De Janeiro, Brazil. *Quaternary International*.

Coffey, Emily E. D., Cynthia A. Froyd, and Katherine J. Willis

Coffey, Emily E.D., Cynthia A. Froyd, and Katherine J. Willis

Colinvaux, Paul A.


Colinvaux, Paul A., and Eileen K. Schofield


Collins, A., and M. B. Bush
Compañía "Guía del Ecuador

Conroy, Jessica L., Jonathan T. Overpeck, Julia E. Cole, Timothy M. Shanahan, and Miriam Steinitz-Kannan

Conroy, Jessica L., Alejandra Restrepo, Jonathan T. Overpeck, Miriam Steinitz-Kannan, Julia E. Cole, Mark B. Bush, and Paul A. Colinvaux

Consejo de Gobierno de Régimen Especial Galápagos
2014 Sistem Integrado de Indicadores para la Provincia de Galápagos (SIIG).

Cosgrove, Denis E.

Coulter, John

Cowie, Sarah E

Crosby, Alfred W
Crumley, Carole L.  


Crumley, Carole L., A. Elizabeth van Deventer, and Joseph J. Fletcher  

Cummings, Linda Scott  

Currie, Christopher Keith  

Currie, David J.  

Curtin, Philip D.  
David, Bruno, and Julian Thomas

De Kay, Drake
1872 In relation to occurrences at Magdalena Bay, Lower California, Mexico. publisher not identified, San Francisco.

Deagan, Kathleen

Deagan, Kathleen A.


DeFrance, Susan D., and Craig A. Hanson

Delle, James A.

Dickau, Ruth, Maria C. Bruno, José Iriarte, Heiko Prümers, Carla Jaimes Betancourt, Irene Holst, and Francis E. Mayle

Dickau, Ruth, Bronwen S. Whitney, José Iriarte, Francis E. Mayle, J. Daniel Soto, Phil Metcalfe, F. Alayne Street-Perrott, Neil J. Loader, Katherine J. Ficken, and Timothy J. Killeen

Dimbleby, G. W.

Dunbar, Robert B., Gerard M. Wellington, Mitchell W. Colgan, and Peter W. Glynn

Duncan, Kenneth, Ian Rutledge, and Colin Harding

Dye, Alan

Eckhardt, Robert C.
Edwards, Ryan

Engerman, Stanley L.

Epler, Bruce

Epperson, Terrence W.

Evett, Rand R., Arthur Dawson, and James W. Bartolome

Evett, Rand R., Ernesto Franco-Vizcaino, and Scott L. Stephens

Ezell, Karol Chandler, Deborah M. Pearsall, and James A. Zeidler
2006  Root and tuber phytoliths and starch grains document manioc (Manihot esculenta) arrowroot (Maranta arundinacea) and llérén (Calathea sp.) at the real alto site Ecuador. *Economic Botany* 60(2): 103–120.
Fahmy, A. G.

Fernández Honaine, Mariana, Margarita L. Osterrieth, and Alejandro F. Zucol

Fernández Honaine, Mariana, Alejandro F. Zucol, and Margarita L. Osterrieth

Fiedler, Paul C., and Lynne D. Talley

Figueiral, Isabel, and Volker Mosbrugger

Fisher, Christopher T, J. Brett Hill, and Gary M Feinman

Fishkis, Olga, Joachim Ingwersen, and Thilo Streck
Flett, Iona, and S. G. Haberle  

Foote, Nicola  

Franz, H.  

Fredlund, Glen G.  

Fredlund, Glen G., and Larry T. Tieszen  


Funari, Pedro Paulo A, Andrés Zarankin, and Melisa A Salerno  
Gale, Rowena, D. F Cutler, and Kew Royal Botanic Gardens

Gale, S. J., and R. J. Haworth
2002 Beyond the limits of location: human environmental disturbance prior to official European contact in early colonial Australia. Archaeology in Oceania: 123–136.

Gallego, Lucrecia, and Roberto A. Distel

García Basalo, J. Carlos


Geist, Dennis
Gherini, John, Doyce B. Nunis, and Marla Daily

Gibb, James G., David J. Bernstein, and Stephen Zipp

Gillespie, Rosemary G., and Bruce G. Baldwin

Gleason, Kathryn L.

Glynn, P. W., and J. S. Ault

Gonzales, Michael J
1985 *Plantation agriculture and social control in northern Peru, 1875-1933*. University of Texas Press, Austin.

Gonzales, Michael J.
Goodwin, Conrad McCall, Karen Bescherer Metheny, Judson M. Kratzer, and Anne Yentsch

Graves, Adrian

Grehan, John

Gromme, Sherman, Edward A. Mankinen, and Michel Prévot
2010 Time-averaged paleomagnetic field at the equator: Complete data and results from the Galapagos Islands, Ecuador. Geochemistry, Geophysics, Geosystems 11(11): Q11009.

Gu, Yansheng, Hongye Liu, Hanlin Wang, Rencheng Li, and Jianxin Yu

Guézou, A., S. Chamorro, P. Pozo, Ana Mireya Guerrero, Rachel Atkinson, Chris Buddenhagen, P. Jaramillo Diaz, and Mark R. Gardener

Guézou, Anne, Mandy Trueman, Christopher Evan Buddenhagen, Susana Chamorro, Ana Mireya Guerrero, Paola Pozo, and Rachel Atkinson
Haberle, Simon G.  

Hamann, O.  

Hamilton, Kevin, and R. R. Garcia  

Harbaugh, Danica T., Warren L. Wagner, Gerard J. Allan, and Elizabeth A. Zimmer  

Hardesty, Donald L.  

Hennessy, Elizabeth, and Amy L. McCleary  

Heyerdahl, Thor, and Arne Skjølsvold  
1974 *Archaeological evidence of pre-Spanish visits to the Galápagos Islands.* Kraus Reprint Co., Millwood, N. Y.
Hoadley, R. Bruce  

Hollis, Margaret Belser, and Allen H Stokes  

Holm, LeRoy G., Donald L. Plucknett, Juan V. Pancho, and James P. Herberger  


Horrocks, Mark, John Peterson, and Mike T. Carson  

Horrocks, Mark, Ian W.G. Smith, Scott L. Nichol, and Rod Wallace  

Idrovo, Hugo  
Iriarte, José

Iriarte, José, Bruno Glaser, Jennifer Watling, Adam Wainwright, Jago Jonathan Birk, Delphine Renard, Stéphen Rostain, and Doyle McKey

Iriarte, José, Irene Holst, Oscar Marozzi, Claudia Listopad, Eduardo Alonso, Andrés Rinderknecht, and Juan Montaña

Iriarte, José, and Eduardo Alonso Paz

Jäger, Heinke, María José Alencastro, Martin Kaupenjohann, and Ingo Kowarik

Jamieson, Ross W., and Meridith Beck Sayre
Jaramillo Díaz, P., and A. Guézou

Jaramillo Díaz, P., A. Guézou, A. Mauchamp, and A. Tye

Jaramillo, Patricia, and Anne Guézou

Johnson, Matthew

Jones, Robert L., and A. H. Beavers

Jørgensen, Peter Møller, Susana Léon-Yánez, and Missouri Botanical Garden
1999 Catalogue of the vascular plants of Ecuador = Catálogo de las plantas vasculares del Ecuador. Missouri Botanical Garden Press, St. Louis, Mo.

Keppel, Gunnar, Andrew J. Lowe, and Hugh P. Possingham
Kerns, Becky K., Margaret M. Moore, and Stephen C. Hart

Kessler, William S.

van der Knaap, WO van der, Jacqueline FN van Leeuwen, Cynthia A. Froyd, and Kathy J. Willis

Knapp, Bernard, and Wendy Ashmore

Knight, G. Roger
2014 *Sugar, Steam and Steel: The Industrial Project in Colonial Java, 1830-1850*. University of Adelaide Press, South Australia.

Kok, Annette

Korstanje, M. A., and M. P. Babot

Korstanje, M. Alejandra, and Patricia Cuemya
Krueger, Meghan Elizabeth

Landon, David B.

Langer, Erick D.

Lara, Antonio, María Eugenia Solari, María Del Rosario Prieto, and María Paz Peña

Larco Chacón, Carolina

Larsen, Clark Spencer

Larson, Edward J.

Latorre, Octavio
1999  *El Hombre en las Islas Encantadas. La Historia Humana de Galápagos.* Fundacyt, Quito.


Lea, David W., Dorothy K. Pak, Christina L. Belanger, Howard J. Spero, Mike A. Hall, and Nicholas J. Shackleton 2006  Paleoclimate history of Galápagos surface waters over the last 135,000 yr. *Quaternary Science Reviews* 25(11–12): 1152–1167.


Leone, Mark P.


Leone, Mark P., James M. Harmon, and Jessica L. Neuwirth

Leone, Mark P., Parker B. Potter, Paul A. Shackel, Michael L. Blakey, Richard Bradley, Brian Durrans, Joan M. Gero, G. P. Grigoriev, Ian Hodder, and Jose Luis Lanata

León-Yánez, Susana, Renato Valencia, Nigel Pitman, Lorena Endara, Carmen Ulloa Ulloa, and Hugo Navarrete (editors).
2011  *Libro rojo de las plantas endémicas del Ecuador.* Herbario QCA, Pontificia Universidad Católica del Ecuador, Quito.

Liese, Walter
1998  *The Anatomy of Bamboo Culms.* BRILL.

Liese, Walter, and Michael Köhl (editors).

Liese, Walter, and Thi Kim Hong Tang
Mackenna, Benjamín Vicuña  
1883 *Juan Fernández: historia verdadera de la isla de Robinson Crusoe*. R. Jover.

Madella, M., A. Alexandre, and T. Ball  

Malek, Amina-Aïcha, and Fondation des Parcs et jardins de France  
2013 *Sourcebook for garden archaeology*.

Mann, Alexander  
1909 *Yachting on the Pacific: together with notes on travel in Peru, and an account of the peoples and products of Ecuador*. Duckworth & Co., London.

Martínez, Nicolás G  
1915 *Impresiones de un viaje*. Talleres de policía nacional, Quito, Ecuador.

McBirney, Alexander R., and Howel Williams  

McCook, Stuart  

McCune, Jenny L., and Marlow G. Pellatt  
McCune, Jenny L., Mark Vellend, and Marlow G. Pellatt
2015 Combining phytolith analysis with historical ecology to reveal the long-term, local-scale dynamics within a savannah-forest landscape mosaic. *Biodiversity and Conservation* 24(3): 609–626.

McGuire, Randall H
2008 *Archaeology as political action*. University of California Press, Berkeley.

McMullen, Conley K.

Melossi, Dario, and Massimo Pavarini

Meniketti, Marco G.

Mercader, Julio, Fernando Astudillo, Mary Barkworth, Tim Bennett, Chris Esselmont, Rahab Kinyanjui, Dyan Laskin Grossman, Steven Simpson, and Dale Walde

Mercader, Julio, Tim Bennett, Chris Esselmont, Steven Simpson, and Dale Walde

Miller, Naomi Frances, and Kathryn L Gleason
Mintz, Sidney W. (Sidney Wilfred)  
1985  *Sweetness and power: the place of sugar in modern history*. Viking, New York, NY.

Monteón, Michael  

Morcote-Ríos, Gaspar, Diego Giraldo-Cañas, and Lauren Raz  

Morris, Lesley R., Neil E. West, Fred A. Baker, Helga Van Miegroet, and Ronald J. Ryel  
2009  Developing an approach for using the soil phytolith record to infer vegetation and disturbance regime changes over the past 200 years. *Quaternary International* 193(1–2): 90–98.

Morris, Lesley R., Neil E. West, and Ronald J. Ryel  

Mountz, Alison  

Mrozowski, Stephen A  
Mrozowski, Stephen A.


Mrozowski, Stephen A., Maria Franklin, and Leslie Hunt


Mrozowski, Stephen, Katherine Hayes, Heather Trigg, and Jack Gary

2011 Conclusion: Meditations on the Archaeology of Northern Plantations. *Northeast Historical Archaeology* 36(1).

Mueller-Dombois, Dieter

1998 *Vegetation of the Tropical Pacific Islands*. Springer.

Mulholland, Susan C.

Munro, Doug  
1995  The Labor Trade in Melanesians to Queensland: An Historiographic Essay.  

Muratorio, Blanca  

Murphy, Peter, and Patricia E. J Wiltshire  

Myers, Adrian, and Gabriel Moshenska (editors).  

Myers, Adrian T  
2009  Bodies and Things Confined: Archaeological Approaches to Studying Control and Detention.  

Myers, Adrian T., and Gabriel Moshenska  
2013b  Confinement and Detention in Political and Social Archaeology.  
*Encyclopedia of Global Archaeology*.

Nassaney, Michael S., and Marjorie R. Abel  
Neall, Vincent E, and Steven A Trewick  
2008 The age and origin of the Pacific islands: a geological overview.  
*Philosophical Transactions of the Royal Society B: Biological Sciences* 363(1508): 3293–3308.

Newell, Reginald E.  

Newman, Elizabeth Terese  

Orellano, Mario  

Orser, Charles E.  

Ortlieb, Luc  

Ortlieb, Luc, and José Macharé  
Palmer, Steven

Parks, E. Taylor, and J. Fred Rippy

Parr, Jeff, Leigh Sullivan, and Robert Quirk

Pearsall, Deborah M.


Pearsall, Deborah M, Karol Chandler-Ezell, and Alex Chandler-Ezell

Pearsall, Deborah M., and Michael K. Trimble

Pfister, Christian, Rudolf Brázdil, Barbara Obrebska-Starkel, Leszek Starkel, Raino Heino, and Hans von Storch

Pineo, Ronn F

Piperno, Dolores R.
2006 *Phytoliths: a comprehensive guide for archaeologists and paleoecologists.* AltaMira Press, Lanham, MD.


Piperno, Dolores R., and Deborah M Pearsall

Prieto, María del Rosario, and Ricardo García-Herrera
Puseman, Kathryn, Linda Scott Cummings, and Chad Yost

Quinn, William H., Victor T. Neal, and Santiago E. Antunez De Mayolo

Quiroga, Diego

Redfield, Peter

Rein, Bert, Andreas Lückge, Lutz Reinhardt, Frank Sirocko, Anja Wolf, and Wolf-Christian Dullo
2005 El Niño variability off Peru during the last 20,000 years. *Paleoceanography* 20(4): n/a–n/a.

Reitz, Elizabeth J., Lee A. Newsom, Sylvia J. Scudder, and C. Margaret Scarry

Reitz, Elizabeth Jean, and Myra L Shackley
Restrepo, Alejandra, Paul Colinvaux, Mark Bush, Alexander Correa-Metrio, Jessica Conroy, Mark R. Gardener, Patricia Jaramillo, Miriam Steinitz-Kannan, and Jonathan Overpeck

Riedinger, Melanie A., Miriam Steinitz-Kannan, William M. Last, and Mark Brenner

Romano, Ruggiero

Rudall, Paula J., Christina J. Prychid, and Thomas Gregory

Ruggiero, Kristin

Rulau, Russell
2000 *Latin American tokens: an illustrated, priced catalog of the unofficial coinage of Latin America--used in plantation, mine, mill, and dock--from 1700 to the 20th century*. Krause Publications, Iola, WI.

Salvatore, Ricardo Donato, and Carlos Aguirre
Salvin, Osbert

Sánchez

Sato, Akie, Colm O’hUigin, Felipe Figueroa, Peter R. Grant, B. Rosemary Grant, Herbert Tichy, and Jan Klein

Schaefer, Timo

Schofield, Eileen K.

Schofield, Eileen K

Schweingruber, F. H

Schweingruber, Fritz Hans, A Börner, and E.-D Schulze
Seddon, Alistair W. R., Cynthia A. Froyd, Melanie J. Leng, Glenn A. Milne, and Katherine J. Willis

Seiter, Jane I., and Michael J. Worthington

Simkin, Tom

Smith, Angèle P, and Amy Gazin-Schwartz
2008 Landscapes of clearance: archaeological and anthropological perspectives. Left Coast Press, Walnut Creek, Calif.

Smith, C. Wayne, Javier Betrán, and E. C. A Runge
2004 *Corn: origin, history, technology, and production*. John Wiley, Hoboken, N.J.

Solari, María Eugenia, Clara Cueto, Fernando Hernández, Juan Facundo Rojas, and Pablo Camus

Stewart, Alban
1911 *A Botanical survey of the Galapagos Islands*. San Francisco:
2011 Pre-colonial (AD 1100–1600) sedimentation related to prehistoric maize

Stoops, G.
2013 A micromorphological evaluation of pedogenesis on Isla Santa Cruz

Stoops, Georges
2014 Soils and Paleosoils of the Galápagos Islands: What We Know and What

Strömberg, Caroline A.E.
2009 Methodological concerns for analysis of phytolith assemblages: Does

Strömberg, Caroline A.E., Verónica S. Di Stilio, and Zhaoliang Song
2016 Functions of Phytoliths in Vascular Plants: An Evolutionary Perspective.
Functional Ecology: n/a-n/a.

Szabó, Péter
2015 Historical ecology: past, present and future. Biological Reviews 90(4):
997–1014.

Takahashi, Daisuke, David H. Caldwell, Iván Cáceres, Mauricio Calderón, A.D.
Morrison-Low, Miguel A. Saavedra, and Jim Tate
2007 Excavation at Agua Buenas, Robinson Crusoe Island, Chile, of a
gunpowder magazine and the supposed campsite of Alexander Selkirk, together with an
Takaki, Ronald T

Taussig, Michael T

Taylor, Christopher

Thorn, Vanessa C.

Trigg, Heather

Trigg, Heather, and Ashley Leasure

Trueman, Mandy, Richard J. Hobbs, and Kimberly Van Niel

Trueman, Mandy, and Noémi d’Ozouville
Trusty, Jennifer L., Alan Tye, Timothy M. Collins, Fabian A. Michelangeli, Madriz, and Javier Francisco-Ortega

Twiss, P. C., J. D. Meunier, and F. Colin

Twiss, PAGE C.

Twiss, Page C., Erwin Suess, and Robert M. Smith

Tye, A., and J. Francisco-Ortega

Vargas, José María

Vargas, Pablo, R. Heleno, A. Traveset, and M. Nogales
Vidal Gormaz, Francisco
1894 *Anuario hidrográfico de la Marina de Chile. Año 17.* Imprenta Nacional, Moneda 73, Santiago.

Walker, John H.

Waller, Thomas R.
2007 The evolutionary and biogeographic origins of the endemic pectinidae (Mollusca: Bivalvia) of the Galapagos Islands. *Journal Information* 81(5).

Wasserstrom, Robert

Watkins, Graham

Watling, Jennifer, and José Iriarte
Wells, Allen, and G. M Joseph  

Werner, Reinhard, Kaj Hoernle, Udo Barckhausen, and Folkmar Hauff  

Werner, Reinhard, Kaj Hoernle, Paul van den Bogaard, Cesar Ranero, Roland von Huene, and Dietmar Korich  

Wheeler, Elisabeth A., Pieter Baas, and Peter E. Gasson  
1989 IAWA list of microscopic features for hardwood identification.

Whittaker, Robert J., and José María Fernández-Palacios  

Wiggins, Ira Ira Loren, Duncan MacNair Porter, and Edward F. Anderson  

Williams, Derek  

Wolf, Eric R., and Sidney W. Mintz  
Woodward, Ralph Lee
1969 *Robinson Crusoe's island; a history of the Juan Fernández Islands.* University of North Carolina Press, Chapel Hill.

Wright, Shane D., Catherine G. Yong, Stephen R. Wichman, John W. Dawson, and Richard C. Gardner

Wunder, Sven

Wurst, LouAnn

Yamin, Rebecca, and Karen Bescherer Metheny

Zhang, Zhaohui, Guillaume Leduc, and Julian P. Sachs

Zhang, Zhaohui, Pierre Metzger, and Julian P. Sachs
Zhang, Zhaohui, and Julian P. Sachs

Zhao, Zhijun, and Deborah M. Pearsall

Zurro, Débora, Juan José García-Granero, Carla Lancelotti, and Marco Madella
Appendix A.

Soil Phytoliths Database. Scalesia Zone, San Cristóbal Island (Galápagos).

The database of the phytoliths analysis of San Cristobal Island collected and processed from 2014 to 2016, is attached to this dissertation as an Excel file:

astudillo-database-paleoethnobotany-galapagos-2017.xlsx
Appendix B.

Digital Channel and Social Media: Historical Ecology and Archaeology of the Galapagos Islands

The main objective of this side project was to socialize our research in a friendly format and short video clips. Specific objectives were briefly explaining the objectives of each component of the project. The channel was produced by the Ecuadorian independent film company LaVainillaFilms and Fernando Astudillo. Seven short videos were created and published on the YouTube platform, which is accessible in the URL: https://www.facebook.com/elprogreso1866/?ref=aymt_homepage_panel
https://www.youtube.com/channel/UCZsdX8g0fqKk-Kntfhan31A

27 https://www.facebook.com/profile.php?id=100008101276036