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by

Lara M. Sánchez-Morales

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**A Political Ecology approach to investigate the environmental impacts
of cattle management in Puerto Rico, 16th to 19th centuries**

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Dedication

I dedicate this work to my home: Puerto Rico. To my father Félix Sánchez-Díaz and my mother Marilyn Morales-Font; because without them, I truly would not be here doing the things I love. To my brothers Leopoldo, Leoniv, and Diego because, one way or another, we are always together. To my *tías, tíos y primos*: my eternal cheerleaders, and to my grandmothers Isabel and Mary, for all the things they dreamed of doing that drove them to push me forward. I also dedicate this to my friends in Puerto Rico, Austin, and all over the world for their reminders that I “need a beer”. To my colleagues and friends in the Department of Anthropology: Carlisia, Kelsie, Ana María, Emmy, Nelson, Hannah, Qui’chi, Rachel, Krishanta, and Fatemeh, for making graduate school that much more inspiring. And finally, to my cats, Pepper and Volta, because they can’t escape my stress when the rest of you could!

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Abstract

A Political Ecology approach to investigate the environmental impacts of cattle management in Puerto Rico, 16th to 19th centuries

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The nature and scale of environmental impacts due to the introduction of livestock into New World contexts has been the subject of much debate within disciplines concerned with changes of land use and land cover. The introduction of Old World species of herbivores into New World landscapes is often regarded as a catalyst to rapid environmental changes and a prevailing notion associates the presence of cattle with environmental degradation. My research aims to explore the environmental effects of cattle in Puerto Rico following European colonization. In this report, I employ a *Political Ecology* framework to contextualize the development of cattle management practices in Puerto Rico from the 16th to the 19th centuries. I discuss the potential of using a *Political Ecology* approach to understand the relationship between Spanish colonialism, cattle management practices, and environmental transformations. Finally, I propose the implementation of a geoarchaeological methodology to answer remaining questions on the impacts of cattle management during the colonial period in Puerto Rico.

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Introduction

The nature and scale of environmental impacts due to the introduction of livestock into New World contexts has been the subject of much debate within disciplines concerned with changes of land use and land cover. The introduction of Old World species of herbivores into New World landscapes is often regarded as a catalyst to rapid environmental changes and a prevailing notion associates the presence of cattle with environmental degradation. My research aims to explore the environmental effects of cattle in Puerto Rico following European colonization. In this report, I employ a *Political Ecology* framework to contextualize the development of cattle management practices in Puerto Rico from the 16th to the 19th centuries. This framework will help answer questions about the relationship between human adaptation and landscape change. This research will add another layer to our knowledge of the impacts of Spanish colonialism in the Caribbean. The main questions guiding this report are: *How did Spanish colonization reshape the cultural and environmental landscapes of the New World? How did internal processes (i.e. labor relations and social status) play a role in the development of subsistence practices in Puerto Rico? How did the synergies between local and external political factors influence the distribution of cattle management during the colonial period and what environmental impacts could have taken place consequently?*

This report is divided in chapters that answer the previous questions. In Chapter 1, I introduce the relevance of integrating information from archaeology research projects to

characterize the Spanish colonialist enterprise and understand its varied experiences in the Caribbean. Also, I discuss the potential of using a Political Ecology framework to understand the relationship between Spanish colonialism, cattle management practices, and environmental transformations. In Chapter 2, I describe Puerto Rico's climate and biogeographic characteristics, followed by a brief discussion of the Indigenous cultural landscapes before European arrival. Chapter 3 comprises an overview of demographic change, settlement patterns, subsistence practices and economic activities in Puerto Rico from the 16th to the 19th century; this panoramic focuses on external and internal events that influenced the development of cattle economies throughout these centuries. In Chapter 4, I rely on various historical sources (i.e. historiographical essays, expedition surveys, transcribed documentation, and municipal records) to correlate data of geographical distribution, grazing land dimensions, and cattle population numbers with the available literature on pastures and vegetation dynamics available for Puerto Rico. I incorporate this information to discuss the possible environmental impacts of cattle management across the landscapes of Puerto Rico during the colonial period. Finally, in Chapter 5, I propose the implementation of a geoarchaeological methodology to answer remaining questions on the impacts of cattle management during the colonial period in Puerto Rico.

Chapter 1: Why study colonialism?

In 1992, the *Annals of the Association of American Geographers* published a special issue titled *The Americas before and after 1492* in commemoration of the Columbian Quintencentennial. With the collaboration of geographers Karl W. Butzer, B.L. Turner II, Brian Harley, and William M. Denevan, this contribution addressed the nature of human-environment interactions in the Americas prior and after European conquest (Denevan 2011: 576). Karl Butzer regarded the issue as twofold, stating the importance of considering both the extent of Indigenous landscape alterations and the environmental degradation of European colonization (Butzer 1992). William Denevan's pivotal article "The Pristine Myth" approached both sides of this debate. Millennia of Indigenous landscape management transformed these settings into anthropogenic environments, but the rapid decimation of indigenous populations must have led to marked shifts in land use and land cover (Denevan 1992: 370). Denevan questions the widespread notion of "devastated colonial landscapes", or the assumption that the exploitative nature of European economies led to overall environmental degradation in the New World. Denevan proposes that by the 18th century, succession and forest recovery most have been observable in areas of low colonial settlement.

The overseas expansion of European colonialism into the New World set the stage for the cultural and environmental transformations that have shaped the modern world (Mrozowski 2010). Spanish colonialism was at the forefront of this venture, and its grasp over vast territories of the Americas lasted over four centuries. The first Spanish colonies

in the New World were established in the Caribbean, where the interactions between locals and outsiders led to cultural and environmental adaptations. The translocation of Spanish lifeways propitiated the introduction of exotic plant and animal species. The transformative effect of these species upon native ecosystems is still being assessed using different lines of evidence.

Archaeologists are in the perfect position to investigate the environmental effects of colonialism in the New World. Through archaeological lenses, landscapes constitute a material dimension of negotiation between political and cultural differences. Political economies influence management decisions that can potentially lead to lasting changes in landscapes. A *Political Ecology* approach helps explain the influence of colonialist politics to the development of cattle management in Puerto Rico, and allows an approximation to this practice's potential environmental outcomes.

A Political Ecology Approach to Investigate Cattle Management

Political Ecology encompasses a collective of approaches that tie environmental changes to issues of power and conflict (Tetreault 2017:1). This approach rose as a reaction to previous frameworks (i.e. human ecology and ecological anthropology), and considered how power dynamics structure the distribution, access, and use of productive ecological resources in a particular environmental context (Vayda and Walters 1999:167; Escobar 1999:4). In this sense, Political Ecology expands our understanding of the dialectic nature of landscape and social changes by outlining the course of interaction

between local and external factors. Proximate and distal factors influence the arrangement of power dynamics within social groups, and how these decisions lead to the shifts in land use and land cover (Turner and Robbins 2008: 299; Baver 2012: 17; Rice 2013: 652-653; Turner, Lambin, and Reenberg 2007: 20667). Proximate factors are those decisions at the local level which drive the expansion of certain land uses; distal forces are remote influences implicated in the restructuring of national economies, institutions, and policies (Geist and Lambin 2002:143). In hierarchically structured contexts, such as colonial societies, access and control over productive areas is gained through definitions of identity based on class, race, gender, and/or ways of life.

The framework provided by *Political Ecology* has been applied in a variety of spatial and temporal contexts to investigate processes of land use change and issues of environmental managerialism in the contemporary world (Sayre 1999; Bury 2008; Benjaminsen, Aune, and Sidibé 2010; Holmes 2014). Among the most investigated topics is the development of cattle economies and their role in shifting economic and social values. For example, Hoelle (2011) investigated how environmental legislation and government incentives in the past 40 years have shifted cultural perceptions of cattle, and influenced changes in economic practices among three groups in Acre, Brazil. During the decades of 1970-1980s, government-sponsored migration to expand agriculture frontiers, and the introduction of fiscal incentives for the establishment of large-scale cattle ranching led to conflicts over land between local communities of rubber tappers, farmers, and ranchers (Hoelle 2011: 98). In the following decade, decreased governmental support

for agriculture, coupled with forest conservation policies increasingly hampered extractivist and agricultural activities leading to a shift in cultural perceptions of cattle. In light of these new economic restraints, cattle raising became associated with social mobility and an alternative source of livelihood for displaced groups, with the unintended consequence of smallholders resorting to the conversion of agricultural lands and forests into pastures to adopt cattle raising practices (Hoelle 2011:100).

Various authors have applied a *Political Ecology* framework to studying the development of cattle ranching economies and their environmental consequences in North America. Sayre (1999) studied the ecological consequences of Southern Arizona's cattle ranching boom (1873-1893) by critically examining the roles of intra-group conflicts, market fluctuations, and ranching practices in shaping the distribution and overstocking of cattle. From late 17th to early 18th century, cattle were left to freely reproduce throughout the landscapes of Arizona - rich in forage and water resources - but by the end of the century 18th century the expansion and contraction of cattle raising heavily depended on the state of relations with local Indian groups (Sayre 1999: 245). He explains that from 1751 to 1790, missions and estancias established by Spanish colonizers had been abandoned due to the Pima uprising, and livestock had been captured by Apache and Seri Indians. From 1790 to 1890, a series of local and external politico-economic and environmental events combined leading to the eventual degradation of the desert's grasslands. In 1853, South Arizona was incorporated to the U.S. through the Gadsden Purchase, shifting the nature of land tenure structures towards landownership

guided by capitalist interests. Increase in the cattle population was facilitated by the construction of a transnational railroad and prompted by the deterioration of grazing lands in the Great Plains. Capital flows from Scottish and British interests fueled the cattle economy between 1870 and 1880, but overstocking followed due to the inability to balance import/export rates because of the Panic of 1873 that caused market prices to fall (Sayre 1999: 252). Between 1870 and 1891, cattle numbers in South Arizona went from less than 40,000 to 1.5 million (Sayre 1999: 242). The combination of these external factors with Anglo-Americans' limited experience managing arid environments led to overgrazing, unleashing hilltop erosion, shrub invasion, and aggradation of most major valleys (Sayre 1999: 250).

Sayre's political ecology approach for explaining the environmental degradation experienced in southern Arizona's desert landscapes can be used to study colonialism in the New World. Spanish colonialism was characterized by profit-oriented enterprises (Lightfoot et al. 2013:102) that readjusted to constant clashes with other imperial interests and local conflicts with its colonies. Our knowledge of Spanish colonialism has been enriched by material culture analyses from historical sites in the continental Americas and the Caribbean. In the following section, I discuss the general characterizations of the Spanish colonial experience from historical archaeology works.

Spanish Colonialism and the Caribbean

Colonialism is one of the central topics of historical archaeology, a field that has

contributed more nuanced interpretations of the dynamic and variable experiences of conquest in the Americas (van Buren 2010:166). In the last decades, the archaeology of the Spanish colonial period has shifted its emphasis of unidirectional models of cultural interaction (i.e. acculturation) by emphasizing the dialectical nature between colonizer and colonized (Beaudry, Cook, and Mrozowski 1991; Silliman 2010). As Spaniards arrived in the Caribbean, so did their mental templates template on how to organize their settlements. Faced with the challenges of new social and natural environments, these factors delayed the full replication of Iberian traditions, and resulted in the creation of contextually unique colonies (Beaudoin 2013: 45). In practice, the social dynamics of colonial life were complicated by the differences of local conditions in which Spanish colonizers inserted themselves. Colonial sites are constituted by multi-ethnic expressions of identity and are ideal for examining the material manifestations of social agency and negotiation (Pavao-Zuckerman and Loren 2012: 200; Sampeck 2015: 18; Maxwell and Oliver 2017: 29).

Beaudoin (2013) argues that colonies can be seen as spaces of negotiation between the colonial center, the colonizer, and the colonized. In colonial situations, the center exerts its power over peripheral groups through the management of social relations, space and local resources (Beaudoin 2013: 45-46). However, the total translocation of the center's traditions is often limited by local conditions and must rely on the traditional knowledge of indigenous or peripheral groups to survive. For example, in 16th century New Spain, as was the case in other early colonies including Puerto Rico,

conquerors depended on the ecological knowledge and social networks of indigenous groups to ensure subsistence acquisition and determine the course of territorial expansion (Hunter and Sluyter 2011: 298; Mrozowski 2010: 120).

Spanish colonization in the Americas comprised the translocation of civil and ecclesiastical institutions from the mainland, transatlantic and inter-regional migration, forced relocations, establishment of mercantilist economies, and the accumulation of capital by combining expansive resource extraction and coerced labor (Sued-Badillo 1992: 601; Altman 2013: 225). In the Caribbean, the establishment of European institutions brought about confrontations, enslavement, and intra- and inter-island movement of local populations (Rivera-Collazo 2015:1608), but it was characterized by the integration of multiethnic populations through kinship and familial structures (Deagan 1996: 151; Keegan 1996: 271). This fact stands out from contemporary forms of colonialism (i.e. Anglo-American colonialism) - where non-European groups were systematically excluded. As will be discussed later in this chapter, the integration of multiethnic communities was crucial in the development of cattle management in the Spanish Americas.

Livestock in the New World: A Varied Experience

Initially, Spanish colonizers in the Caribbean attempted to recreate their homeland through the introduction of key foods such as cereals, olives, and grapes but differences in climate and soils hindered these endeavors (Keegan 1996: 270). Another way Spanish

colonists attempted to replicate the ‘colonial center’ in the New World was through the introduction of domestic species of animals. These species had been domesticated in the European and African continents for thousands of years –their last stages of adaptation had taken place in the climates and ecosystems of the Andalusian plains and the more arid climates of the Canary Islands (Reitz 1992: 85; Gelpí-Baíz 2000: 47). Cattle, sheep, goats, hogs, mules, and chickens were amongst the primary species introduced since Columbus’ first voyage, and were subsequently shipped to other colonies in the Antilles and to the continent from Hispaniola. Sheep were one of the most difficult to relocate because they are very sensitive to heat and humidity. Changes in their surroundings are known to alter male fertility (Reitz 1992:84-85). On the other hand, cattle and pigs are less stressed by these factors, which led to their rapid proliferation in the landscapes of the Antillean archipelago (Reitz 1992: 85-86).

The natural diversity of environmental conditions in the New World played a major role in the successful adaptation of these exotic animals and decisions to adjust foodways and economic practices in each of the colonies (Reitz 1992: 84; Deagan 1996: 48). The two major taxa of cattle introduced to the Caribbean during the colonial period were the humped zebu (*Bos indicus*) and the humpless taurine (*Bos taurus*) (Magee et al. 2002: 429). In the Greater Antilles, the combination of abundant rainfall, fertile soils, extensive savannas, and the absence of ruminants allowed cattle and pigs to proliferate throughout the landscape with minimal human intervention (Deagan 1988: 215; Watlington 2009: 399). For example, the earliest cattle ranching community in the Caribbean, Puerto Real (Haiti), benefited from a large cattle population leading to the

development of illicit commerce based on hides and other products (Reitz 1986: 318-319; McEwan 1986: 44). In the colonies of Nueva Cádiz, located on the Island of Cabagua, Venezuela, and Spanish Florida, the adaptation of cattle and sheep was likely hindered by limited soil resources and the presence of disease vectors such as deer (Reitz 1992:88-89). In the localities where livestock did not thrive, food consumption significantly shifted to marine resources (Reitz 1992: 89).

The unprecedented successful adaptation of cattle in some areas of the Americas permitted the transplantation of cattle-based economies, although associated management practices changed through time with the incorporation of new actors, and changing political and economic panoramas. Cattle-raising, first in its free-range form and later in enclosed ranches, quickly became a significant occupation in the Americas. The Spanish Crown created an asymmetrical power structure where individuals had to negotiate new forms of livelihood through the organization of labor and land tenure systems based on elite status. Cattle herding was associated with elite status as it was valued over other forms of labor such as farming (Gelpí-Baíz 2000:50). This is a cultural value that can still be observed in contemporary cattle-ranching communities (Hoelle 2011:96).

Land Tenure and Social Organization in the Spanish Caribbean

Changes in economic practices at the local scale are the result of interactions between individuals, communities and/or regional groups. Identities within a shared setting may be based values attributed to different forms of subsistence acquisition

(Hoelle 2011: 96). Conflicts between local interests and external structural influences within this local sphere open the way for instances of agency to manifest in the landscape. Labor relations formed the core of experiences in colonial contexts by shaping the economic and social structures that dictated the lives of Indigenous, African, and European groups (Silliman 2010: 33). The Spanish projected a social order through the redistribution of territory under different types of land tenure according to class and labor distinctions.

In the case of Puerto Rico, colonialism led to the almost complete decimation of Taíno populations, but surviving individuals, along with African groups, were incorporated into the Spanish *encomienda* system as slaves and laborers. Gold-mining efforts during the first decades were supported by subsistence agriculture, and complemented by cattle management carried out by slave labor (Moscoso 2001:7). Agricultural practices in the early years were probably mostly based on Taíno strategies of land management, a fact supported by accounts of Spaniards appropriation of *conucos*¹ and *yucayeques*² (de las Casas 1986: 414). African slaves performed all kinds of tasks on sugar plantations, and with ginger cultivation, ship building, construction, and hide production. The position of foreman in grazing lands was usually performed by *mulatos* or freed-black men (Gelpí-Baíz 2000: 17, 48).

Under the *encomienda* system land belonging to the Crown was given no legal

¹ *Conucos* was the name of agricultural mounds where the Taíno cultivated manioc and other crops.

² *Yucayeques* refer to agricultural villages comprised of *conucos*.

right to individual ownership, and therefore, it was shared by all colonial subjects. The Crown issued land grants (*repartimientos de tierra*) to colonists and royal officials to develop an agricultural economy that could support the local population and mining efforts (Moscoso 2001: 8). Permission to develop parcels of land was requested through the viceroy, and later granted by the Crown through *mercedes de gracia* (Hunter and Sluyter 2011: 290). Under the *encomienda* system, these early land grants facilitated the monopolization of territory by individuals of higher status -mainly miners, Crown officials, and local regents. At the same time, this form of land tenure paved the way for the distinctions of class and status rooted in the Iberian ideal of *hidalguía*. This claim of elite lineage was made visible through acquisition of wealth by service to God and the Crown, and maintained through control of land and slaves, and evasion of work (Deagan 2003:6). In this context, cattle herders held a higher prestige than farmers and other occupations.

During the early stages of colonization in Puerto Rico, social classes included individuals laboring in different sectors. The upper class was a rather small group of Royal officials and local regents who had profited from the *encomiendas*, as well as merchants, wealthier farmers, miners and cowboys (Moscoso 1997: 14). The middle class was comprised also of lower status artisans and merchants, while the lowest class was the enslaved population comprised of *naborías* (Indigenous laboring classes subjected to *encomenderos*) and African slaves (Moscoso 2006: 14-15). Historian Francisco Moscoso emphasizes that in colonial Puerto Rico, neither herders (*hateros*) nor farmers

(*estancieros*) formed entirely homogeneous classes. Rather, both designations constituted sectors which owned the land to various degrees according to political and kinship ties (López-Cantos 1975: 41).

As previously mentioned, using a *Political Ecological* approach allows us to integrate both local and external factors to explain the motivations and actions which led to the institution of cattle management in Puerto Rico. External factors reflected the interests of the Spanish crown and the obstacles it faced to maintain control over its colonies due to continuous rivalry with foreign powers. Internal factors were those local situations which ensued because of conflicts between the different actors implicated in the development, maintenance, and dependency of commercial economies of the island. These external and internal factors influenced social organization, geographic distribution and hegemonic presence of cattle economies over Puerto Rico's landscapes between the 16th and 19th centuries.

Chapter 2: Puerto Rico: Climatic, Environmental and Cultural History

Puerto Rico is in the Caribbean bioregion of the Neotropics at 18.2208° N, 66.5901° W'. It is the smallest of the Greater Antilles, and comprises five islands and several smaller cays; off the western coast are Mona and Desecheo, and on the east, are Vieques, Culebra, Palomino, and Icacos. The island formed between 135 and 185 million years ago through tectonic collision of the Caribbean and North American plates, leading to its division into three geographic regions: the mountainous interior, the northern karst, and the coastal lowlands. Today, the mainland extends 170 km, bathed by the Atlantic Ocean on its north and eastern sides and by the Caribbean Sea over the southern and western coasts. Puerto Rico has a strong diversity of soils with over 352 types and 115 series (Quiñones and Palacios 2004:1). These soils form the foundation to the rich diversity of ecosystems observed throughout the island.

Mid- to Late-Holocene Climate in the Caribbean

Climate variations in the Tropics are driven by changes in the westerly winds (North Atlantic Oscillation) and their interaction with changing sea temperatures of the Southern Oscillation (SO) (Malmgren, Winter, and Chen 1998: 2713). Changes on sea surface temperatures influence the relative position of the Intertropical Convergence Zone (ITCZ), a convection band of moisture that distributes precipitation over the Tropics (Rosner 2006: 12). The underlying area of the ITCZ is characterized by frequent rainfall and storm activity, and its annual shifting position from north to south produces

the seasonal changes in precipitation over the Tropics (Peterson and Haug 2006: 97). Northward movement of the ITCZ increases precipitation over the north-eastern Caribbean, while its southern movement produces lower than average rainfall (Nyberg et al. 2001: 8).

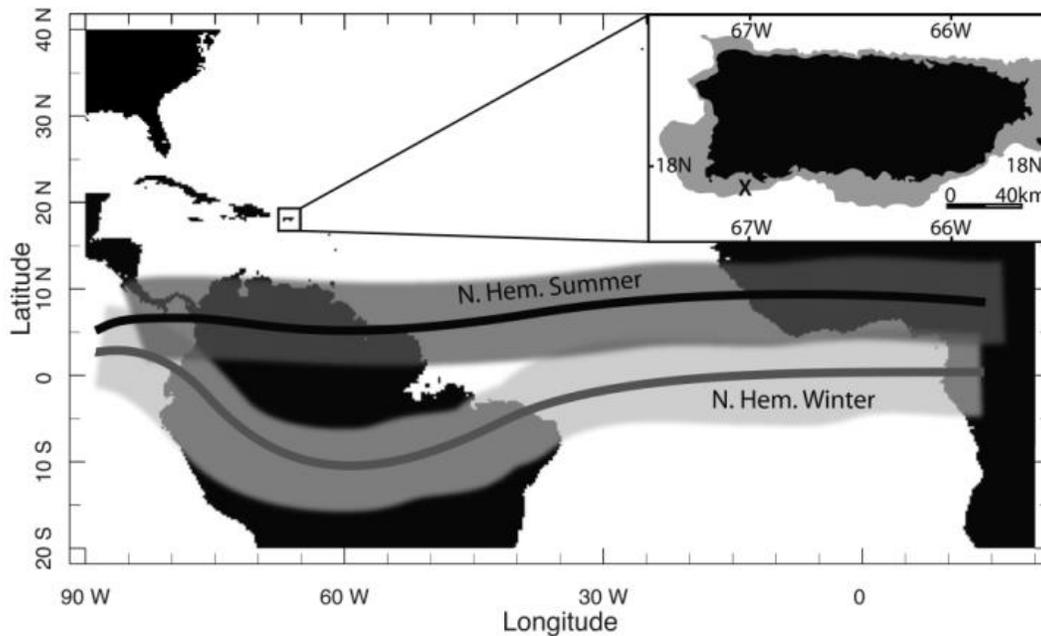


Figure 1: Map showing seasonal movement of the ITCZ relative to Puerto Rico.
Source: (Kilbourne et al. 2010).

The climatic transition experienced from the early (10,500 – 8,000 BP) to the mid-Holocene (7,000 – 5,000 BP) was characterized by the stabilization of seasonality, increased precipitation, and increased hurricane activity over the Caribbean (Donnelly and Woodruff 2007; Woodruff et al. 2008; Hodell et al. 1991; Giry et al. 2013; Gregory et al. 2015). These conditions might have intensified during the Little Ice Age (LIA)

(1350-1850 AD), a period when many parts of the Tropics experienced colder and drier conditions (Lozano-García et al. 2007; Shanahan et al. 2009). This event was characterized by an increase of seasonality, with colder and drier conditions over the Caribbean (Nyberg et al. 2002; Kilbourne et al. 2010).

Geography, Soils and Ecological Life Zones

Puerto Rico's biogeographic regions are conditioned by the interaction between topography, soils, and climate. The Central Mountain Range (*Cordillera Central*) runs from east to west and distributes precipitation unequally over the northern and southern edges. The crest of the Central Mountain Range is closest to the southern coast, causing higher amounts of rainfall over the north-northeastern parts, and lesser precipitation over the south (Miller and Lugo 2009: 86). Drier conditions and higher temperatures in the southern part of the island reduce the abundance of surface hydrological resources, while rivers in the north usually have higher flowing capacity (Miller and Lugo 2009:20). Coastal lowlands are characterized by sandy to rocky beaches, mangrove swamps and forests, fertile soils and water drainage systems (Cohen et al. 2016). Puerto Rico has artificial reservoirs created through damming of rivers, but has not natural lakes³. The karstic areas in the northern region (from San Juan to Aguadilla), and a lesser extension in the south (from Ponce to San Germán) are characterized by haystack hills (known as *mogotes*), sinkholes, and subterranean rivers and caves systems (Miller and Lugo 2009:

³ "Reservoirs of Puerto Rico." *Enciclopedia de Puerto Rico*. Accessed May 2, 2018. <https://enciclopediaipr.org/en/encyclopedia/reservoirs-of-puerto-rico/>.

23). These limestone formations constitute the largest water reservoir storing precipitation (Rivera-Collazo et al. 2015: 628).

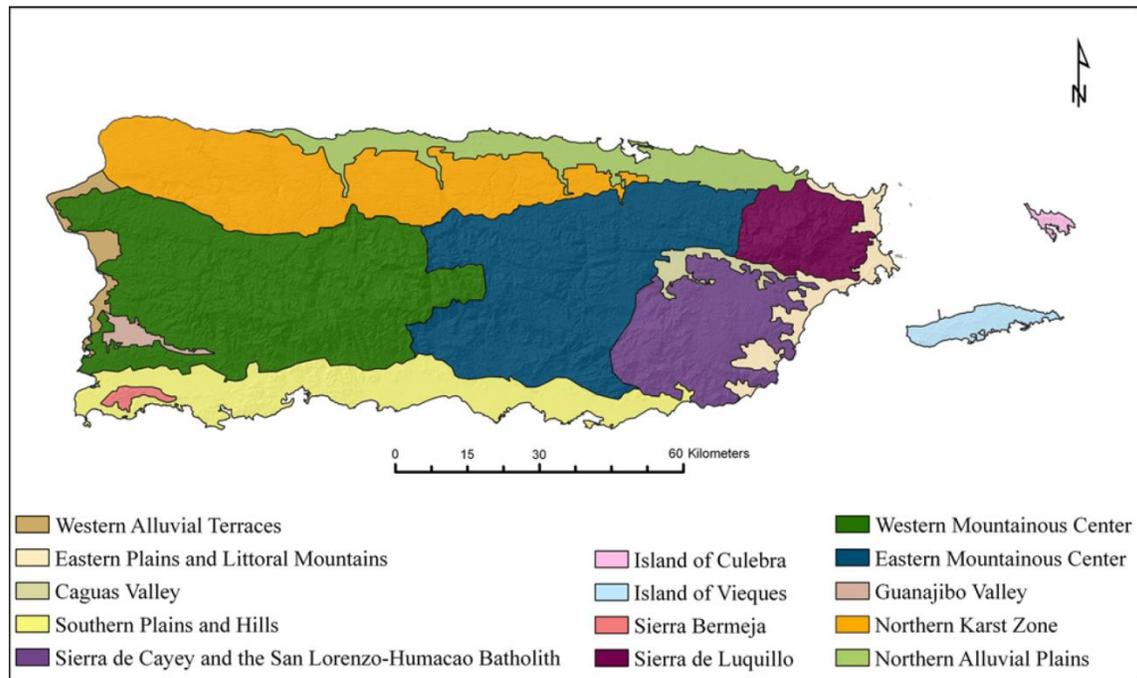


Figure 2: Landscape units for Puerto Rico. Source: (Soto and Pintó 2010).

Soils in the humid mountainous interior derive from igneous, metamorphic, and sedimentary rocks dating to the Cretaceous Period (Quiñones and Palacios 2004:1). The northern valley soils have formed over the deposition of miscellaneous volcanic rocks transported from alluvial processes. Associations tend to have deep profiles ranging from well-drained to extremely well-drained with clay and sandy textures. At the hilltops and hillsides of the south-central region soils are of volcanic origin, well-drained, slightly acid to neutral pH, with clay-loam horizons forming over weathered rock. In the semi-

arid coastal zone, soils are alkaline, well-drained, and clay-loamy textured. In the southwestern edge, near the Lajas Valley, soils of calcareous origin with drainage characteristics ranging from deficient to extremely good (Quiñones and Palacios 2004: 2). In the western coastal valleys, principal soil associations are extremely clayey and compacted, and porous (Quiñones and Palacios 2004: 2). In the western limestone formations over this area are found soils of moderate depth, porous, and clayey to loamy textured soils (Quiñones and Palacios 2004: 2).

Over the 27,000 species of plants are found throughout the island with approximately 243 endemic (Santiago-Valentín 2008:79). The clear majority of botanical species are native -250 of them endemic-, and about 3,000 alien species have been introduced from the Old and New Worlds over time (Miller and Lugo 2009: 27). Puerto Rico has six subtropical life zones that range from dry to moist forest over the coastal lowlands, and subtropical moist forest is the largest life zone of the mainland (Miller and Lugo 2009:82).

Rainfall Regimes of Cattle Management Sectors

Historically, cattle management has been circumscribed to the coastal lowlands and the lower elevations zones of the mountainous region. Rainfall distribution through these areas is highly variable. Rainfall is yearly distributed between a rainy season (May through November) and a drier season (January through March) (Miller and Lugo 2009: 20). Over the northern karst region, which spans from the municipality of Aguadilla all

the way to the capital San Juan in the east, we move from a sub-humid to humid regime which varies from 40 inches to 90 inches (Picó 1974: 159-161). From the coastal plain of Manatí to Canóvanas, we find the northern humid region, where precipitation ranges from 60-90 inches. The Sierra de Luquillo extends from the mountain range to part of the coastal plain. The area is a rainy region that experiences 90 to 200 inches of rainfall annually. The humid region of the northern hills includes the hills and valleys between Moca and south of Río Piedras; 70-100 in; the regimen is those northern hills resembles that of the north coast but it is typically more humid because of the higher latitudes and less regular topography which lead to more orographic precipitation.

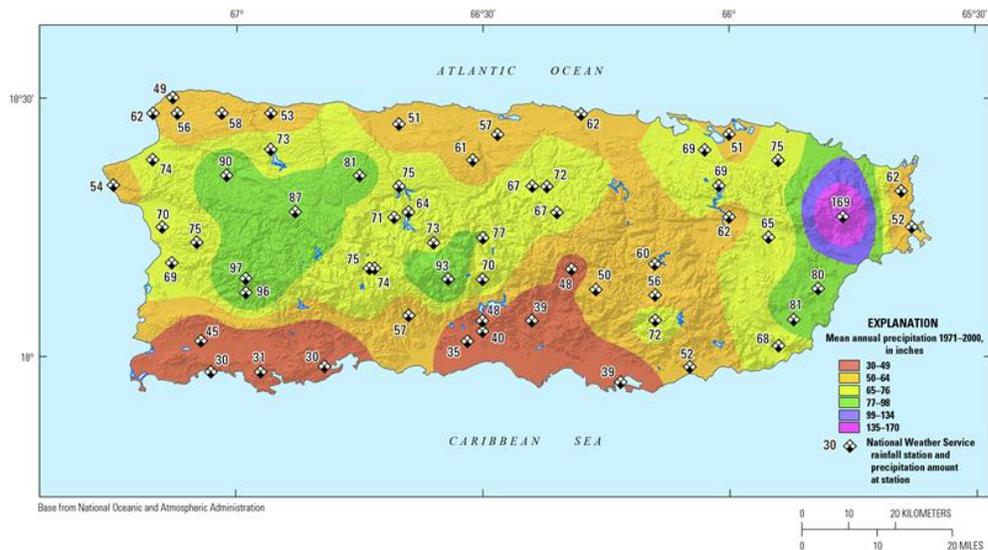


Figure 3: Map of rainfall distribution in Puerto Rico. Source: (U.S. Geological Survey).

On the eastern edge of Puerto Rico, mean annual rainfall ranges from 90-200

inches (Picó 1974:161). The humid valleys of the east, located between the municipalities of Naguabo and Maunabo, transition from the interior mountains to the coastal valleys, changing their regime to 70-90 inches annually. The humid region of the eastern mountains experiences an annual precipitation of 50-80 inches (Picó 1974:162). This region is located at a lower altitude, sheltered by the Sierra de Luquillo on the east, which causes less orographic-driven precipitation. This area presents more complex patterns of rainfall associated to changes in topography (Picó 1974:164). Here lays an important region of cattle management since its incipient times, where the municipalities of Caguas, Juncos and San Lorenzo are located. The valley of Caguas is sheltered by the Luquillo Range, while San Lorenzo, a little farther south, is located close to the northern slope of the Sierra de Cayey (Picó 1974:167).

Moving southward are the arid coastal plains, which are divided into two regions because rainfall tends to diminish towards the west but increases towards the interior mountains up north. On the eastern side of the division, between Patillas and Salinas rainfall averages 40-60 inches, while on the western side, from Salinas to Boquerón, rainfall is typically between 35-45 inches annually (Picó 1974:163). Extending along the southern slopes of the Central Mountain Range and over part of the southern piedmont hills are the semiarid hills of the south. In this region, annual rainfall averages 40-70 inches, with wetter conditions experienced towards the west in San Germán and northward towards the mountains (Picó 1974:163). The wet-dry region of the western coastal valleys includes the lower parts of the valleys from Guanajibo to Culebrinas with

annual precipitation between 65-90 inches. The municipality of Cabo Rojo is more arid and serves as a transition zone moving northward. These valleys experience typical convection rainfall as they are shielded from the trade winds by the central mountain range (Picó 1974:164).

Pre-colonial Societies and Anthropogenic Landscapes

By the time Europeans made their way to the Greater Antilles, the islands' landscapes had gone through almost four millennia of human activity. Archaeological evidence places initial human colonization of Puerto Rico about 5.3 kya with the arrival and settling of humans over a diversity of environments along coastal ecosystems (i.e. marshland, maritime and riverine zones) rich in resources (Rivera-Collazo 2015; Rodríguez Ramos et al. 2013). By 2.4 kya these groups had settled along the north-central coast of the island, in the site of Angostura, -about the same time they start making their way into the mountainous interior through the karstic region (Rodríguez Ramos 2014). These early contexts are associated with the introduction of important starchy foodstuffs like manioc and sweet potato, as well as the introduction of maize, beans, zapote and avocado (Pagán-Jiménez 2009; Pagán- Jiménez et al. 2005; Pagán-Jiménez 2012). The production of some of these cultigens was probably tied to strategies of landscape management by control of fire regimes and soil fertility enhancement (Burney 1997; Rodríguez Ramos et al. 2013; Rivera-Collazo 2015; Caffrey and Horn 2014). Settlement patterns, zooarchaeological and paleoethnobotanic evidence suggest that these groups led semi-sedentary lives based on complementary subsistence practices

that included some form of agriculture/horticulture, fishing, and gathering (Rivera-Collazo 2011).

Around 500/200 BC new wave of migration of Arawak groups (also known as *Saladoid*) from the Orinoco brought new ceramic technologies and foodways from the continent. Settlement patterns of these groups suggest an egalitarian/tribal socio-political organization (Rodríguez-Ramos et al. 2013:502). By 800 AD, settlement spread into the alluvial valleys of the mountainous interior. During the period 1100 – 1492 AD, the archaeological record points towards political and religious nucleation that led to what is known as the Taíno culture (Rodríguez Ramos et al. 2013:505). Settlement was intense in the mountainous interior and villages were distributed in relationship to *cacicazgos*, a form of asymmetrical political organization manifested through the production of elaborate ritual paraphernalia, and increased complexity of iconographic expression in civic-ceremonial centers (Rodríguez Ramos et al. 2013:505). The prevalent form of cultivation was done in *conucos*, a type of field preparation that included the creation of mounds, ranging from 9 to 12 feet in extension, and separated by 2 to 3 feet from each other (Domínguez-Cristóbal, 2000: 18).

Chapter 3: Cattle Management Practices in Puerto Rico: An Overview

The history of Puerto Rico's cattle management has been mainly studied from a historiographic point of view (Picó 2006; Moscoso 1997, 2000, 2006; Gelpí-Baíz 2000). This work will enhance our understanding of Puerto Rican environmental history by proposing to incorporate data from geoarchaeological research projects. Teasing apart previous works carried out by historians, we can surmise that cattle management has been an important component of Puerto Rican subsistence since European colonization to the present. In this chapter, I outline the relationships between inter-group conflicts – based on social distinctions, and economic interests- and the policies pushed by the Spanish Crown, its institutions, and interventions by rival powers.

From Mining to Sugar estates (1508-1650)

During the early years of colonization in Puerto Rico, production of cattle products was to supply local markets; grazing was open-range, and individuals could herd their cattle within each other's lands. This situation created tension between *señores de hatos* (cattle herders) complaining that neighboring cattle grazed in their lands. To resolve these conflicts, the local government (*Cabildo*) passed a local ordinance (*Ordenanza de Pastos Comunes*, 1516-1521) which granted the demarcation of grazing lands, and provided the parameters for their extension. The ordinance established the following: each *hato* had to be located one league (1 *legua*= 5.6 km⁴) apart from one

⁴ Conversion of units are according to Moscoso (2013).

another and each could not extend more than 2 *leguas* in all cardinal directions (Gelpí-Baíz 2000: 38). During this time, ranchers had their cattle free-range, without marks, killing them periodically as needed (Picó 2006:71). However, this measure would only benefit those who carried the title of *vecino*⁵.

By 1541 the economic situation of the island shifted dramatically with the decline of indigenous labor and gold, driving many settlers to relocate to other colonies in the New World, mostly Peru and Mexico, which held the promise of further exploitation opportunities. For those who stayed in the island, access to land tenure became a priority, as efforts refocused on expanding sugar and cattle-raising industries for exportation (Gelpí-Baíz 2000:38). The construction of sugar estates (*ingenios azucareros*) formally began in the decade of 1540 (Moscoso 2001:40). This process however, was dependent on the resolutions which stemmed from the first agrarian conflict documented in the island, which took place between 1541 and 1545. In his book *Lucha agraria en Puerto Rico, 1541-1545: Un ensayo de historia*, historian Francisco Moscoso conducted an in-depth study of the documentary evidence and highlights some of the main reasons behind the conflict. Framed during the transition towards a mercantile logic of capital accumulation, the dispute focused on territories adjacent to the capital of Puerto Rico (today San Juan), located on the northern coastal lowlands (Moscoso 2006:12). The main issue was the great extension of the *hatos* which did not allow for other individuals to produce on lands near the capital and take advantage of the proximity to the port.

⁵ To carry the title of *vecino*, the individual had to be married, with good public standing, and had to provide proof of having resided in the island for at least 5 years.

During the decades of 1540-1550, Puerto Rico experienced the rise of the slave-sugar economy, followed in importance by cattle ranching, and ginger cultivation. In 1566, sugar estates had already been established on the north-central part of the island, on the regions of Toa, Bayamon, Canóvanas, Loíza, Yabucoa and Añasco (Moscoso 2001:81-82). The foundation of these estates resulted in the conglomeration of people in their surroundings, in turn shaping the main population nuclei at the time. These were not limited only to the northern part of the island near the Ciudad de Puerto Rico (the bureaucratic and administrative center) and San Felipe de Arecibo, but also to the southern part in the Villa de San Germán and San Blás de Illescas (municipality of Coamo today). The sugar estates, along with their herding lands, became the focus of socio-economic cohesion alongside a shift towards a mercantilist economy- exclusive commerce with the metropolis- (Moscoso 2001:59; Gelpí-Baíz 2000:28-29). Historian Fernando Picó notes that the southern coastal lowlands were scarcely populated by farmers and were mainly dedicated to cattle grazing (Picó 2006:72).

Contraband, Hides and Herd Demolition (1660-1790)

The beginning of the 17th century saw the development of an illicit trade economy between the Spanish colonies and other nations. Political and economic interests in Spain left Puerto Rico with limited access to the transatlantic trade. Various issues played a role in this situation. First, Seville had become the locus of a commercial monopoly between Spain and its colonies, which mostly responded to the interests of bankers and merchants who sponsored the trips (Picó 2006:83). Second, changes in

navigation routes and the fleet system marginalized Puerto Rico from the trading routes (Picó 2006:84-87). The island experienced a range of vicissitudes, as years could go by with few ships arriving at the ports in the capital, and even then, the supplies brought in were not enough to sustain the population's needs. Since 1625, the new commercial hegemony progressively left Puerto Rico marginalized from the commercial traffic between the New World and Seville, affecting local agricultural interests (Picó 2006: 87).

European demands for Caribbean products boosted British and Dutch interests to establish colonies in the Caribbean. During this time, tobacco became the main export product in British and Dutch colonies in the Lesser Antilles, later succeeded by sugar as tobacco prices collapsed due to overproduction in relation to market demands (Picó 2006:102-103). These factors developed two regional production areas between the Greater and Lesser Antilles, where both sides complemented each other with necessary products. For example, Puerto Rican imports consisted of slaves, spices, salt and other general products, while it exported live cattle, meat, hides, timber, and cacao among others (López-Cantos 2017:372-379). Many governors, clergymen, and royal officials between 1650 and 1700, were accused of participating in contraband activities (Picó 2006:105; López-Cantos 2017:249-280). The principal loci for contraband during this period were the Capital of San Juan, Cibuco, Arecibo, and Bella Vista in the north, and San Germán, Ponce, and Santa Isabel in the south, and Aguada in the west (Picó 1986:106).

By 1650 the production of sugar decreased and the mercantile agricultural

economy was completely depleted given the poor ties with the metropolis and the increased reliance on contraband. During the 17th century cultivation was pushed to river margins and up the hillsides, while haciendas were last in importance as grazing lands became more profitable (Picó 2006: 78). Therefore, cattle ranching assumed a regular mercantile character and became the main economic practice in Puerto Rico. Official records show that the total of hide exports often exceeded those of sugar and other products (Gelpí-Baíz 2000: 88-89). The development of a cattle ranch-centered economy was a direct consequence of the formation of huge landholdings and the concentration of large extensions of land at the hands of an elite few (Moscoso 1997). Pasturelands varied between 2.5 - 10 *cuerdas* and occupied plains and coastal valleys

	Extension (<i>cuerdas</i>)	Extension (km)
<i>Menores</i> (Minor)	2,500 – 5,000	17.2 – 34.4
<i>Medianos</i> (Medium)	5,000 – 7,500	34.4 – 51.7
<i>Grandes</i> (Major)	Up to 10,000	Up to 68.9

Table 1: Pastureland measurements for Puerto Rico, 1775. Source: Moscoso (1997).

In addition to the grazing lands, many historical documents mention the abundance of feral cattle on the island (also known as *ganado montresco* o *cimarrón*); these animals provided the main source for the illegal trade of hides, meat and tallow (Gelpí-Baíz 2000: 8). The production of hides along the lines of contraband became very

profitable, leading to the indiscriminate slaughtering of feral cattle on a large scale only to obtain their leather (Gelpí-Baíz 2000: 48). This, along with the butchering of young cattle by packs of wild dogs and the exhaustion of lands to graze, contributed to the decimation of this practice (Gelpí-Baíz 2000: 48).

By mid-17th century, the Spanish Crown attempted to strengthen its political, economic and military ties with its Caribbean colonies for fear of losing them to foreign powers (Cosme-Arroyo 2005). The main centers of official commerce were in the north (Capital) and the west (Aguada), while the bays of the southern coast and to the east were the epicenter of unofficial transactions (Picó 2006: 77). At the same time, the southern coasts of the island remained vulnerable to piracy and invasion attempts because of the lack of fortifications. One of these counteracting measures was *el Corso* – a system of coastal surveillance whereby all ships approaching the island had to provide legal documentation prior disembarking- (Morales Carrión 1995:113). These measures had a minimal impact on contraband, and instead opened to the door for illegal transactions to take place alongside official trade (Gutiérrez-Meza 2012).

Between 1700 and 1765, Puerto Rico's population experienced an unforeseen increase from 6,000 to 44,000 inhabitants since the reported decimation of indigenous societies. Picó suggests that this population increase might have been due to lower mortality and higher birth rates, both probably associated with fewer incidences of epidemics, better nutrition, a more balanced ratio of females and males, which had been an obstacle in previous centuries (Picó 2006: 116). By the beginning of the 18th century,

grazing lands and sugar estates were controlled by an elite class, interrelated by family ties and occupying government jobs (Moscoso 200: 108-109). In this local context, the dominating grazing-based economy represented an outdated structure of land tenure that was detrimental to a large part of the population, whose only means of subsistence production was through incorporation as laborers in grazing lands (Picó 1984; Moscoso 1997). The individuals who lived under these conditions between the 17th and 18th centuries were known as *agregados* (which roughly translates to “aggregates”).

In 1757, the movement known as *demolición de hatos* (“parcel demolition”) was initiated by the wealthiest individuals from the farming sector, demanding the division and redistribution of grazing lands to stimulate the commercialization of coffee, sugar, and tobacco (Moscoso 1997, 1999). The first stage of this redistribution process took place in the lands closest to the capital: Bayamón, Cangrejos, Guaynabo, Río Piedras, Toa Alta, and Toa Baja (Delgado-Plasencia 2012: 9). By the mid-18th century, the founding of new towns became more structured and expansive following the breaking-up of the cattle estates. The foundation of new towns due to population increase was a result of a long process of breaking up previous grazing lands and the establishment of new towns resulted from conflicts between upper-class farmers and the owners of grazing lands (Picó 1986: 120). Moscoso emphasizes throughout his works that this process was not the result of disputes between farmers and herders but rather due to the dissatisfaction with the traditional mercantile system, and private interests in expanding the sugar industry. The *Real Cédula de 1778*, gave deeds over land to proprietors, conditioned to

productivity and payment of taxes, but its implementation got delayed until 1785 due to ongoing conflicts with the British (Picó 2006: 171). From 1757 to 1790, land concessions started around the capital and the eastern region aimed at enhancing the productivity of the island.

Industrialization of Crops and the Displacement of Cattle (1790-1890)

The 19th century in Puerto Rico comprises one of the most dynamics periods of the island's history. The Peninsular War (1809 – 1814) broke out between France, Britain, Spain and Portugal. Following the closure of the war and, out of fear that the Haitian Revolution would promote rebellions by slaves, the Spanish Crown passed a series of economic reforms to maintain its foothold on Puerto Rico. The *Real Cédula de Gracias de 1815* promoted immigration from European regions into Puerto Rico, producing an influx of workforce, capital, and new technologies that changed the agricultural and economic panorama of the island.

New technologies like the *tren jamaicano*, hydraulic and steam engines, chimneys and boilers resulted revolutionized the efficiency of sugar production (Picó 2006: 176; Cabrera-Salcedo 2010: 293). However, this demographic shift had the unintended consequence of displacing local populations that lacked enough capital to finance their agricultural endeavors and compete with the markets of the sugar estates. In the decade of 1820, the municipalities with more slaves –Ponce, Mayagüez, and Guayama- became the main centers of sugar production and sugar (Picó 2006: 202). The

rapid expansion of the sugar estates (*industriales azucareras*) resulted in the accelerated settlement and cultivation of coffee and tobacco up the slopes of the mountainous interior. The establishment of the plantation systems fueled the demand for labor force and led to the increase in the importation of more African slaves until 1840 (Picó 2006: 198).

Restrictions posed to the introduction of slaves led to a shortage of labor necessary to maintain the expansion of the sugar estates. For this reason, landowners pushed the government to force peasants devoid of land to work as wage-laborers. The result of these measures was the enforcement of a series of laws that required men and women to work for these landowners under a strict and oppressive regimen known as *Régimen de la libreta* (1849-1873). Under this regimen, laborers had to carry notebooks where their employers would make annotations about their behavior at all times (Picó 2006: 191). On March 22 of 1873 the institution of slavery was officially abolished in Puerto Rico, but under certain conditions. Newly freed slaves had to maintain three year contracts under wage labor –often having to resume working for their former masters-, and would not have civic rights until five years later. (Picó 2006: 228-230).

Between 1820 and 1875 sugar cane production was in its apogee, and the economic refocus led to the substitution of grazing lands for sugarcane plantations - mostly at the hands of newly arrived foreigners-, displacing small farmers (Picó 2006: 201). The lack of banks and financial institutions led to the creation of credit systems that allowed small businesses in the rural and urban sectors to flourish. Under this credit

system, farmers paid their debts with their harvests. These exchange systems eventually led to a collective debt of farmers when the market for brown sugar collapse due to the new emphasis on refined sugar (Picó 2006:203-204). To counteract this sugar-based crisis, farmers and merchants shifted their focus to coffee production, which experienced ups and downs until 1870 (Picó 2006:205).

In the decade of 1880, Brazilian coffee industry experienced a pronounced decrease that created a niche in the global markets where Puerto Rico to sell its coffee. The apogee of coffee was further propelled by credit accessibility, the development of roads, the availability of cheap labor, but led to the widespread deforestation (Picó 2006: 218). The apogee of coffee would not last long because of the nature of the credit mechanisms in the island. The financing of local agriculture was conditioned by the fluctuation of prices in the international markets and the financing of merchants by external interests. Thus, this relationship tied merchants with suppliers from Europe and the United States, broadening the effects of national debt (Picó 2006: 220).

The process of herd demolition continued well into the 19th century, as was the case for municipalities like Camuy and Arecibo, where final division of grazing lands was completed by 1837 (Picó 1984; Delgado-Plasencia 2012). Process of *repartimientos de tierras* followed the division of grazing lands, leaving around 2,000 km of unlabored land (*tierras realengas*) between the Central Mountain Range and the northern and southwestern lowlands. These lands were sold between 1820 and 1868 (Picó 2006: 201). While the overall agriculture of the island experienced marked shifts towards the

intensification of monocultures, cattle ranching continued to be an important component of export products throughout the 19th century. During first half of the century, new breeds of cattle were introduced to increase the quality of the production (Cruzado-Carrasquillo 2012: 67). The ranching industry continued to expand and intensify, mostly along municipalities that experienced a decrease in other types of agricultural production such as Vega Baja and Toa Alta, in the northern coast (Cruzado-Carrasquillo 2012: 2).

By the end of the 19th century, Puerto Rico's governance transferred to the United States under the Paris Treaty (1898). In 1899, hurricane San Ciriaco caused some of the great mortality rates ever recorded in the island, at the same time that severely impaired the coffee industry. Recuperation of coffee plantations would take at least five and would necessitate capital to finance it; faced with these options, the North American government opted instead for the financing of the sugar and tobacco sectors (Picó 2006:257). This crisis led to an exodus from the mountainous interior into the metropolitan areas located near the coasts, and emigration to Hawaii, Ecuador, and other countries in the following decades (Picó 2006: 257-259).

Chapter 4: Grazing, Pastures and Changing Landscapes

Tropical savannas and grasslands occur in the semi-arid to semi-humid climate regions of the subtropical and tropical latitudes of Earth. The distinctions between these classifications lie in the type of plants that dominate the overall botanical composition of the area. In grasslands, grasses and herbaceous plants dominate. Savannas comprise grassland characterized by drought-resistant species with a presence of scattered trees (Miller and Lugo 2009: 420). At the beginning of European colonization, cattle economies in the Caribbean, Orinoco, and the Argentinian Pampas benefited from the abundance of natural savanna landscapes maintained by anthropogenic fires (Murgueitio et al. 2011: 1655; Etter, Mcalpine, and Possingham 2008: 7). Watlington (2009) and others⁶ have proposed that anthropogenic savannas were an important component of the Taíno domesticated landscapes, and that the presence of these anthropogenic landscapes was suitable to the introduction and rapid adaptation of grazing animals into the Caribbean. Grassland and savanna environments have a series of characteristics which aid landscape stability, but this can be significantly affected by grazing activities. To understand how cattle management might have changed Puerto Rico's landscapes requires an understanding of how these ecosystems interacted with grazing activities.

Grasses constitute one of the main food sources for cattle and other livestock, but grazing activities often also include defoliation of shrub and trees, and eating of fruits and

⁶ Reinaldo Funes Monzote discusses the works of previous authors on the presence of anthropogenic savannas in Cuba by the time of conquest. (p. 9-10).

their seeds. Grazing ungulates entering an area for the first time establish a general pattern of behaviors which increase the propensity of pastureland quality and health to deteriorate over time. At first, grazing focuses on short-leaf areas, avoiding previously ungrazed patches of vegetation but with time expand into these areas ((Teague, Dowhower, and Waggoner 2004: 98). Stocking numbers are usually higher in these short-leaf areas, with taller perennial grasses progressively replaced by shorter ones, then by annual species until eventually the ground is barren (Teague, Dowhower, and Waggoner 2004: 98). This selective behavior combined with the effects of trampling alters soil characteristics with repercussions to landscape stability and eventual biogeographic transformations at larger scales.

Soil compaction usually results from trampling by cattle. Soil structural characteristics such as bulk density are reduced, decreasing water infiltration and retention rates, and increasing the propensity for runoff and erosion. Decreased bulk density inhibits nutrient cycling, root penetration and nutrient uptake by plants, reduces primary productivity. In semi-dry and dry regions, a barren surface increases reflectance and evapotranspiration rates, leading to a rise in temperatures that can exacerbate the effects of drought. High rainfall areas are more prone to over-saturation of the soil due to compaction, thus sheet-erosion might be experienced more readily. At the landscape level, grasslands provide generalized stability through their roots systems and fast turnover rates. Grasslands generally dominate in landscapes where moisture regimes are sufficient for the growth of grasses, but where this and other environmental conditions

pose constraints to trees and other plants (Boval and Dixon 2012: 749). Grasses contribute high amounts of organic matter into the soil micro-biome, maintaining productivity and vegetation over the landscape at fast rates. For example, the time lapse between photosynthesis and carbon processing by soil microbes can take hours, while in forested areas it takes days (Bardgett and Van Der Putten 2014: 507). These qualities have the potential to ameliorate the effects of climate and disruptive processes such as erosion, which often leads to channel aggradation and reduced flow capacity in alluvial landscapes.

Pastures and Forest Recovery Dynamics in Puerto Rico

Small-scale studies of forest recovery on pastures have been carried out in Puerto Rico. Aide et al. (1996) studied forest structure and composition in 23 abandoned cattle pastures along an elevational gradient from 10-450 m in the Luquillo Forest Reserve, northeastern Puerto Rico. This region is representative of subtropical wet and moist forest life zones. The overall results of this study suggest various trends for succession and forest recovery dynamics in pastures. First, woody plant density, species number, and diversity were lowest during the first ten years following abandonment, but increased rapidly after 10-15 years. Elevation and age since abandonment were significant to species composition with elevations higher than 100 m> At higher elevations *Miconia prasina* (shrub) was the dominant pioneer species, while in lower elevations shrubs and small trees were first to colonize. The study area has a complex land use history of deforestation, agriculture and grazing going back 150-years (Aide et al. 1996: 358).

Analysis of soil structure and nutrient content suggest that 40-50 years of grazing (coupled with sugarcane agriculture in some sites) were not likely to limit forest recovery in the area (Aide et al. 1996: 544).

On a similar study, Myster (2003) looked at the first five years of plant community structuring after pasture abandonment in eastern Puerto Rico, and compared them with a coffee plantation. The results showed that grasses (i.e. *Panicum* spp. and dicotyledonous herbs) dominated the plot within the first three years. After the fourth year, ferns and woody species gradually increased with some tree and shrub species dominating, and decreased the dominance of grasses. In comparison, coffee plantation plots showed that coffee trees continued after abandonment along grass dominance with herbs, vines, and ferns attaining greater cover than in the pasture. His study also found that species-specific strategies and mechanisms were driving succession patterns. He suggests that soil compaction, increased bulk density although pastures have had crops growing in them previously; they have a distinct recovery that may be due to the presence of cattle because trampling compacts the soil, increasing soil bulk density, more resistance to penetration, the creation of hummocks, and deposition of dung.

Rivera and Aide (1998) conducted a study of contrasted patterns of forest recovery in abandoned coffee plantations and pastures in Ciales and Morovis, northern Puerto Rico. They looked at eleven pasture sites ranging from 15 to 35 years' abandonment on alluvial valleys overlaying the karstic region. They found that abandoned pastures had greater woody species diversity in comparison with coffee sites.

Initial recovery composition in the pastures changes with more shade-tolerant species taking over time. Nearby forest patches and the presence of bats appear to have enhanced forest recovery in the area.

Brown and Lugo (1990) compared soil organic carbon and nitrogen content to succession patterns from forest conversion in subtropical-wet and sub-tropical dry forests of the U.S. Virgin Islands and Puerto Rico. Their study suggested differential soil C and N loss between forest-to-crop and forest-to-pasture conversion. Conversion of forest-to-pasture exhibited less C and N loss possibly associated to grasses maintaining constant vegetation cover on the soil, reducing soil temperatures and increasing rates of biological activity, and turnover rates that add organic matter from belowground to the soil. Cropland-to-pasture conversion in subtropical forests of Puerto Rico has been found to lead to soil C accumulation (Lugo and Sánchez 1986). The time of recovery of soil C and N suggested in this study is approximately the same in the three life zones investigated, with N recovering between 15-20 years and C at 40-50 yrs.

Zimmerman, Pascare, and Mitchell Aide (2000) studied barriers to forest recovery on abandoned pasture in subtropical wet forest of at least 40 years of age. Soil nutrient availability between the pasture nearby forests was negligible but earthworm presence was much higher than in the forest (Zimmerman, Pascare and Aide 2000:351). Their results showed that seed bank and seed rain were negatively affected with increased distance from the forest edge, and the shrub *Miconia prasina* dominated in both (Zimmerman, Pascare and Aide 2000: 353). Restoration of pastures benefits initial rate of

succession by establishing a canopy earlier and providing a habitat for the dispersal of other native species. Pioneer species (*C. schreberiana* and *P. berteriana*) following natural disturbance do not readily grow in abandoned pastures. Common colonizing species *M. prasina* and *T. heterophylla* do appear to facilitate colonization of many common forest species that are unable to establish in recently abandoned pastures (Zimmerman, Pascare and Aide 2000:358).

The patterns of succession and forest recovery observed for these pastures might not be transferable to other regions in the island where cattle management had a more extensive and intensive presence. For example, a recurring observation in the historical literature was that the eastern edge of the island produced some of the best quality pastures in contrast to those in the west. The differences between rainfall regimes, topography, and soil quality at both ends of the island might appear slight, but the effects of these local conditions coupled with internal economic, demographic, land use dynamics have likely led to different environmental and societal outcomes. The importance of local environmental conditions made a difference to the development of cattle management in Puerto Rico. Previous land uses probably impacted vegetation cover and hydrology in the long term.

Hypothesizing Four Centuries of Cattle Impacts in Puerto Rico

It has been 500 years since the introduction of livestock species into Puerto Rican environments, making the presence of grazing ungulates a potential source of long-term

ecosystemic disturbance and landscape transformation. Puerto Rico is an extremely biodiverse archipelago, thus the effects of cattle grazing will be contingent on the particular trajectory of cattle ranching in relation to local conditions of topography, rainfall, fauna and vegetation, stocking rates per designated area, and contemporary land uses. In this section, I articulate the history of cattle management with available environmental data to propose a generalized picture of the possible impacts of this practice along different locales in the main island.

Most historical accounts point towards the generalized presence of feral cattle throughout most landscapes of Puerto Rico since the 16th century. From the onset of conquest, it is known that a variety of livestock species were introduced into the island with the intent that they would reproduce freely throughout the landscape (Domínguez-Cristóbal: 41). These animals quickly proliferated due to the mild climate and the abundance of pastures –possibly anthropogenic savannas. The open-range system of management that prevailed during the 16th century most likely permitted their reproduction beyond the margins of *hatos*. In fact, colonists in the 16th century recognized four types of cattle: pen, tame, *alzados* (branded cattle escaped to the mountains) and feral (Gelpí-Baíz 2000:46). Cattle behaviors suggest that individuals might have spread to a variety of locales but the spatial arrangement of grazing patches is also dependent on the distribution of topographic features, water availability, and social interactions of the animals (Teague et al. 2004:99). This means that feral grazing into the mountainous interior might have been concentrated in areas of lesser inclination

gradients.

Other accounts for the 16th century point to other possible impacts of cattle grazing. Juan Melgarejo, in his 1582 description of Puerto Rico⁷, explains that cattle and other livestock acted as seed dispersers of the Guayabo tree, as seeds spouted from their manure. The presence of guava and other genera of shrubs (*Miconia*, *Tabebuia*, and *Casearia*) are associated with accelerated forest recovery after pasture abandonment in Puerto Rico by establishing canopy during early stages of succession and providing a habitat for the dispersal of other native species (Cubiña and Aide 2001: 266; Zimmerman, Pascare and Aide 2000: 358). Thus, ruminant activities could have speeded the process of succession and recovery patterns of forests in Puerto Rico by aiding the process of seed dispersal. Although seed dispersal might have been facilitated by grazing, its effects can be counteracted by changes in land use which alter seed bank composition (Aide et al. 1996:354).

In the 16th century cattle numbers within *hatos* ranged anywhere from 1,000 to 2,000 heads (Gelpí-Baíz 2000: 48). However, there is an account⁸, of a herder in the town of Aguada who owned 12,000 heads of cattle –according to the observant this was supposed to be one the least suitable areas in the island for raising cattle. This observation suggests that cattle numbers were higher, but regardless of the limitations of extrapolating this observation to other areas of the island, this highlights the benefits of

⁷ *Boletín Histórico de Puerto Rico*, Vol. I, Tomo I, p. 77.

⁸ *Boletín Histórico de Puerto Rico*, Vol III, Tomo V, p. 65.

integrating historical sources into a geoarchaeological project. The high demand for cattle products –supplied through illegal trade- during the 18th century could have led to the decimation of their numbers in some areas.

Municipality	Total
Arecibo ^a	5,988
Manatí ^b	4,780
Coamo ^c	4,780
Caguas ^d	3,188

Table 2: Total cattle population in the main cattle ranching regions of Puerto Rico, 1775. Source: (Moscoso 1997).



Figure 4: Map of Puerto Rico showing distribution of cattle-ranching during the 18th century. Data from Table 2 corresponds to A, B, C, and D, cattle-ranching loci. Sources: (Ledru 2013; Abbad y Lasiera 2002, Moscoso 1997).

Cattle management practices in the island from the 17th to the 18th century

continued a generalized pattern of distribution which concentrated pastures along the lowlands and interior valleys. As discussed in the previous chapter, the establishment of the first colonial towns stayed along the coastal fringes and subsequent settlement branched out from these loci. By the late 18th century, *hatos* were classified according to their extension and this type of land use covered 83% of the total landscape, while the remaining percent was dedicated to agriculture in various levels of intensity (Moscoso 1997: 16). Historical data suggests that cattle management expanded and intensified for to supply the illegal markets. We know though, that the reason why hides became such a productive resource for this time of crisis was because of the natural productivity of cattle within the landscape. The presence of agricultural practices often occurred within the ranges of *hatos*, although cattle were maintained away from these areas. An important variable to consider is the possibility that herders in the colonial period practiced some variation of today is referred to as silvopastoral system. These landscape management systems combine fodder vegetation (i.e. grasses and legumes) with shrubs and trees, at the same time that sustain biodiversity at the local scale (Murgueitio et al. 2011: 1656).

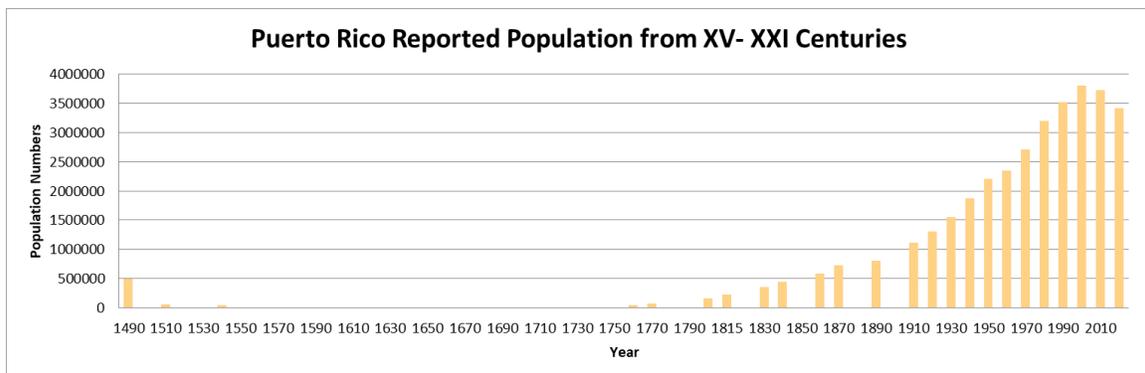


Figure 5: Reported population of Puerto Rico, 15th to 19th centuries. Graph prepared by Dr. Samuel Wilson.

Although there is a clear gap in reported population numbers for the island between the mid-1500s to mid-1700s, we can infer that population numbers stayed relatively low during these two centuries, and in fact continued to stay low until the beginning of the mid-19th century. Various historical accounts also attest to a vastly unpopulated landscape where villages were small and scattered throughout the island. Low population numbers meant fewer hands to manage and reproduce cattle in larger numbers, while land tenure politics were key in maintaining cattle numbers spread throughout vast expanses of land. These large estates were in the hands of few landlords, and it must not have been until the 19th century, when landownership became more accessible other sectors of the population, that greater numbers of cattle were kept in relatively smaller expanses of land and closer to streams and rivers, where their stocks numbers might have reached the carrying capacity of the land.

The 19th century saw a shift in economic interests and along with the modernization infrastructure, administrative, labor and social reforms. The expansion of industrial agriculture interests focused on the production of sugar, coffee, and tobacco drove intense settlement pattern towards the mountainous interior. Main areas in the lowlands, particularly in the northern region, were rapidly converted to cane fields but data suggests that areas destined for cattle pastures continued to rise during the century. By 1828, the total are of land was divided into cultivation (3%), pastureland (24%), and

forest and other uses (73%); by 1900: cultivation (12%), pastureland (52%), and forest and other uses (36%) (William 1943: 3). These percentages, plus the numbers of live cattle and hides exports, suggest that cattle management continued to be an extensive and intensive practice throughout the 19th century. Cattle censuses from this period suggest an average of 2,321 cattle heads within municipalities (*see Figure 6*).

Year	Live exports	Hides (lbs.)	Year	Live exports	Hides (lbs.)	Year	Live exports	Hides (lbs.)
1828	6877	517800	1844	4129	651812	1860	5524	672472
1829	6189	419100	1845	3623	577238	1861	5896	407889
1830	6073	448700	1846	4510	689973	1862	5803	600854
1831	4179	476800	1847	4476	677146	1863	5927	496855
1832	4072	388700	1848	4372	745880	1864	7513	449868
1833	3998	445200	1849	3700	519070	Total	174121	20893108
1834	431	562700	1850	4376	544752			
1835	4426	600600	1851	6053	362706			
1836	4911	868600	1852	6220	508820			
1837	4221	1336111	1853	6019	507251			
1838	3939	537603	1854	5678	552502			
1839	3891	673832	1855	4425	802762			
1840	3590	607385	1856	6153	685196			
1841	3613	543984	1857	8071	604666			
1842	3548	507052	1858	6328	444646			
1843	2595	509777	1859	6285	396674			

Table 3: Live cattle and hide (lbs.) exported from Puerto Rico to other Antillean islands. [Annotations by José Julián Acosta, In *Historia geográfica, civil y natural de la Isla de San Juan Bautista de Puerto Rico* by Iñigo Abbad y Lasierra].

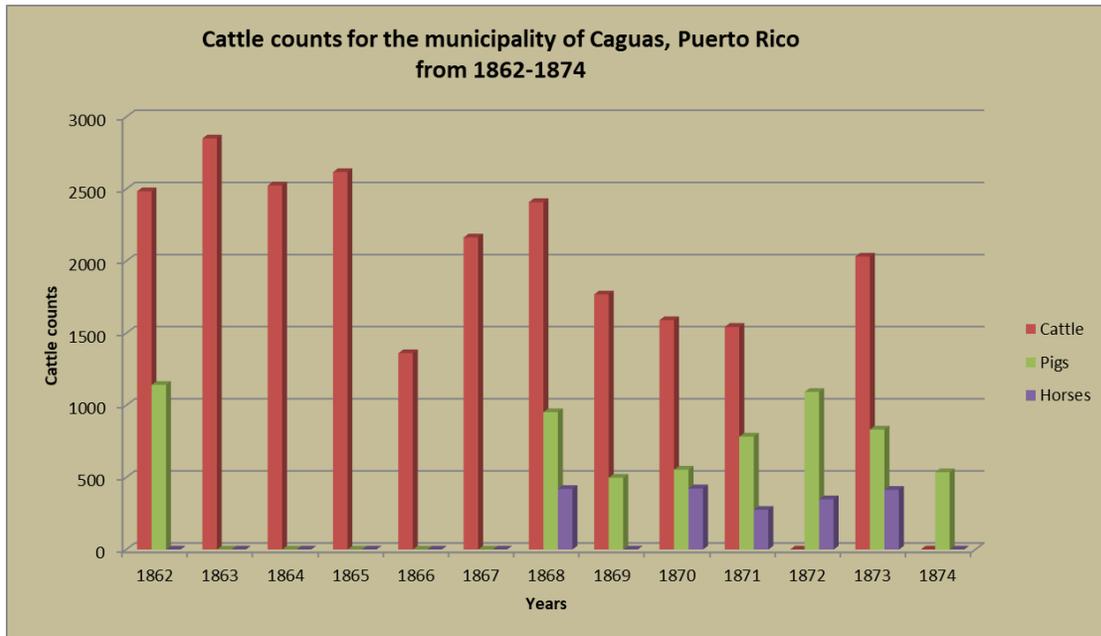


Figure 6: Graph showing the amount of cattle, pigs, and horses documented in the municipality of Caguas from 1862-1874. Absent bars indicate that no records were found for those specific years.

Contrary to some historiographic assertions the technique of arado, or pulled oxen, was implemented in Puerto Rico since the 16th century (Moscoso 2000:48). This land-preparation technique for cultivation reaches deeper parts of A horizons in soils, leading to higher destabilization of soil properties important for landscape stability. Alteration of the surface horizon of soils not only changes to soil, but also removes the organic-rich layer and disrupts rates of aggregation and microbiotic community composition (Lal 2003: 440). Aggregation of organic and inorganic particles stabilizes the soil and decreases the propensity of erosion by water and wind, limiting soil loss during periods of reduced vegetation cover due to droughts or herbivore activities (Bird

et al. 2007:115).

Another indirect impact associated with European colonization and probably exacerbated by the expansion of livestock into these environments is the introduction of exotic species of grasses. Fire resistant and graze-tolerant grasses were introduced into the New World from Africa to enhance the productivity of pasturelands for cattle management (Sluyter and Duvall 2016: 307; Miller and Lugo 2009: 285; Etter et al. 2008: 18). In Puerto Rico, these exotic species continue to expand, altering ecosystems and fire regimes that impede the regeneration of native species (Miller and Lugo 2009: 285). Here is a topic where a geoarchaeological study can expand current knowledge on ecosystem dynamics and exotic species by providing empirical data on the dates of introduction of some of these species. For example, Allen (2010) proposes that the spread of European weeds in California coastal environments was a result of dispersion by cattle. Using pollen and seed remains sampled from the adobe bricks from a previous study found that the proliferation of European weeds was already in place by 1769 (Allen 2010:71).

According to historical sources and the previous overview of landscape management practices for the island, the period when Puerto Rico most likely experienced forest recovery was between the 17th and 18th centuries, when human population numbers were at their lowest since pre-colonial times, and major settlement in the mountainous interior was reportedly low or inexistent. Understanding current forest recovery trends and landscape structures could benefit from localized studies that account

for 3,000 years of pre-colonial niche construction and landscape management that followed by 500 years of European colonialism. The accumulation of all these practices and social dynamics have undoubtedly led to significant alterations to soils, sedimentation and erosion rates, and plant community distribution which are still perceivable today.

Conclusions

In this report, I employed a Political Ecology approach to outline the historical events that shaped the development of cattle management practices in Puerto Rico from the 16th to the 19th century. The goal of this overview was to frame the development of cattle management practices in Puerto Rico's cattle management practices have a 500-year history that began with the institution of Spanish colonialism in 1508. In the following centuries, the distribution of cattle management throughout Puerto Rico's landscapes was driven by shifts in external political and economic interests. From the 17th to the 19th centuries, the Spanish Crown focused on passing laws that would support its colonialist enterprise. This came at the expense of the hardships faced by its Caribbean colonies. At the local scale, Puerto Rico's economic practices and their distributions throughout the landscape were continuously shaped by the need to supply the local population with basic products, and the clashes between elite classes and the common people. During these struggles, cattle-raising was envisioned and exploited as an alternative source of income during periods of economic instability.

The natural absence of ungulates in the native fauna of Puerto Rico makes the introduction of livestock a possible source of environmental transformation. Anthropogenic and natural disturbances lead to ecosystem fragmentation, loss of biodiversity, and increased vulnerability to invasion by other exotic species (Moreno-Casasola, López Rosas and Rodríguez-Medina 2012:186-187). During the period under study, Puerto Rico's cattle management practices were concentrated along the coastal

lowlands and low elevations of the mountains, and valleys of the interior. As discussed in the previous chapter, the presence of cattle in Puerto Rico has influenced patterns of seed dispersal, soil characteristics, vegetation recovery trends, and the introduction of exotic plant species. However, most empirical studies of pastures in Puerto Rico have considered only the short-term (<80 years) impacts of these dynamics.

Understanding the impacts of the introduction and management of cattle over Puerto Rico's landscapes would benefit from. Implicated in this long-term perspective are the feedbacks between landscape change and adaptation of human strategies to cope with environmental and socio-political changes. These feedbacks will be better assessed through a geoarchaeological study that integrates historical, archaeological, and sedimentological data. For example, in the dry areas of the southern and western coasts, the effects of overgrazing could have been experienced more readily, but evaluating these scenarios must consider how people adapted their management practices to overcome these challenges. Traditional ecological knowledge associated to the management of cattle was a part of the repertoire of European and African communities that increasingly constituted the cultural landscape of Puerto Rico after the 16th century.

Moving forward

Tracing the spatial and temporal characteristics of landscapes as human behavior modifies them through time allow us to address important questions about cultural interactions in the past. In this case, the study of land use destined for cattle grazing

proves an important intersection of the economic, political, cultural, and environmental histories of Puerto Rico. In the main island, cattle management is the longest standing economic activity since colonization to the present. This practice has had a myriad of environmental consequences in the Americas; most have resulted in landscape degradation. Despite these detrimental effects, cattle-ranching continues to be a valued practice in the Americas. In Latin America -as in the case of Puerto Rico- cattle-raising has been a reliable alternative when other modes of subsistence acquisition fail (Hoelle 2011; Murgueitio et al. 2011). This report highlights the relevance of this topic, and answering remaining questions will further our knowledge on present day landscapes. Some of the questions that remain from this exercise are: how did pre-colonial societies modify their landscapes through agricultural practices? How did these anthropogenic landscapes serve as a type of landscape capital to cattle management economies during Spanish colonization? How did centennial-scale grazing activities alter landscape stability/instability through changes in vegetation cover, soil characteristics, and sedimentation rates? I propose that a study that reconstructs sedimentation rates, erosion, and vegetation change along a hydrological basin in Puerto Rico can begin to answer these questions. Detecting the presence of cattle in these sedimentary archives can be accomplished through the identification of fungal spores (*Sporormiella*), which grow in the dung of herbivores (Raczka et al. 2016). Interpretations of environmental transformation would be enhanced by integrating various lines of evidence: historical documentation, archaeology, and environmental data.

A long-term perspective allows us to recognize century and millennial-scale patterns of social and environmental change feedbacks. Understanding these processes can reconnect seemingly divisive stages of human history in a place. An example of this is the concept of *landesque capital*, or the creation of productive landscapes through intentional or unintentional improvements to the land (Erickson and Walker 2009; Bevan et al. 2013; Beach 2016; Scarborough and Valdez 2014). This type of beneficial legacy is inherited by future generations or social groups, which can use, maintain or transform it according to their respective interests and knowledge (Brookfield 2001). Political Ecology frames human-environment interactions in ways that historical and political processes can be correlated with a physical record of anthropogenic impacts through time. Anthropogenic activities are not necessarily beneficial or degrading to ecosystems, but their outcomes increasingly transform environments in ways that are perceivable through the detailed study of the archaeological record (Balée 1998; Balée 2006). I argue that studying Puerto Rico's cattle management practices from a long-term perspective can add to the discussion initiated by Karl W. Butzer's and William Denevan's proposal about the transformation that the New World experienced after European colonization. In Puerto Rico, some strides have been within the literature to emphasize the need to investigate the environmental legacies of 5,000 years of human occupation in the island (Rivera-Collazo 2015; Rivera-Collazo, Rodríguez-Franco, and Garay-Vázquez 2017).

Although not explicitly said, views on ecology and ecosystems dynamics in Puerto Rico are still embedded within the dichotomy of the "benign Indian" and the

“devastated colonial” landscape. Historical works have emphasized the fact of rapid indigenous decimation to the point of reproducing narratives that dismiss the role of pre-colonial landscapes in the success of colonization. I argue this conceptual divide is detrimental to the understanding of our history, but that it can be slowly overcome by engaging articulating the processes of “prehistory” with “history”. Furthermore, in the process of writing this report, it became very apparent that many ethnic groups have played a role transforming the landscapes of Puerto Rico. In this sense, I think that applying geoarchaeological methods can bring more visibility to the multiplicity of ecological knowledges (i.e. African) that have shaped our current environmental resources.

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