Pterocarpus officinalis DOMINATED WETLANDS AND DEPENDENT FAUNA

A Thesis

by

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ABSTRACT

Pterocarpus officinalis dominated forests are a rare ecosystem, found only in fifteen locations in Puerto Rico, all of which are adjacent to the coast and at risk from sea level rise, as well as nutrient pollution, upstream hydrological modifications, and deforestation. All forests of this type that were located further inland were destroyed by agricultural development during the early decades of the 1900's, in particular to grow sugarcane. Prior to this study, there was little information on the diversity of organisms that live in these forests. The central objective of this proposal was to examine the diversity and species composition of three *Pterocarpus* forests in Puerto Rico located near Humacao, Patillas, and Dorado, and to compare and contrast diversity among the three forests, and identify possible differences caused by human impacts or natural factors. The data was collected through surveys and sampling at each location. Transect surveys, plots, pitfall traps, insect traps and audio recordings were carried out to identify organisms including birds, mammals, amphibians and reptiles, insects, mollusks, invertebrates, plants and fungi.

The Dorado *Pterocarpus* forest is the most rich and diverse in terms of organisms and has the highest amount of native and endemic species, while the Humacao *Pterocarpus* forest is the least rich and diverse. Yet conversely, the Dorado forest is the smallest forest, covering only 2.4 ha, while Humacao is the largest, with an area of 150 ha that comprises 63% of the total *Pterocarpus*

coverage in Puerto Rico. The most obvious factor influencing richness and diversity among the forests is the adjacent land cover and history of the sites. Inflow and water sources may also be a factor that alters richness and diversity. This knowledge will assist in the appropriate management of this rare resource in the context of ongoing sea level rise, climate change, nutrient pollution, upstream hydrological modifications, and deforestation. Coastal managers need this information to manage and protect these valuable and rare ecosystems.

DEDICATION

I would like to dedicate this work to my family and friends for their support, especially to my mother, Gladys, and my sisters, Elizabeth, Chemika and Noemi, for their unconditional love and encouragement at every step and throughout my life; and because they have never left my side since this journey started. In addition, I dedicate this work to my boyfriend, Jay, for his continuous presence and his never-ending encouragement during the last two years. Last but not least, I thank two very special friends, Cynthia, for her presence and support in most of the field trips during the course of this research, and to Kimberly, for enabling me to fly back and forth between Texas and Puerto Rico.

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I want to extend a big thank you to Alejandro Santana, Natalia López, Carlos Zayas, and Cynthia Morales for their assistance in the field; to Billy Santiago for his help in the identification of species and the audio recordings; to the Puerto Rico Conservation Trust and the "Frente Ambiental Amigos por la Naturaleza" organization for the support and help during the field trips as well as providing us with access to the protected areas; to the Hispanic Leaders in Agriculture and the Environment (HLAE) program, especially to Dr. Piña for his great management and dedication to the HLAE organization. Finally, I would like to thank Dr. Feagin for his guidance and support throughout the course of this research, my committee members Dr. Lopez and Dr. Smeins, Dr. Denny Fernandez from the University of Puerto Rico-Humacao, and fellow explorer Ricardo Colón.

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1. INTRODUCTION

Tropical wetlands are considered among the most valuable (Costanza et al. 1989) and important ecosystems in the world due to the ecosystem services they provide (Mitsch & Gosselink 2007, Kabii and Bacon 1997).Wetlands are areas of relatively flat land in which the surface is permanently or sporadically flooded. Since it is regularly covered with water, the soil is saturated and lacking oxygen. The vegetation and fauna in the wetlands are generally endemic and differ from nearby upland areas. A wide variety of birds and reptiles are uniquely adapted to this kind of habitat.

Forested wetlands in particular are a feature of low-lying coastal areas in the Caribbean (Bacon 1990). Mangroves dominate most of these wetlands except for forested areas influenced by freshwater, where the leguminous tree *Pterocarpus officinalis* is the main species. Adapted to flooded ecosystems, *Pterocarpus* inhabits river floodplains, coastal basins and subtropical rain forests (Alvarez-Lopez 1990). *Pterocarpus* wetlands are now limited to small genetically isolated patches that are scattered throughout the Caribbean region, due to human disturbance and clearing (Rivera-Ocasio et al. 2006, Muller et al 2009). Although the floristic composition of these wetlands has been well described by Alvarez-Lopez (1990) and Imbert et al. (2000), these ecosystems have not received the same research attention as mangroves or upland rainforests (Imbert et al. 2000).

In the last century, Puerto Rico (Figure 1) lost nearly all of its *Pterocarpus* forested wetland cover (Helmer 2004). Today, the total area of *Pterocarpus* is estimated to cover only 238 ha in 15 locations. Furthermore, remnant *Pterocarpus* wetlands in Puerto Rico are restricted to the coast, abutting mangrove ecosystems (Cintrón 1983).The remaining stands now occur near their ecological limits in term of salinity (Rivera-Ocasio et al. 2007). Though work has also been done on drought tolerance (Lopez and Kursar 2007) and nutrient depletion (Medina et al. 2008), currently sea level rise and associated saltwater intrusion are the most serious threats affecting the *Pterocarpus* ecosystem. Salinities above approximately 14% can kill populations of these trees.

Pterocarpus wetland forests sustain a unique set of fauna, mainly composed of reptiles, water birds, amphibians, crustaceans and mollusks (Quiñones-Ramos et al. 1992). This wetland type is recognized by the Puerto Rico National Heritage Program (Schwartz 2004). Their importance rests on their limited representation elsewhere, high level of biological productivity, and outstanding floral composition. These ecosystems are also of unique interest to science and have enormous intrinsic and social value (Figueroa et al. 1984). The biodiversity of Puerto Rican wetlands is one factor that makes them a crucial ecological resource (Common Wealth of Puerto Rico HB 3385, Act 92 2008).

The central objective of this work was to examine the diversity and species composition of three *Pterocarpus* forests in Puerto Rico (Humacao Natural Reserve, Dorado Pterocarpus Forest Natural Protected Area and Punta Viento Wetland Natural Reserve). The specific objectives of this project were to sample and list a wide range of plant and animal species, and then to compare and contrast the diversity among the three forests, and identify possible differences caused by human impacts or natural factors.

2. METHODS

2.1 Study Sites

Humacao Natural Reserve. The Humacao Natural Reserve (HNR) in Puerto Rico contains the largest and best preserved *Pterocarpus* forest in the United States, yet the forested stand is only 150 ha in size (this is still over half of all its coverage in the USA, Alvarez-Lopez, 1990). Much of the original forest acreage was converted into sugarcane, and eventually into flooded lagoons (Figure 2).

FIG. 1. (a). Map of Puerto Rico in the Caribbean Sea (http://www.resortvacationstogo.com/vacations/Caribbean_Vacations.html).
(b). Locations of the three research sites in Puerto Rico.
Imagery courtesy of USGS

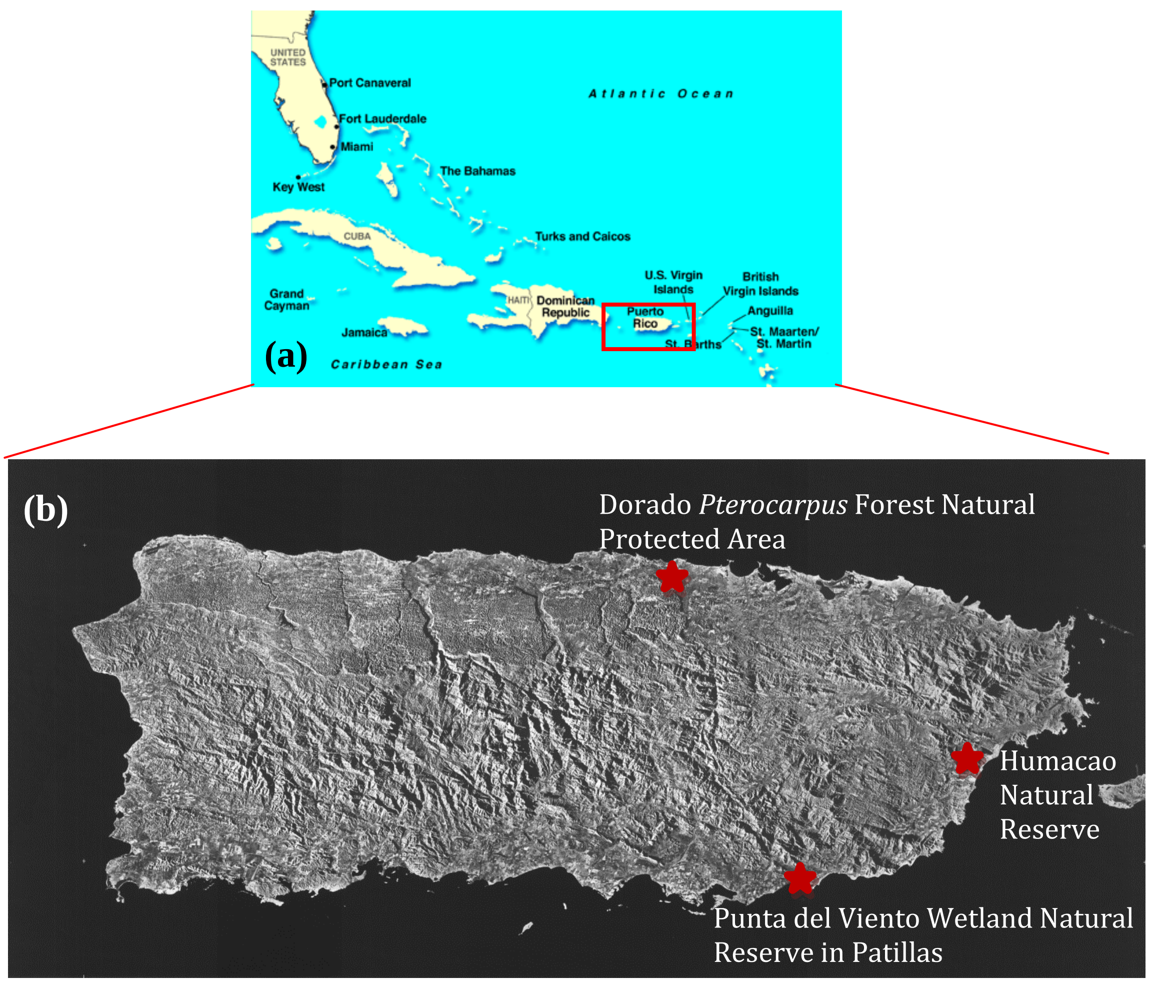


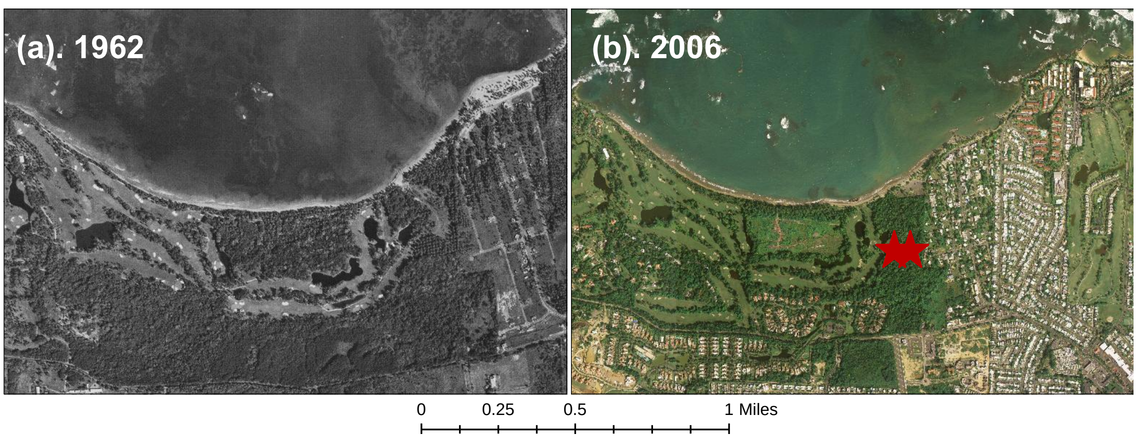
FIG. 2. (a). *Pterocarpus* forest area in Humacao, 1977 and (b). 2006. Imagery courtesy of USGS.

The community of Punta Santiago sits immediately adjacent to the forest, between the lagoons and the ocean. This low-income residential area flooded repeatedly after the 1970’s, as there was reduced forest cover to absorb or reduce this flow. Subsequently in 2000, the US Army Corps of Engineers modified the Antón Ruiz River and several other drainages, opening up a connection between the lagoons and the ocean, and allowed flood waters to flow into the ocean (Schwartz 2004). Unfortunately, this has also increased salt water intrusion into the lagoons and the adjacent *Pterocarpus* forest (Ferrer 2007). The remnant *Pterocarpus* wetlands are now threatened by salt water intrusion due to rising global sea levels, a problem that may be exacerbated by climate change over the next 100 years (Rivera-Ocasio et al. 2007).

<u>Dorado *Pterocarpus* Forest Natural Protected Area (DPFNPA).</u> The DPFNPA forest was donated to the Puerto Rico Conservation Trust as a requirement of the Planning Board (Junta de Planificación) to the proponents of a housing development project in the neighboring areas in 1995. The forest is located within the property of the Dorado Beach Hotel Corporation; a luxury

resort community (Figure 3). It is considered the best example of the forest that remains on the north coast of the island. The DPFNPA forest covers 2.4 ha. Endangered species like a *Peltophryne lemur* (Puerto Rican crested toad), *Eleutherodactylus karlschmidti* (web-footed coqui) *Sabicea cinerea* (Woody liana) and the *Epicrates inornatus* (Puerto Rican boa) have been known to occur in this forest (Quiñones-Ramos et al. 1992, Figueroa et al. 1984).

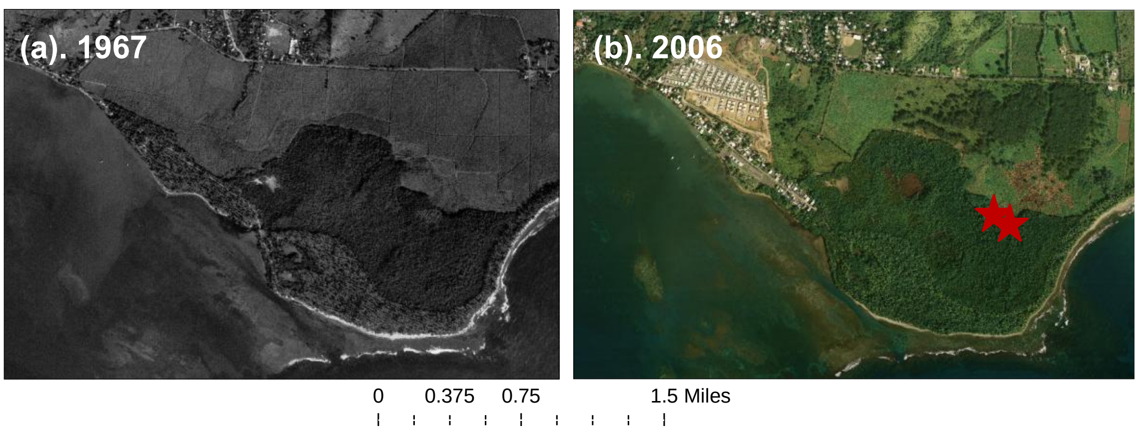
FIG. 3. (a) *Pterocarpus* forest area in Dorado, 1962, and (b). 2006. Imagery courtesy of USGS.



In 1984, the USDA repeated a 1926 study (Gleason & Cook 1926), finding that the *Pterocarpus officinalis* and six other tree species formed a climax swamp forest that did not change in composition in 54 years (1926 - 1984). However, forested area was reduced by 30 percent over this time period. The primary cause of this loss was anthropogenic tree-cutting and hydrological modification. Construction of a golf course west of the study area altered the drainage patterns, resulting in declines of both the *Pterocarpus* and old secondary forest.

Punta del Viento Wetland Natural Reserve in Patillas. The Punta Viento Natural Reserve forest is located on the south coast of Puerto Rico in “El Bajo” sector of the Municipality of Patillas (Figure 4). The forest covers an area of 4.6 ha and is enclosed within the Patillas Punta del Viento Wetland Natural Reserve. The reserve contains more than 500 acres of wetlands. In 2008, the community-based organization “Frente Ambiental Amigos de la Naturaleza, Patillas”, urged legislators to pass Act No. 92, designating the wetlands of Punta Viento as an ecological reserve (Common Wealth of Puerto Rico HB 3385, Act 92 2008).

FIG. 4. (a). *Pterocarpus* forest area in Patillas, 1967 and, (b). *2*006. Imagery courtesy of USGS.



2.2 Sampling and Identification of Organisms

A wide range of plant and animal species was sampled at the three different *Pterocarpus* forest areas in Puerto Rico (located near Humacao, Patillas, and Dorado). Organisms were identified to the lowest taxonomic level possible in two sections of each forest. The Dorado and Patillas forests were relatively small, and each of the sampled sections of the forest were relatively close together (approximately 67 and 141 m distance between the sampled sections, respectively) and thus relatively similar. Subsequently, for each of these two forests, we group the data section to present a single list for each forest. In contrast, the Humacao forest was relatively large and contained two different sections (approximately 1755 meters apart). The H1 section was composed of primary forest that had not been cut in historical times and has exclusively freshwater inputs, whereas the H2 section was composed of secondary re-growth after this portion of the forest was cut in the decade of the 1920's and has both saltwater and freshwater inputs. Subsequently, for Humacao, we present the lists for each section separately where applicable. Within each section of forest, two 80 m long, parallel transects were established. Each transect line had five points spaced 20 meters apart (Figure 5). The first transect line was used to identify birds, amphibians, reptiles, insects, invertebrates, vegetation, and fungi, whereas the second was used to identify birds only. All organisms were identified during four 2-4 day sample sessions over a two-year period, with at least two sessions in the rainy season and two in the dry season (Table 1). The driest months in Puerto Rico are from December to April and the wet months are from May to November. Two sessions were carried out during the wet season and two during the dry season.

FIG. 5. Transect lines for trap placement and sampling

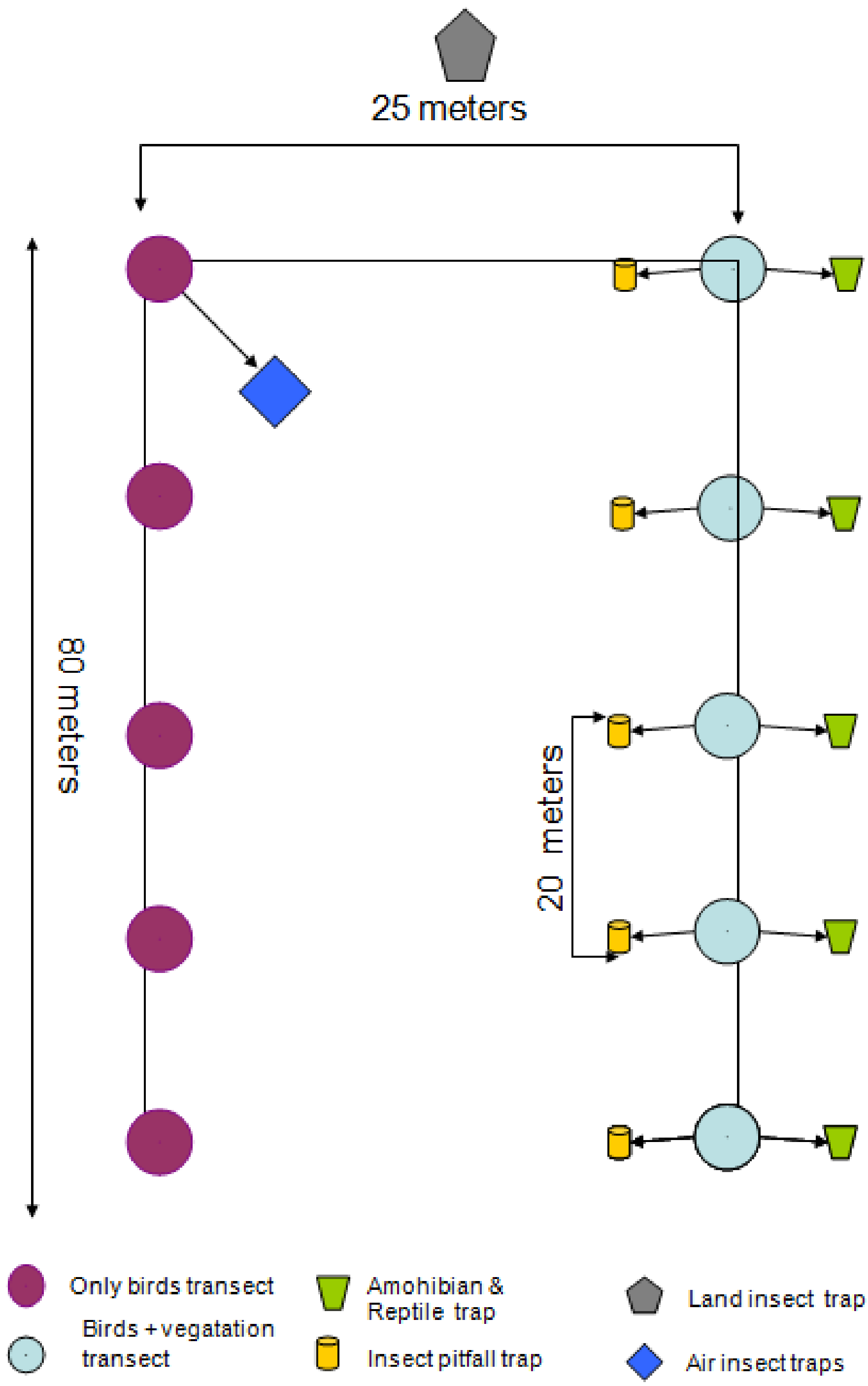


TABLE 1. Timeline of visits to sites.

	2011-2012		2012-2013	
	Session I	Session II	Session I	Session II
Humacao Natural Reserve	Nov 13/ Nov 17	March 15 / March 16	Dec 23 / Dec 24 Jan 11 / Jan 12	May 1 / May 2 May 6 / May 7
Dorado *Pterocarpus* Forest Natural Protected Area	Nov 28 / Nov 29	March 22 / March 23	Dec 20 Jan 19/ Jan 20 Jan 8 / Jan 9	April 15 /April 16 April 17 / April 18
Punta Viento Wetland Natural Reserve in Patillas	Nov 18 / Nov 19	March 20 / March 21	Jan 17 /Jan 18	April 11 /April 12 April 13 / April 14

To identify the birds, surveys were conducted at 7:00 AM to 7:30 AM in the morning (UTC -4). We recorded all birds observed and heard during a period of 5 minutes, and in a 5 meter radius around each point (Hill et al. 2005, Bibby et al. 2000). Audio recording equipment (Olympus, Olympus Linear Recorder, LS-11) was placed at the deepest part of the forest (last point on the transect lines) and left overnight to record both amphibians and birds. The lowest taxonomic level of each organism was identified by listening to the audio recording at intervals of every hour for 10 minutes of duration through the entire recording.

Reptiles and amphibian were additionally surveyed at 9:00 AM to 9:30 AM through visual observation and traps. Pitfall traps of 1.5 gallons with an opening of 27.75 cm were placed at each point and were recovered 24 hours later (Corn and Bury 1990, Lambert 2002, Hill et al. 2005). Amphibians, particularly the endemic coquis, were also identified using the audio recordigs, as mentioned above for the birds.

To identify insects, 16 ounce pitfalls traps were placed at each point and recovered 24 hours later (Raghavendra et al. 1990, Grootaert et al. 2010). Additionally, air traps (hanging) and ground level traps were placed at the deepest part of the forest transect for a 24 hour period.

Vegetation surveys were centered on each point along the transects (Figure 6). To estimate the understory cover, a 10 meter transect was stretched horizontal to the primary transect at each point and the percent cover by species was recorded within ten 1 m^2 quadrats (WHEP, Fidelibus and Mac Aller 1993, Hill et al. 2005). Understory was defined as the vegetation at the lower level in the forest, below 1.3 m in height. We also recorded the percentage of the ground that was covered by woody *Pterocarpus officinalis* roots in these quadrats. For trees, a 5 meter radius was measured around each point and then divided into four quadrants; for each quadrant, all tree species present were identified and the Diameter Breast Height (DBH) of the 5 largest trees was recorded. The DBH measurement was taken at 1.3 meters from the ground and included the buttress root width, which can be relatively large on these *Pterocarpus* in particular. The percent cover of the upper forest canopy was quantified using a Spherical Crown Densitometer. The overstory canopy cover was recorded for the largest single tree at every quadrant, for a total of 4 trees per point. The coverage of each single tree was taken at the 4 cardinal directions (North, East, South and West), and the average was taken to record the canopy cover of each tree. The single tree canopy cover values were then averaged to estimate the canopy cover in the transect area.

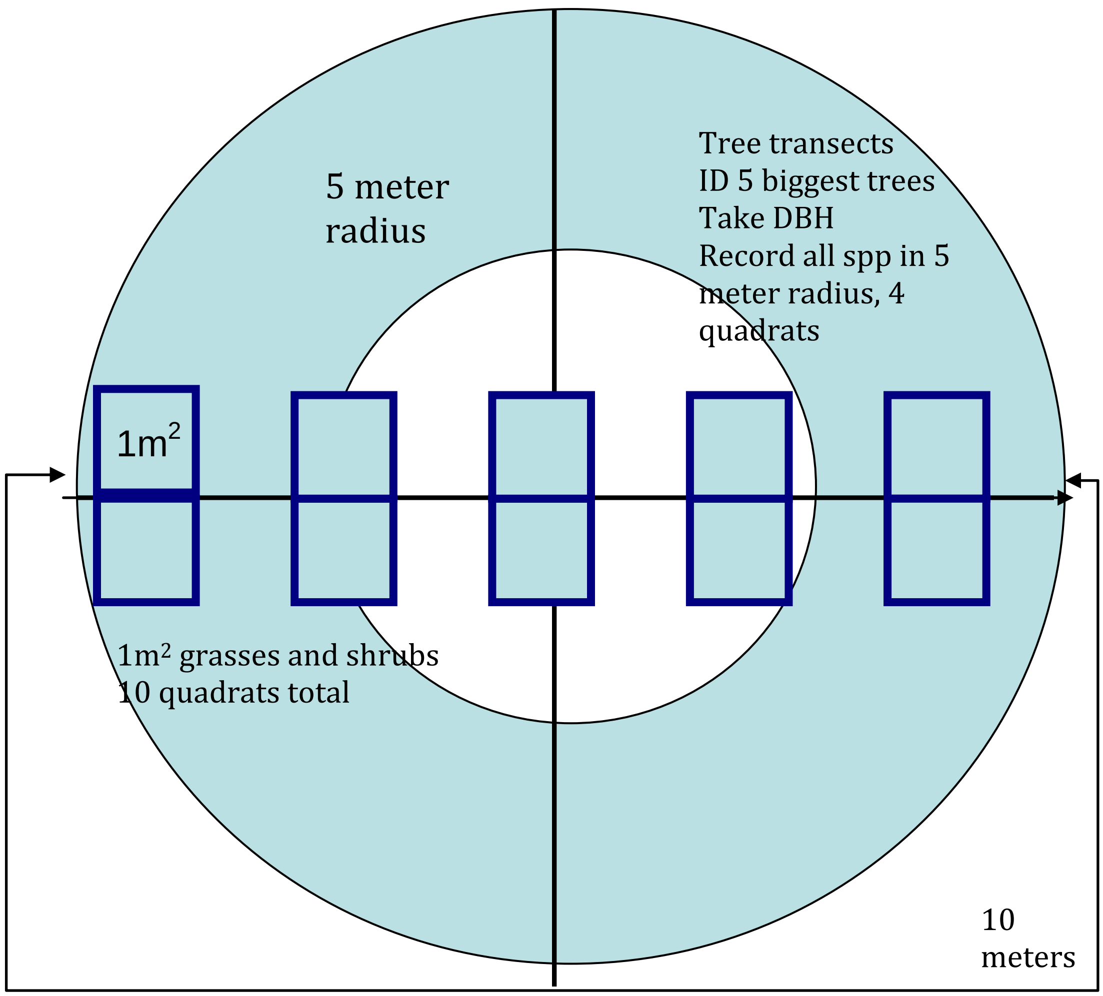
Fungi and fishes were also identified when encountering them along the transect sampling points (Hill et al. 2005, Schieck and Stambaugh 2006, Backiel 1980, B. C. Ministry of Environment, Lands and Parks 1997). The organism composition and variety among the different forests was then compared, and species were categorized as Endemic, Native, Common Resident, Visitor, or Introduced, when applicable. Shannon's H diversity was calculated as a total of all species within an organismal group, and for all species together, for a particular forest.

Shannon's diversity index (H) was calculated for each forest using the following formula:

$$H = \Sigma \, pi \ln (pi)$$

where pi is the relative abundance of each species, that is the total number of observation of the species divided by the total number of observations.

FIG. 6. Vegetation survey scheme, centered on transect points



2.3 Soil, Land Cover, and Environmental Factors

We sought to identify the environmental differences among the three forests that were related to human impacts or natural factors. Temperature and precipitation records were collected from NOAA-NCDC for nearby stations for the period of 1980 to 2010 (NOAA-NCDC 2012). The station for the Dorado Forest data is Dorado 2, WnW PR, for the Patillas forest is Patillas PR US and Guayama 2E, PR US, and for the forest in Humacao is Roosevelt Roads.

Soil samples were collected from each forest, from the surface and at every 10 cm of depth to a depth of 40 cm. Samples were immediately bagged and sent to Servi-Tech Laboratories to determine Nitrate-nitrogen, Phosphorus, Potassium, Sulfur, Calcium, Magnesium, Sodium, Organic matter, Soil pH, Buffer pH, Soluble salts, Cation exchange capacity and Base saturation %.

Within a Geographic Information System (GIS), the land cover that surrounded each forest was digitized and mapped. Land cover classes included *Pterocarpus* forest, agricultural or human managed, forest, pasture, forest and pasture mix, mangrove forest, marsh, open water, palm forest, and urban. We then measured the distance from each forest to the following closest features: house, street, ocean, agricultural land and human managed area. Cover classes and distances where used to determine the possible human impact to the forest.

3. RESULTS

3.1 Sampling and Identification of Organisms

Among all *Pterocarpus officinalis* forests, we found 39 birds (Table 2). Dorado had 33, Patillas had 23, and Humacao had 21. The primary section of forest in Humacao (H1) had 11, while the secondary section (H2) had 19. After visiting each forest 6 times, the number of newly-identified organisms slowed rapidly for nearly all organisms except for birds (Figure 7). It appeared that the sampling effort had not yet picked up all birds at Dorado or Patillas, though the numbers at Humacao began to level out.

Among all forests, we found 17 amphibians and reptiles (Table 3). Dorado had 15, Patillas had 10, and Humacao had 11. The primary section of forest in Humacao (H1) had 10, while the secondary section (H2) had 11.

TABLE 2. Birds

Scientific Name	Spanish Common Name	English Common Name	Status	D	P	H1	H2
Ammodramus savannarum	Gorrion Chichara	Grasshopper Sparrow	Common Resident	√			
Anthracothorax dominicus	Zumbador Dorado	Antillean Mango	Common Resident	√	√		√
Anthracothorax viridis	Zumbador Verde de Puerto Rico	Green Mango	Endemic		√		
Ardea alba	Garza Real	Great Egret	Common Resident	√	√		√
Ardea Herodias	Garzon Cenizo	Great Blue Heron	Visitor		√	√	√
Brotogeris versicolurus	Perico Ali - Amarillo	White - winged Parakeet	Introduced, 1912	√			
Buteo jamaicensis	Guaraguao	Red- tailed Hawk	Common Resident	√	√		
Butorides virescens	Martinete	Green Heron	Native	√	√		√
Coccyzus minor	Bobo Menor	Mangrove Cuckoo	Common Resident	√	√	√	√
Coereba flaveola	Reinita	Bananaquit	Common Resident	√	√	√	√
Crotophaga ani	Judio Garrapatero	Smooth-billed Ani	Common Resident	√			√
Dendroica adelaidae	Reinita Mariposera	Adelaide's Warbler	Endemic	√	√		
Dendroica discolor	Reinita Galana	Prairie Warbler	Visitor	√			
Gallinula chloropus	Gallareta Comun	Common Moorhen	Permanent Resident	√			
Icterus dominicensis	Calandria	Puerto Rican Oriole	Common Resident	√			
Margarops fuscatus	Zorzal Pardo	Pearly - eyed Thrasher	Common Resident	√	√		
Megascops nudipes	Mucaro Comun / Mucarito	Puerto Rican Screech-Owl	Endemic			√	√
Melanerpes portoricencis	Carpintero de Puerto Rico	Puerto Rican Woodpecker	Endemic	√	√	√	√
Mimus polyglottos	Ruiseñor	Northern Mockingbird	Common Resident	√			√
Molothrus bonariensis	Tordo Lustroso	Shiny Cowbird	Invasive, 1955	√	√		
Myairchus antillarum	Jui, Juí de Puerto Rico	Puerto Rican Flycatcher	Endemic	√	√	√	√

TABLE 2. Continued

Scientific Name	Spanish Common Name	English Common Name	Status	D	P	H1	H2
Myiopsitta monachus	Perico Monje	Monk Parakeet	Introduced, 1970	√			
Nyctanassa violacea	Yaboa Comun	Yellow-crowned Night - Heron	Common Resident	√	√	√	√
Oxyura jamaicensis	Pato Choriso	Ruddy Duck	Rare visitor			√	
Parula americana	Reinita Pechidorada	Northern Parula	Visitor	√			
Patagioenas leucocephala	Paloma Cabeciblanca	White-crowned Pigeon	Common Resident, Near Threatened	√	√		
Pandion haliaetus	Aguila de Mar	Osprey	Migrant		√		
Patagioenas squamosa	Paloma Turca	Scaly-naped Pigeon	Common Resident	√	√	√	√
Progne dominicensis	Golondrina de Iglesisas	Caribbean Martin	Native	√			
Quiscalus niger	Mozambique, Chango	Greater Antillean Grackle	Native	√			√
Seiurus noveboracensis	Pizpita de Mangle	Northern Waterthrush	Common Resident	√	√	√	√
Spindalis portoricensis	Reina Mora	Puerto Rican Spindalis	Endemic	√	√	√	
Tardus plumbeus	Zorsal de Patas Coloradas	Red-legged Thrush	Common Resident	√	√		
Tiaris bicolor	Gorrion Negro	Black - faced Grassquit	Common Resident	√			
Tyrannus caudifasciatus	Clerigo	Loggerhead Kingbird	Common Resident				√
Tyrannus dominicensis	Pitirre	Gray Kingbird	Common resident	√			√
Vireo altiloquus	Julian Chivi	Black - whiskered Vireo	Common Resident	√	√		
Vireo latimeri	Bien-te-Veo	Puerto Rican vireo	Endemic	√	√		√
Zenaida aurita	Tortola Cardosantera	Zenaida Dove	Common Resident	√	√		√

TABLE 3. Amphibians & Reptiles

Scientific Name	Spanish Common Name	English Common Name	Status	D	P	H1	H2
Ameiva exsul	Siguana Común	Common Siguana	Native	√			
Annolis Gunladchi	Lagartijo Barba Amarilla	Yellow-Bearded Anole	Endemic	√			
Annolis pulchelus	Lagartijo Jardinero	Common Grass Anole	Endemic	√	√		√
Annolis stratulus	Lagartijo Manchado	Barred Anole	Endemic	√	√		
Anolis cristatellus	Lagartijo Común	Puerto Rican Crested Anole	Endemic	√	√	√	√
Anolis evermanni	Lagartijo Verde	Emerald Anole	Endemic	√			
Anolis pulchellus	Lagartijo de las Yerbas	Common Grass anole	Endemic	√	√		
Buffo marinus	Sapo Marino	Cane Toad	Introduced, 1920	√	√	√	√
Eleutherodactylus antillensis	Coquí Churri	Field Coqui	Endemic	√	√	√	√
Eleutherodactylus brittoni	Coquí de las Hierbas	Grass Coqui	Endemic	√	√	√	√
Eleutherodactylus cochranae	Coquí Pitito	Whistling Frog	Endemic	√	√	√	√
Eleutherodactylus coqui	Coquí Común	Coqui	Endemic	√	√	√	√
Iguana iguana	Gallina de Palo	Green Iguana	Introduced, 1970			√	√
Leptodactylus albilabris	Ranita de Labio Blanco	White-lipped Frog	Native	√	√	√	√
Rana catesbeiana	Rana Toro	American Bull Frog	Introduced	√		√	√
Rana grylio	Rana Cerdo	Pig Frog	Introduced, 1998			√	√
Sphaerodactylus macrolepis	Salamanquita Común	Common Dwarf Gecko	Native	√	√		

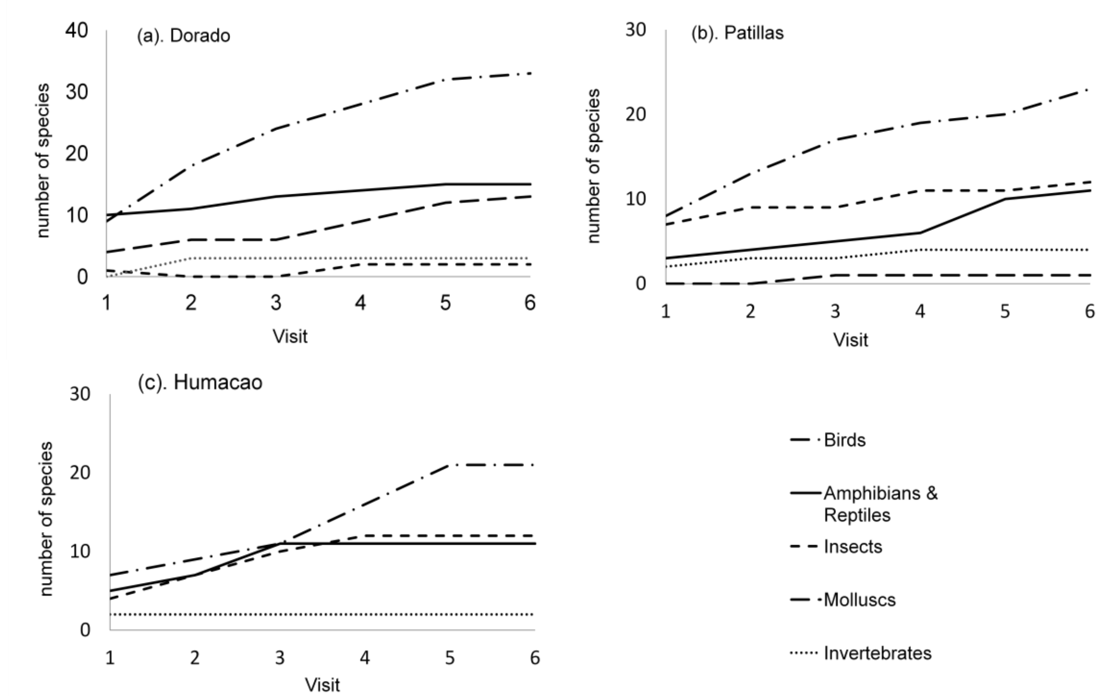
TABLE 4. Insects, Invertebrates, Mollusks, & Others

Insects						
Scientific Name	**Spanish Common Name**	**English Common Name**	**D**	**P**	**H1**	**H2**
Pholcidae spp	Araña de Patas Largas	Daddy- longlegs / Cellar spider	√	√		
Family Lycosidae	Araña Lobo	Wolf Spiders	√	√	√	
Opiliones spp	Opilión	Harvestmen	√			
Corythalia banski	Araña Saltadora	Jumping Spider	√			√
Leucauge regnyi	Araña Tejedora	Orchard Spiders	√	√	√	√
Odontomachus haematodus	Berraco / Hormiga	Fiercely biting black ant / trap-jaw ants	√	√	√	√
Emesinae spp	Chinche Depredador	Thread Legged Assassin Bug	√			
Scapteriscus borellii	Grillo Topo	Southern Mole Cricket	√	√	√	√
Orocharis spp	Grillo de Arbusto	Loud-singing Bush Crickets	√	√	√	√
Super FamilyFulgoroidea	Salta Hojas / Salta Plantas	Plant hopper	√			
Termitoidae spp	Comején	Dry wood Termite	√	√	√	√
Doldinainterjungens	Chinche Depredador	Assassin Bug	√			
Apis spp	Abeja de Domestica o Aveja Africanizada	Domestic Honeybee or Africanized Honey Bee		√		
Dysdercus andreae	Bomberitos	Love Bug		√		
Scolopendra alternans	Ciempiés	Centipedes		√	√	
Selenops insularis	Araña Plana	Flat Spider	√			
Julidae spp	Milpiés	Millipede		√		
Battus polydamas	*Oruga de Mariposa Papilio*	Caterpillar of Gold Rim Swallowtail			√	
Hemiptera spp	Insecto, no identificados mas	Bug, not identified further		√		
Hemiptera spp	Insecto, no identificados mas	Bug, not identified further			√	
Hemiptera spp	Escarabajo Rojo	Builder Bug's			√	√
Tetragnatha spp	Araña Extensa	Stretch Spiders				√
Dysdercus andreae	Bomberitos	St. Andrew's Cotton Stainer				√

TABLE 4. Continued

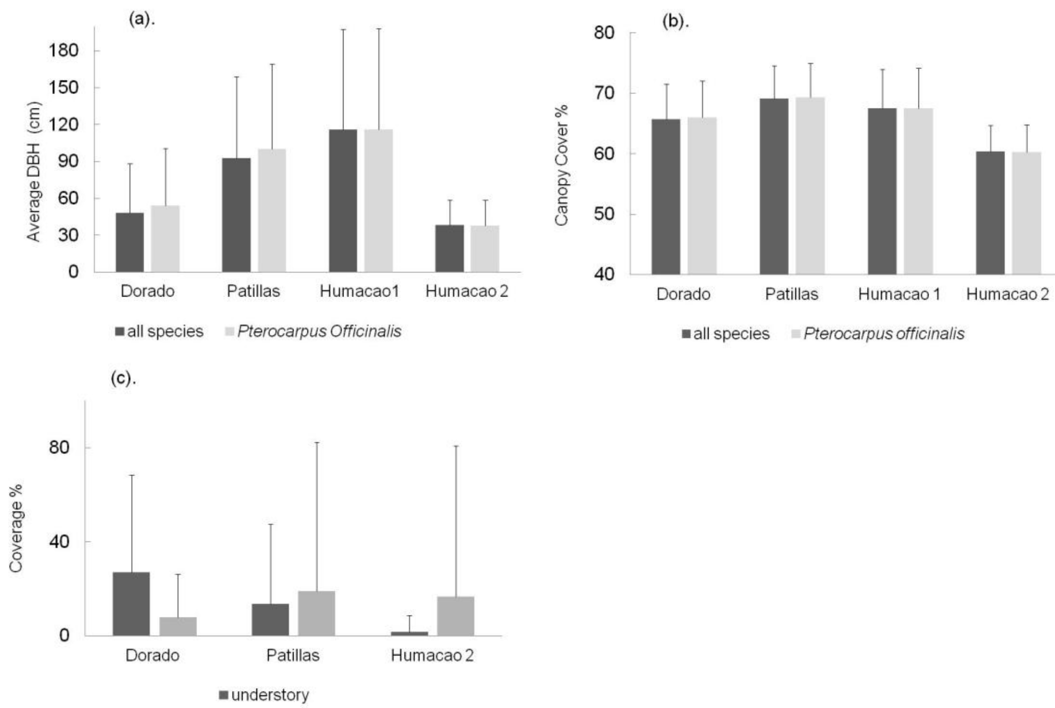
Mollusks						
Scientific Name	**Spanish Common Name**	**English Common Name**	**D**	**P**	**H1**	**H2**
Polydontes lima	Caracol Áspero o Raspado	Rasping nipple snail	√			
Caracullus marginella	Caracol de Bandas	Banded Caracole	√	√		
Invertebrates						
Uca leptodactyla	Cangrejo Violinista	Fiddler Crab	√	√	√	√
Cardisoma guanhum	Juey Común	Blue Land Crab	√	√		
Ucides cordatus	Juey Pelú Zambuco	Mangrove Land Crab		√	√	
Estherella spp	Lombriz de Tierra	Earth Worm	√	√	√	√
Other Animals Present						
Buthidae spp	Escorpión	Scorpion			√	√
Class Actinopterygii	Peces, no identificados mas	Fish, not identified further			√	

FIG. 7. Species area curves for birds. amphibian, reptiles, insects, mollusks and invertebrates per sites. (a). Dorado (b). Patillas (c). Humacao



Among all forests, we found 23 insects, 2 mollusks, 4 invertebrates, and two additional animals (Table 4). For insects, all forests had nearly the same amount, Dorado had 13, Patillas had 12, Humacao 1 had 10 and Humacao 2 had 9. Only Dorado and Patillas had mollusks present. Patillas had the most invertebrates, while the secondary forest in Humacao 2 had the least. Only the primary forest in Humacao 1 had fish, and interestingly this section of forest is relatively distant from obvious sources of water input.

FIG. 8. Average DBH (a), Canopy coverage percentage (b), Understory coverage percentage and coverage of *Pterocarpus officinalis* roots (c) for Dorado, Patillas, Humacao 1 and Humacao 2. The designation "all species" included Pterocarpus trees.



Among all forests, we found 56 plants and 6 fungi (Table 5). For the plants, Dorado had 47, Patillas had 16, and Humacao had only 6. The primary forest in Humacao 1 had the largest trees followed by Patillas, while Dorado and the secondary forest in Humacao 2 had much smaller trees (Figure 8). The canopy cover percentage was similar, showing Humacao 2 will much less coverage. The understory coverage was highest at Dorado and lowest at Humacao 2. Patillas had the most visible root coverage on the surface of the ground (Figure 8).

TABLE 5. Plants & Fungi

Plants						
Scientific Name	**Spanish Common Name**	**English Common Name**	**Status**	**D**	**P**	**H**
Acrostichum aureum	Helecho de Mangle	Golden Leather Fern	Native	√	√	√
Andira inermis	Moca	Cabbage Bark tree	Native	√		
Annona glabra	Cayur	Pond Apple	Native	√	√	
Anonacea spp	Annonaceae Desconocida	Custard Apple Family		√		
Anthurium crenatum	Lengua de Vaca	Scalloped Lace leaf	Native	√	√	√
Ardicea spp	Ardicia spp	Ardicea spp		√		
Ardisia elliptica	Mameyuelo	Shoe Button Ardisia.	Introduced	√		
Bucida buceras	Ucar	Gregory Wood	Native	√		
Bursera simaruba*	Almacigo	Gumbo Limbo	Native	√		
Calophyllum calaba	María	Santa- Maria	Native	√	√	
Casearia guianensis	Palo Blanco	Guyanese wild coffee	Native	√		
Casearia sylvestris Sw.	Laurel Espada	Crack open	Native	√		
Clusia rosea Jacq.	Cupey	Wild-mamee	Native	√		
Coccoloba diversifolia	Uva de Sierra	Tie tongue	Native	√		
Didymopanax morototoni	Yagrumo Macho	Matchwood	Native	√		
Eugenia jambos	Pomarrosa	Malabar plum	Introduced	√		
Eugenia pseudopsidium Jacq.	Guayaba Silvestre	Christmas Cherry	Native	√		
Fabaceae spp # 1	Fabaceae	Fabaceae			√	
Peltophorum pterocarpum	Flamboyan Amarillo	Golden Flamboyant				√
Faramea occidentalis	Cafecillo	False coffee	Native	√		
Ficus citrifolia Mill.	Jagüey Blanco	Wild banyan tree	Native	√		
Ficus spp	Ficus	Ficus		√		
Genipa americana L.	Jagua	Jagua	Native	√		
Guapira fragrans	Corcho	Black Mambo	Native	√		
Hohenbergia antillana	*Bromelia*	Antilles Lacebark	Native	√		
Hylocereus trigonus	Cactus Pitahaya	Wild strawberry	Native	√	√	
hymenaea courbaril	Algarrobo	Stinking toe	Native	√		
Inga Laurina	Guama	Sacky Sac Bean	Native	√		
Lauracea spp	Lauracea	Lauracea		√		
Licaria parvifolia	Canelilla	Puerto Rico cinnamon	Native	√		
Manilkara bidentata	Ausubo	Bullet wood	Native	√	√	
Mastichodendron foetidissimum	Tortugo Amarillo	False mastic	Native	√		

TABLE 5 Continued

Plants						
Scientific Name	**Spanish Common Name**	**English Common Name**	**Status**	**D**	**P**	**H**
Morinda citrifolia	Noni	Indian Mulberry	Introduced	√		
Morus nigra L.	Moral	Black mulberry	Introduced	√		
Ormosia krugii	Palo de Matos	Peronia	Native	√		
Paullinia pinnata L.	Bejuco de Costilla	Bread and cheese	Native	√		√
Phlebodium aureum	Helecho Espada	Golden serpent fern	Native	√	√	
Piper amalago	Higuillo de Limón	Rough-leaved Pepper	Native	√		
Prunus dulcis	Almendro	Sweet almond	Native	√		
Psilotum nudum	Helecho Escoba	Whisk Fern	Native	√	√	
Psychotria brachiata	Palo de Cachimbo	Palo de Cachimbo	Native	√		
Pterocarpus officinalis	Palo de Pollo	Dragons Blood tree	Native	√	√	√
Randia aculeata	Tintillo	White Indigo berry	Native	√		
Roystonea borinquena	Palma Real	Royal palm	Native	√	√	√
Tabebuia heterophylla	Roble blanco	White cedar	Native	√		
Tillandsia fasciculata	Bromelia	Giant Airplant	Native	√		
Unknown # 1				√		
Unknown # 2				√	√	
Unknown # 3					√	
Unknown # 4					√	
Vanilla claviculata	Orquidea Vainilla	Green With	Native	√		
Fungi						
Chlorophyllum molybdites	Hongo Sombrilla Verde	Green Parasol		√		
Cookeina tricholoma	Copitas	Red Cup fungus				√
Ganoderma applnatum	Oreja de Palo	Artist's Conk			√	√
Phellinus igniarius	Yesca	Phellinus Fungus		√		
Psilocybe spp	Hongos Mágicos	Magic Mushrooms		√		
Trametes gibbosa	Yesquero Blanco	Lumpy Bracket			√	

In summary, Dorado had the highest faunal abundance (66 organisms, without including plants or fungi) and highest faunal Shannon's diversity value (H = 3.4537). Dorado had the most native or endemic birds (7), amphibians/reptiles (12), and plants (43). However, Dorado also had the most invasive or exotic birds (3) and plants (4). For plants and fungi, Dorado was also highest in diversity (H = 2.8766). Patillas was second in richness in both fauna (H = 3.2976) and plants/fungi (H = 1.2662). Humacao 2 was the least rich (23 organisms, without including plants) and least diverse in fauna (H = 2.0801) (Table 6). Still, Humacao had the most invasive amphibians/reptiles (4). All of the plants in both Patillas and Humacao were native or endemic.

TABLE 6. Shannon's diversity index

	Dorado	*Patillas*	*Humacao 1*	*Humacao 2*
Birds	1.6570	1.6738	1.0312	1.3278
Amphibians & Reptiles	0.8781	0.8629	1.0562	1.0490
Insects, Invertebrates & Mollusks	0.9185	0.7606	0.8139	0.7377
Total for fauna only	3.4537	3.2976	3.0614	2.0801
Vegetation & Fungi	2.8766	1.2662		0.7323

3.2 Soil, Land Cover, and Environmental Factors

The Dorado area has an average temperature of 25.1°C (77.2°F) with the maximum temperature being 28.3°C (83.9°F) and the minimum temperature being 21.3 °C (70.4°F) (Table 7). The annual precipitation is 644.5 mm (64.45 in). Patillas has an annual precipitation of 545.7 mm (55.74 in). The average temperature is 27.1 °C (80.9°F), the maximum temperature is 30.7 °C (87.4°F) and the minimum temperature is 23.5°C (74.4°F). The average temperature for the Humacao area is 27.1°C (80.8°F), with 30.2 °C (86.5°F) and 23.8°C (75.0°F) being the maximum and minimum values, respectively. The annual precipitation is 523.4 mm (952.34 in).

For the soil samples, only nitrate, organic matter %, soluble salts, sulfur and calcium are presented here. Nitrate was the highest in Dorado, but was low in Patillas, Humacao 1 and Humacao 2 (Figure 9A). The organic matter had the lowest value in Humacao 1 followed by Humacao 2; higher values were recorded at Patillas and Dorado (Figure 9B). The soluble salts were highest in Humacao 2, but low in Humacao 1 and Dorado (Figure 9C). Sulfur values showed a great difference. Humacao 2 had the highest value, where Dorado and Humacao 1 had the lowest values (Figure 9D). The calcium was the lowest in Dorado, Humacao 1 and Humacao 2, the highest value was recorded at Patillas (Figure 9E).

FIG. 9. Soil components for Dorado, Patillas, Humacao 1 and Humacao 2. (a). Nitrate (b). Organic matter % (c). Soluble salts (d). Sulfur (e). Calcium

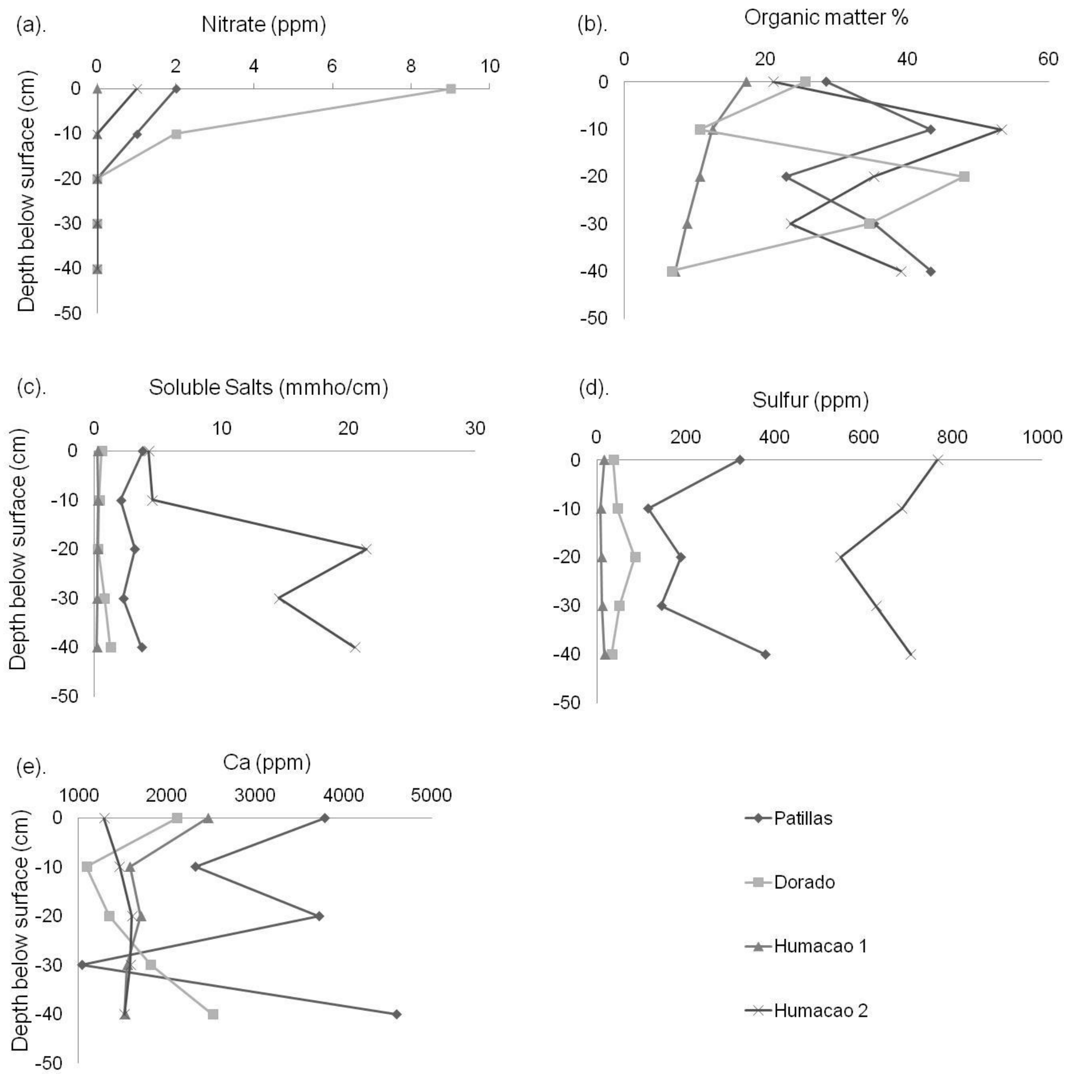
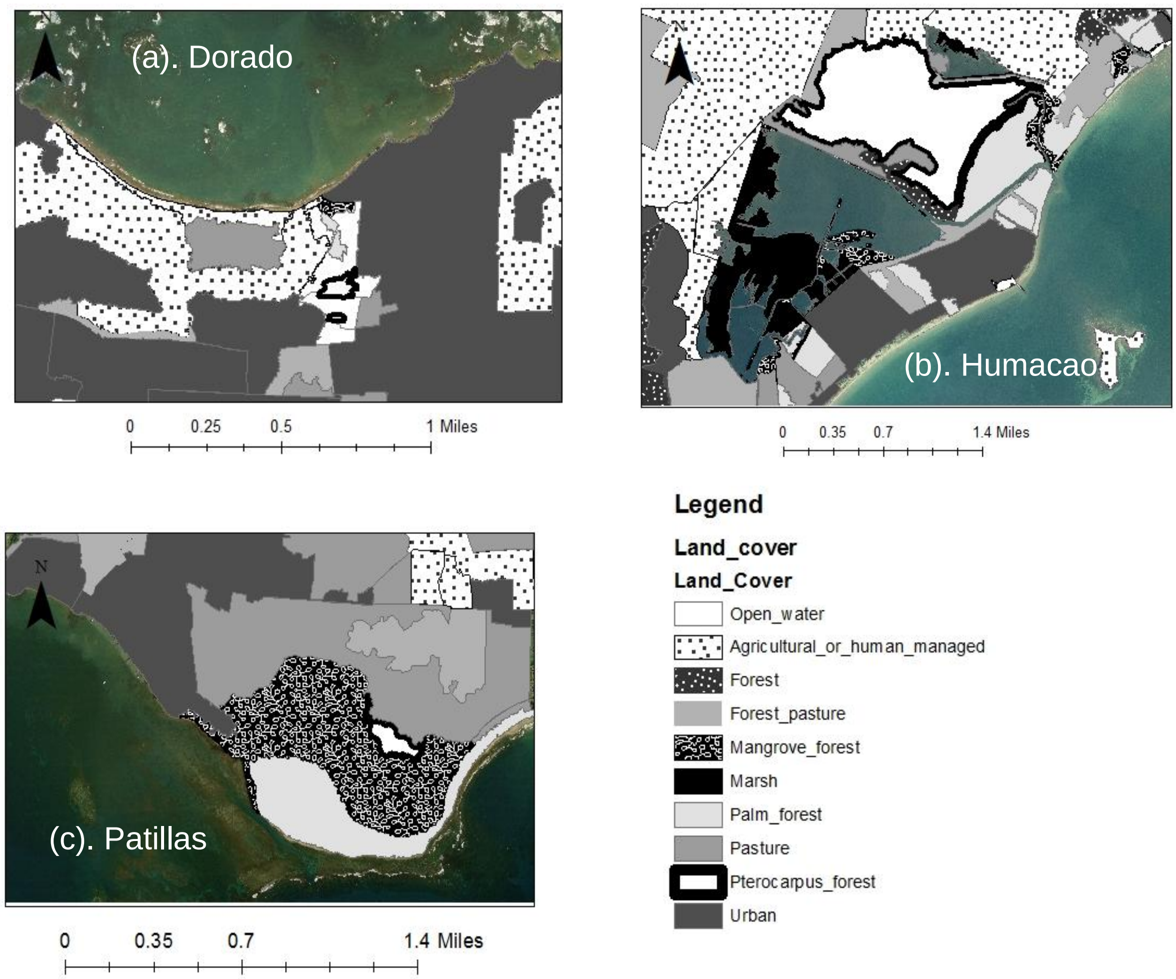


TABLE 7. Temperature and Precipitation Averages from 1980 to 2010

Forest (Station)	Period	Precip mm (in)	Min Temp °C (°F)	Average Temp °C (°F)	Max Temp °C (°F)
Dorado (Dorado 2 WnW PR US)	Annual	644.5 (64.45)	21.3 (70.4)	25.1 (77.2)	28.3 (83.9)
	Winter (DJF)	152.9 (15.29)	19.4 (67)	24.1 (73.5)	26.6 (80)
	Spring (MAM)	137.7 (13.77)	20.7 (69.4)	24.7 (76.6)	28.7 (83.7)
	Summer (JJA)	159.4 (15.94)	22.8 (73.1)	26.6 (79.9)	30.4 (86.8)
	Fall (SON)	194.5 (19.45)	22.2 (71.9)	25.8 (78.6)	29.5 (85.2)
Patillas (Guayama 2 E PR US)	Annual	545.7 (54.57)	23.5 (74.4)	27.1 (80.9)	30.7 (87.4)
	Winter (DJF)	72.0 (7.2)	22.2 (72)	25.9 (78.7)	29.6 (85.4)
	Spring (MAM)	97.6 (9.76)	23.1 (73.5)	26.7 (80.1)	30.3 (86.6)
	Summer (JJA)	165.8 (16.58)	24.8 (76.7)	28.3 (83)	31.7 (89.2)
	Fall (SON)	210.3 (21.03)	24.1 (75.3)	27.7 (81.9)	31.3 (88.4)
Humacao (Roosevelt Roads)	Annual	523.4 (52.34)	23.8 (75)	27.1 (80.8)	30.2 (86.5)
	Winter (DJF)	95.3 (9.53)	22.3 (72.2)	25.5 (78)	28.7 (83.7)
	Spring (MAM)	110.8 (11.08)	23.4 (74.1)	26.6 (79.9)	29.7 (85.6)
	Summer (JJA)	131.1 (13.11)	25.4 (77.8)	28.5 (83.3)	31.5 (88.8)
	Fall (SON)	186.2 (18.62)	24.4 (75.9)	27.6 (81.8)	31.0 (87.8)

FIG. 10. (a). Land coverage class map, Dorado forest. (b). Land coverage class map, Humacao forest. (c). Land coverage class map, Patillas forest.



The Dorado forest (Figure 10A) is located within lands owned by the Dorado Beach Hotel Corporation, which is a luxury resort community. To the north of the *Pterocarpus* forest, there is an additional non-*Pterocarpus* forested area that is managed by the Puerto Rico Conservation Trust. To the east, there is a small patch of trees followed immediately by a large area of urban development. To the south, there is a remaining small patch of forest, that is adjacent to another well-developed urban area. To the west, there is a large golf course.

The Humacao forest (Figure 10B) is the only forest that has direct connections to open water, through channels or lagoons that are themselves connected to the ocean. On the north side, agricultural lands are present. Urban areas are immediately across the lagoon, to the southwest.

The Patillas forest (Figure 10C) is enclosed within the Punta Viento Natural Reserve. To the north of the *Pterocarpus* forest, there is large pasture. To the east, south, and west there are mangrove forests.

The Dorado forest was the closest to roads, houses, human-managed ecosystems, and the ocean (Table 8). In contrast, Humacao 1 had the greatest distances to roads, houses, and the ocean. Patillas was the closest to an agricultural area, whereas Humacao 2 was the farthest.

TABLE 8. Distance from each forest to selected features

	Distance (m)			
Features	**Dorado**	**Patillas**	**Humacao 1**	**Humacao 2**
Road	173.43	542.19	1,455.42	734.58
House	107.57	640.61	1,253.19	723
Agricultural area	1,764.99	620.92	1,443.95	2,509.16
Ocean	477.77	495.61	2,514.75	1,106.54
Human managed ecosystem	118.62	578.52	1,170.34	1,326.03

4. DISCUSSION

4.1 *Richness and Diversity Among the Forests, and Possible Causes for Differences*

The Dorado *Pterocarpus* forest is the most rich and diverse in terms of organisms and has the highest amount of native and endemic species, while the Humacao *Pterocarpus* forest is the least rich and diverse. Yet conversely, the Dorado forest is the smallest forest, covering only 2.4 ha, while Humacao is the largest, with an area of 150 ha that comprises 63% of the total *Pterocarpus* coverage in Puerto Rico.

The temperature and precipitation differences among the forests do not sufficiently explain the difference in richness or diversity. The Dorado forest has an annual precipitation of 644.5 mm (64.45 in) whereas Humacao has 523.4 mm (52.34 in), a difference of only ~1/6 the total. The average temperatures are 25.1 °C (77.2°F) and 27.1°C (80.8°F) for Dorado and Humacao, respectively, a difference of only -15.7°C (3.6°F) (Table 7).

One potential explanatory factor for the organism differences can be found in the soil measurements. Dorado had high nitrate, a component commonly-used in commercial fertilizers. It is also produced by fixation of nitrogen by soil bacteria as part of the nitrogen cycle, as well as through the decay of organic matter in the soil. The relatively high level of nitrate is demonstrative of the level of disturbance as Dorado is surrounded by human-managed areas, including a golf course, and urban areas. Dorado also has the highest organic matter percentage in the soil, likely because of the large amount of plant material deposited due to high understory coverage and low overstory canopy coverage. Humacao 1 has the opposite condition, with nitrate below detectable limits and low human disturbance. The mature trees in Humacao 1 have the largest DBH averages and accordingly, there is low understory coverage and a low amount of organic matter. Additionally, the low organic matter in Humacao 1 forest could be explained by inflow forcing it to wash out downstream during frequent rain events.

Inflow and water sources may also be a factor that alters richness and diversity. The amount of soluble salts and sulfur in the forests soils are likely related to salt water incursion and intrusion, as they were highest at Humacao 2 forest followed by Patillas forest. Hydrogen sulfide often results from the bacterial breakdown of organic matter in the absence of oxygen, such as in swamps, a process is commonly known as anaerobic digestion or reduction. The subsequent oxidation of hydrogen sulfide produces sulfur. Interestingly, Patillas had the highest amount of calcium, reaching almost 4,000 ppm. Patillas is distinctive, as spring water enters the forested wetland's surface waters from underlying karst limestone through the "Pozo Encantado" or "Enchanted Well".

The most obvious factor influencing richness and diversity among the forests is the adjacent land cover and history of the site. As mentioned earlier, the Dorado forest is the smallest as well as the most fragmented one. Dorado also has the highest number endemic and native plants, as wells as invasive plants, and this likely drives the higher richness of fauna. The forest's perimeter-to-area ratio is high and it is surrounded by urban homes, infrastructure, and a golf course .

Patillas is the second smallest forest, but it is entirely enclosed with in a Natural Reserve (Figure 10C). It consistently ranks in the middle, in terms of richness and diversity, proximity to the disturbances, and average DBH. It has the highest *Pterocarpus* roots coverage percentage, likely because it is more dry than Humacao, though it is still influenced to a small degree by salt, rain, and spring water.

Humacao 1 is the best example of a large, mature, historically undisturbed, primary *Pterocarpus* forest in Puerto Rico. Its trees are great in DBH and canopy coverage, while it is low in nutrients, organic matter, and salt water influence.

Humacao 2 is the youngest forest of the group, composed of secondary re-growth since the 1950's. It has the lowest DBH and overstory canopy cover across all the study sites. It is strongly-affected by salt water intrusion, with channels bisecting it that connect directly the ocean. It is also necessary to mention that not all species where necessarily sampled based on the methods selected on this research, for example mosquitoes.

The findings are summarized in Table 9. The categories used are in relative terms to identify the values of each component in each forest.

TABLE 9. Summary

		Dorado	Patillas	Humacao 1	Humacao 2
Diversity	**Birds**	high	medium	medium	low
	Amphibian & Reptiles	high	medium	medium	medium
	Insects	medium	medium	medium	medium
	Molluscs	high	low	absent	absent
	Invertebrates	high	high	high	low
	Fish	absent	absent	present	absent
	Plants	high	medium	low	low
	Fungi	high	medium	medium	medium
Forest Mesuarements	**DBH Pterocarpus officinalis**	medium	high	high	low
	DBH all species	medium	high	high	low
	Canopy coverage %	medium	high	high	low
	Understory	high	medium	not available	low
	Pterocarpus officinalis roots coverage	low	high	not available	medium
Soil Components	**Nitrate**	high	medium	low	low
	Organic matter %	medium	high	low	low
	Soluble salts	low	medium	low	high
	Sulfur	low	medium	low	high
	Ca	medium	high	medium	low

TABLE 9 Continued

		Dorado	Patillas	Humacao 1	Humacao 2
Proximity to:	**Road**	high	medium	low	medium
	House	high	medium	low	medium
	Agricultural area	medium	high	medium	low
	Ocean	high	high	low	medium
	Human manged ecosytem	high	medium	low	low
Sorrounded by:	**North**	forest	pasture	forest	open water
	East	urban	mangrove	human managed	open water, palms
	South	forest, urban	mangrove	pasture, open water	mangrove, open water
	West	human managed	mangrove	agricultural	mangrove, open water

4.2 Primary Versus Secondary Pterocarpus Forests

At Humacao, the primary forest and the secondary forest have been exposed to different human disturbances Humans have altered the water flowing into the forests at both sections of forest, though the primary forest has primarily been affected by altered upstream inflow through digging for sugarcane production. The secondary forest, while also affected, was also directly cut and cleared in the 1920's Subsequently, abandonment of this section resulted in re-growth. By 2000, the US Army Corps of Engineers attempted to reduce flooding to the nearby urban community of Punta Santiago, and the creation of a channel introduced salt water to the Humacao secondary forest. The quantity of birds, amphibians and reptiles is lower in the primary forest (total 21) than the secondary forest (total 30). Moreover, the soil in the primary forest had the lowest organic matter values, and nutrient values such as phosphorus and potassium in general.

Our results suggest that mature *Pterocarpus officinalis* dominated forest, are largely monocultural in vegetation, low in number of dependent species, and with nutrient-poor soils. The fragmentation and conversion of adjacent environments has only increased their floristic and faunal diversity

4.3 Conclusion

Human impacts to these forests have been significant across Puerto Rico and the Caribbean. Our analysis points out that fragmentation and changes in the surrounding land use by humans has increased both richness and diversity in these forests. This increase in the diversity of species comes from both other native and endemic Puerto Rican species that have now entered the fragmented and small remnants, but also from exotic and invasive species.

Still, all *Pterocarpus* forests provide a natural environment to sustain organisms, and there are likely organisms that particularly thrive in conjunction with *Pterocarpus*. For example, though species endemic only to *Pterocarpus* forests where not identified, we did find small, as-of-yet unidentified fish only in the most undisturbed portions of the primary forest in Humacao.

Because of the limited, remaining areas that are covered by the *Pterocarpus* forest, its protection and management are necessary. *Pterocarpus* forests are recognized to support a number of native and endemic species, specifically amphibians, which are known to be in a delicate state worldwide. This study will help in planning and the management of the forest, not only in a broad sense, but also more specifically to the forests that where included in this research. This work will assist in managing this limited resource in the context of ongoing sea level rise, climate change, nutrient pollution, human interaction, upstream hydrological modifications, and deforestation.

REFERENCES

Alvarez-Lopez, M. 1990. Ecology *of Pterocarpus officinalis* in Puerto Rico. In: Ecosystems of the World 15: Forested Wetlands, eds. A.E. Lugo, S. Brown and M.M. Brinson, 251-265. Elsevier Science Publishers, B. V., Amsterdam.

B.C. Ministry of Environment, Lands and Parks. 1997. Fish Collection Methods and Standards. Fish Inventory Unit for the Aquatic Ecosystems Task Force, Resources Inventory Committee.

Backiel, T. Guidelines for sampling inland water. 1980. Fisheries and aquaculture department, Inland Fisheries Institute, Poland.

Bacon, P.R. 1990. Ecology and management of swamp forests in the Guianas and Caribbean Region In: Ecosystems of the World 15: Forested Wetlands, eds. A.E. Lugo, S. Brown and M.M. Brinson, 251-265. Elsevier Science Publishers, B. V., Amsterdam.

Bibby, C., M. Jones, and S. Marsden. 2000. Expedition Field Techniques Bird Surveys. BirdLife International, Cambridge, United Kingdom.

Cintrón, B. B. 1983. Coastal Freshwater Swamp Forests: Puerto Rico's Most Endangered Ecosystem? In: Los Bosques de Puerto Rico (A. E. Lugo, ed.), 249-282. U.S. Department of Agricultural Forest Service, Institute of Tropical Forestry, Río Píedras, PR.

Common Wealth of Puerto Rico. 2008. Act No. 92 (H.B. 3385) 7th Session of the 15th Legislature of Puerto Rico.

Corn, P. S. and R.B. Bury. 1990. Technical Sampling Methods for Terrestrial Amphibians and Reptiles. United States Department of Agriculture, Forest Service, Pacific Northwest Research Station. Technical Report PNW-GTR-256.

Costanza, R., S. C. Farber, and J. Maxwell. 1989. The valuation and management of wetland ecosystems. Ecological Economics 1:335-361.

Ferrer, O. J. 2007. Temporal and spatial environmental structure of the Humacao Natural Reserve lagoon system, Puerto Rico. Ciencia 15:193-204.

Fidelibus, M.W. and R. T.F. Mac Aller. 1993. Methods for Plant Sampling. Biology Department San Diego State University San Diego, CA 92182.

Figueroa, J.C., L. Totti, A.E. Lugo and R.O. Woodburry. 1984. The Structure and Composition of Moist Coastal Forest in Dorado, Puerto Rico. USDA, Institute of Tropical Forestry. Research Paper SO-202.

Gleason, H. A., and M. T. Cook. 1926. Plant Ecology of Porto Rico. In: Scientific Survey of Porto Rico and the Virgin Islands. New York: New York Academy of Sciences; Vol 7.

Grootaert, P., M., Pollet, W., Dekoninck, and C. Van Achterbeg. 2010. Chapter 15: Sampling insects: general techniques, strategies and remarks. In: Volume 8 Manual on Field Recording Techniques and Protocols for All Taxa Biodiversity Inventories, eds. Eymann, J. Degreef, C. Häuser, J. C. Monjes and D. VandenSpiegel.

Helmer, E. 2004. Forest conservation and land development in Puerto Rico. Landscape Ecology 19: 29-40.

Hill, D., M. Fasham, G. Tucker, M. Shewry and P. Shaw. 2005. Handbook of Biodiversity Methods Survey, Evaluation and Monitoring. Cambridge University Press, New York.

Imbert, D., I. Bonheme, E. Saur, and C. Bouchon. 2000. Floristics and structure of the *Pterocarpus officinalis swamp* forest of Guadeloupe, L. Antilles. J. Trop. Ecol. 16, 55-68.

Kabii, T. and Bacon, P. 1997. Protection of Wetlands and Coastal Lands and Their Habitats. In: Proceedings of the XI World Forestry Congress. FAO. Antalya, Turkey.

Lambert M.R.K. 2002. Amphibians and Reptiles. In: Ecological Monitoring Methods for the Assessment of Pesticide Impact in the Tropics, eds. I.F Grant and , C.C.D. Tingle. Natural Resources Institute, University of Greenwich at Medway, UK.

Lopez, O. R. and Kursar, T. A. 2007. Interannual variation in rainfall, drought stress and seedling mortality may mediate monodominance in tropical flooded forests. Oecologia 154(1):35-43.

Medina, E., M. Francisco, and A. Quilice. 2008. Isotopic signatures and nutrient relations of plants inhabiting brackish wetlands in the northeastern coastal plain of Venezuela. Wetlands Ecology & Management 16: 51-64.

Mitsch, W.J., and J.G. Gosselink. 2007. Wetlands. Fourth Edition. Wiley & Sons, New York.

Muller, F., M. Voccia, A. Ba, and J.-M. Bouvet. 2009. Genetic diversity and gene flow in a Caribbean tree *Pterocarpus officinalis* Jacq.: A study based on chloroplast and nuclear microsatellites. Genetica 135: 185-198.

NOAA. 2012. Climate Data Online . Retrieved June 1, 2013 from http://www.ncdc.noaa.gov/cdo-web/#t=firstTabLink

Quiñones-Ramos, M., I. Monefeldt, J. Toro and V. Quevedo. 1992. Bosques de Pterocarpus. Oficina de Educación y Publicaciones del Departamento de Recursos Naturales y Ambientales de Puerto Rico.

Raghavendra Gadagkar, K., K. Chandrashekara and N. Padmini. 1990. Insects Species Diversity in the tropics: Smapling method nad a case study. Journal of the Bombay Natural History Society, Vol. 87, No. 3.

Rivera-Ocasio, E., T.M. Aide, and N. Rios-Lopez. 2007. The effects of salinity on the dynamics of a P. officinalis forest stand in Puerto Rico. J. Tropical Ecology 23: 559-568.

Rivera-Ocasio, E., T.M. Aide, and W.O. McMillian. 2006. The influence of spatial scale on the genetic structure of a widespread tropical wetland tree, *Pterocarpus officinalis* (Fabaceae). Conservation Genetics 7: 251-266.

Schieck, J. and C. Stambaugh. 2006. Field Test of Fungi Data Collection Methods Integrated Resource Plus Protocols Proposed for the ABMP Management . Alberta Research Council Vegreville, AB.

Schwartz, L.N. 2004. Rio Anton Ruiz Wetlands Mitigation Design and Plan. XXIX Inter-American Congress of Sanitary & Environmental Engineering. San Juan, Puerto Rico.

United States Geological Survey. 2012. Aerial images from Earth Explorer. Retrieved August 19, 2011, from http://earthexplorer.usgs.gov/

Wetland Health Evaluation Program (WHEP) Plant sampling protocols. Retrieved August 25, 2011, from http://www.mnwhep.org/id47.html