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Forest Vegetation Cover Assessment on Mona Island, Puerto Rico

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Magnificent frigate bird (*Fregata magnificens*) (photo by Humfredo Marcano, USDA Forest Service)

Front cover: Aerial view of Mona Island, Puerto Rico (photo by Thomas Brandeis, USDA Forest Service)

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Plateau forest vegetation on Mona Island, Puerto Rico.
(photo by Thomas Brandeis, USDA Forest Service)

Contents

Abstract

Permanent plots were installed on the Mona Island natural reserve as part of the U.S. Department of Agriculture Forest Service's forest vegetation assessment and monitoring efforts in the Commonwealth of Puerto Rico. In addition to tree, sapling, and seedling measurements, the data collected included detailed descriptions of percent cover of vascular plants in four height layers (0–0.6 m, >0.6–1.8 m, >1.8–4.9 m, and >4.9 m) and percent ground cover. Based on these data we provide the first description of the structural characteristics, species composition, and vegetative cover of plant associations that stems from a systematic sample extending across the entire Mona Island plateau. We encountered 104 vascular plant species, however, suggesting that our surveys missed less common and sparsely distributed species. Though we also describe depression forests, they were represented by only a few sites in our systematic sample design. These data plus those that will come from future plot remeasurement will provide baseline information otherwise lacking for Caribbean subtropical dry forest ecosystems and will be of value to stakeholders and resource managers charged with management decisionmaking on this unique island.

Keywords: Caribbean, FIA, Mona Island, species diversity, subtropical dry forest, vegetation.

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Introduction

Protected areas such as the Mona Island natural reserve in Puerto Rico are uncommon, though critically important in the Caribbean biodiversity "hot spot" region, which exhibits high species diversity and concentrations of endemic species (Myers and others 2000). Mona Island (67º 53′ W. by 18º 5′ N.) is a 55 km^2 limestone karst plateau that rises sharply out of the Caribbean in the Mona passage between Puerto Rico and the Dominican Republic (fig. 1) (Frank and others 1998). The excessively well-drained karst substrate, tropical temperatures buffered by proximity to the ocean, low elevations (maximum of 80 m), and relatively low annual precipitation (800–950 mm per year) allows for the growth of subtropical dry forest (Cintrón and Rogers 1991, Lugo 1991, Warren 2000). Estimates from previous field work and aerial photographs have found the island to be >90 percent covered in forest and shrublands (Cintrón and Rogers 1991, Brandeis and others 2007, Martinuzzi and others 2008).

The subtropical dry forest life zone on the Caribbean islands of the Puerto Rico and the U.S. Virgin Islands is defined in Ewel and Whitmore (1973) as occurring

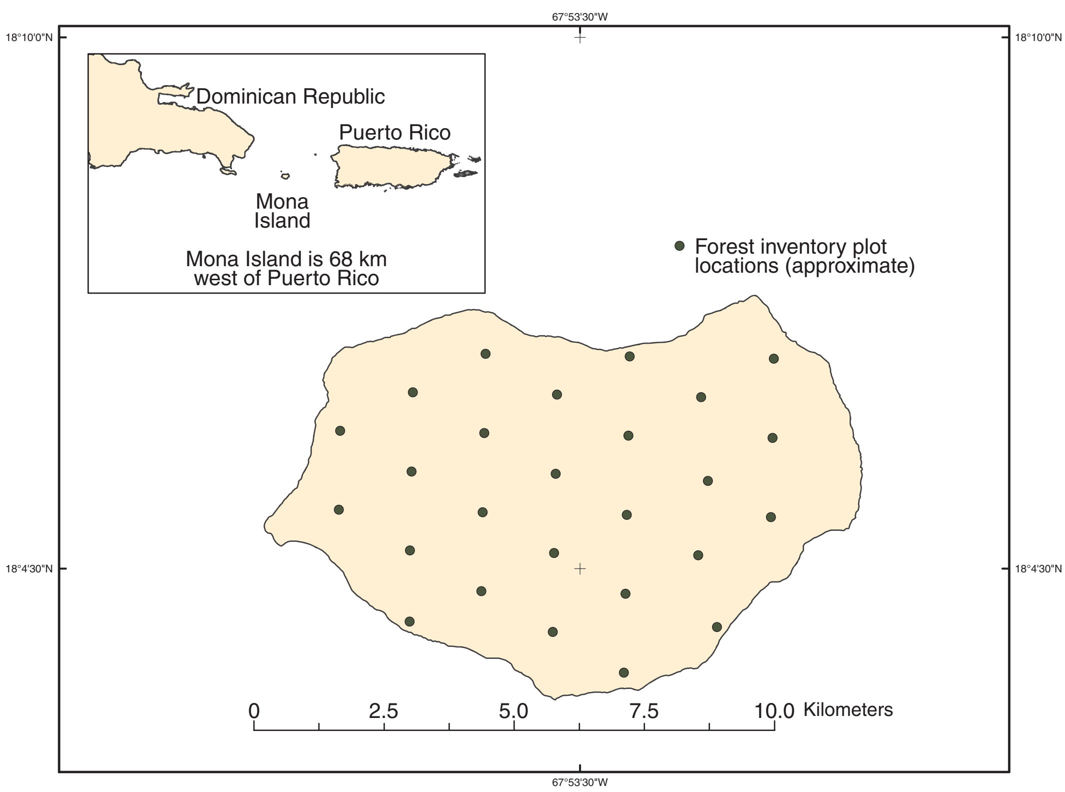


Figure 1—Mona Island with approximate forest inventory plot locations. Inset map shows Mona Island's position relative to mainland Puerto Rico and the Dominican Republic.

in areas with rainfall between 600–1100 mm per year at elevations <300 m. This forested life zone covers about 17 percent of Puerto Rico and the U.S. Virgin Islands and is found along the south coast of mainland Puerto Rico, over most of the outlying Puerto Rican islands of Culebra, Vieques, and Mona, and at lower elevations of St. Croix, St. Thomas, and St. John (Ewel and Whitmore 1973). Caribbean island subtropical dry forest covers a broad transitional zone between subtropical moist forest at one rainfall extreme and tropical dry forest at the other (Ewel and Whitmore 1973). As a result, this life zone encompasses a variety of vegetation and forest types with species of varying degrees of deciduousness and growth form (Murphy and others 1995).

Mona Island's subtropical dry forest ecosystems are particularly unique due to their relative isolation and unique position at the western limit of Lesser Antillean flora and fauna and the eastern limit for many Greater Antillean species (Cintrón 1991). The island is known for its endemic wildlife, particularly the threatened Mona ground iguana (*Cyclura cornuta stejnegeri*) (García and others 2007). Recent efforts have provided more detailed maps of the iguana's habitat (Perotto-Baldivieso and others 2009), and the entire island has been declared critical habitat for the iguana by the U.S. Fish and Wildlife Service. While not as heavily used as the subtropical moist and wet forest found on mainland Puerto Rico, the subtropical dry forest on Mona Island and other Caribbean islands is important wintering habitat for Neotropical migrants (Terborgh and Faaborg 1973). The whole of Mona Island is administered as a natural reserve by the Puerto Rico Department of Natural and Environmental Resources (DNRA is the Spanish acronym). Mona Island was designated a national natural landmark in 1975 by the National Park Service (Natural Resources Stewardship and Science 2009), and the Mona Island Lighthouse is on the list of national historic light stations.

Mona ground iguana (*Cyclura cornuta stejnegeri*). (photo by Iván Vicéns, USDA Forest Service)

The Mona Island Lighthouse is on the list of National Historic Light Stations.
(photo by Kimberly Rowe, USDA Forest Service)

Caribbean subtropical dry forests have been heavily impacted by human activities (Murphy and Lugo 1995). Disturbance has dominated subtropical dry forest development since European colonization. Murphy and others (1995) estimated that only 4 percent of the original subtropical dry forest remains on mainland Puerto Rico after disturbances that have included sugarcane production, livestock grazing, irrigated agricultural crops and fruit trees, urbanization, and industrialization. Mona Island's forests, too, were impacted by human activities, and there has been a long history of human occupation and use of the island's natural resources dating back to the Taíno people (Wadsworth 1973). The impacts were relatively light, however, and most activity ceased over one-half century ago. While direct human disturbances are currently limited, introduced feral goats and pigs in the reserve continue to impact the vegetation, threatening Mona ground iguana habitat (Díaz 1984, Meléndez-Ackerman and others 2008).

Natural disturbances affect Mona Island's flora and fauna as well. Extended droughts are common in the areas where subtropical dry forest is found. In their disturbed state, Caribbean subtropical dry forests might be particularly vulnerable to extended droughts or long-term climate changes. Duration and intensity of droughts are expected to increase in some Caribbean regions with global warming (Campbell and others 2011). Although models that predict the effects of global warming on climate vary somewhat, a recent review shows that all of these models agree that climate will dry in the Caribbean and Central America (Neelin and others 2006). This is highly relevant since the consensus of reviews on factors influencing woody species diversity in tropical forests points towards the importance of rainfall and seasonality. All else equal, tropical tree species diversity tends to decrease with dry season length in mature forests (Givnish 1999). The impacts of a drying trend will extend far beyond forest vegetation. Evidence is clear that droughts already negatively impact Neotropical migratory birds that overwinter in the dry forest of the Guánica Commonwealth forest of Puerto Rico (Dugger and others 2000, Faaborg and others 2000). The subtropical dry forests of Mona Island could be particularly vulnerable to periodic drought or long-term climate change, as the island's predominant limestone and dolomite substrates (Aaron 1973, Frank and others 1998) are excessively well-drained.

The natural resources, especially the vegetation (Woodbury 1973, Cintrón and Rogers 1991, Lugo 1991, Warren 2000, Martinuzzi and others 2008), of Mona Island have been studied previously, and this research provides critical information for resource managers. Cintrón and Rogers (1991) in particular provides detailed descriptions of the vegetation communities that include species compositions, topographic locations and structural characteristics. What has been lacking from this body of research, however, is an extensive, systematic, unbiased assessment of the vegetation across the entire island that would complement and provide a contextual framework for the more detailed, intensive studies. Despite the extent, importance, and threatened nature of subtropical dry forests on Caribbean islands, until recently forest surveys on Puerto Rico excluded dry forests, including the forests on its outlying islands because they were not considered to have the productive capacity to support commercial wood production (Birdsey and Weaver 1982, Franco and others 1997).

The overall goal of this project was to install a network of permanent forest vegetation assessment and monitoring plots on Mona Island that would give stakeholders baseline vegetation information relevant to managing the Mona Island reserve now, and with repeated measurements monitor the effects of periodic disturbance and climate change. To accomplish this goal, this paper addresses the following objectives:

1. Quantify tree and shrub stem density, basal area, aboveground biomass, and canopy height in the subtropical dry forests on Mona Island.

2. Describe the ground cover and vertical structure of the vegetation.

3. Discuss how the survey can be useful for wildlife and plant management and other management goals.

4. Assess how well the forest vegetation assessment captured the vascular plant species and plant community diversity on the island.

Methodology

Sampling design—A computer generated hexagonal grid that provides an unbiased, spatially systematic sampling framework produced a sampling point about every 67 ha on Mona Island. This sampling intensity is 12 times more intensive than that used on mainland Puerto Rico and across the continental United States (for details on the Forest Inventory and Analysis (FIA) sampling design, see Reams and others 2005). This intensity was chosen based on the island's size and the resources available to install the plot network at this remote location. During April 2008, field crews visited the 26 sampling locations across Mona Island (fig. 1). Permanent plots were installed at all sampling points, because they all met the FIA program's definition of forest, which is land having at least 10 percent cover of forest trees, or that must have had such tree cover and not be undergoing development for a nonforest use.

Forest vegetation assessment data collection— The permanent plots consist of a 4-subplot cluster (fig. 2). Each subplot in the cluster has a 7.3-m radius, giving a total sampled area of 0.067 ha (see Bechtold and Scott 2005 for further details on plot layout). The center of subplot 1 is located using a global positioning system receiver and orthorectified color digital aerial photos that were taken in 2004 that had the plot center projected onto it. Subplots centers 2, 3, and 4 were located with tape measures and compass. There was a 2.1 m radius microplot nested within each subplot, offset 4 m from subplot center to reduce trampling. All subplot and microplot centers were monumented with steel pins.

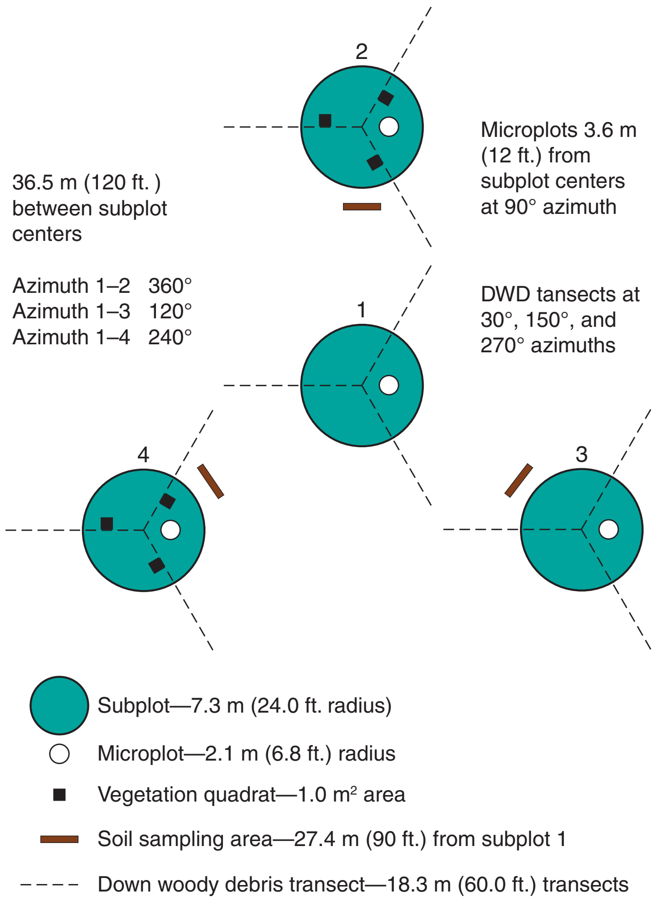


Figure 2—U.S. Forest Service FIA forest inventory plot layout with vegetation diversity and structure sampling locations.

All trees within the subplots with a diameter at breast height (d.b.h., measured at 1.37 m) ≥12.5 cm were identified and measured for d.b.h. and total height. Tree distance and azimuth from subplot center were also noted for future individual tree remeasurement. All saplings with a d.b.h. ≥2.5 cm, and all seedlings with a height >30 cm, were identified and measured within the microplot. Sapling distance and azimuth from microplot center was also noted for future tracking. (See U.S. Department of Agriculture Forest Service 2002 for further details on measurements taken on FIA plots.)

Aboveground live tree biomass was estimated for all trees with d.b.h. ≥2.5 cm using the allometric equations from Brandeis and others (2007). Biomass in shrub species or herbaceous vegetation was not estimated.

Vegetation diversity and structure data collection—Vegetation diversity and structure data were collected on only two of the four subplots (numbers 2 and 4) of each plot due to resource constraints. The following description of the data collection protocols for vegetation diversity and structure is derived from the U.S. Department of Agriculture Forest Service's FIA National Core Field Guide—Vegetation Diversity and Structure (2007) where further details can be found.

First, total cover of all vegetation foliage in four height layers (0–0.6 m, >0.6–1.8 m, >1.8–4.9 m, and >4.9 m) was estimated on each subplot. Canopy cover estimates were based on a vertically-projected polygon described by the outline of the foliage, ignoring any normal spaces occurring between the leaves of plants (Daubenmire 1959). Ground cover estimates were also recorded on the 7.3 m radius subplot as percent cover in the following categories: cryptobiotic crust, lichens, litter/duff, mineral soil, moss, road/trail, rock, standing water/flooded cover, stream/lake, trash/junk/other, and wood (e.g., logs, stumps, roots, etc. >8 cm in diameter).

Then, on each sampled subplot, three 1 m^2 quadrats were installed on the right sides of lines at azimuths of 30º, 150º, and 270º (fig. 1). (These lines also serve as transects for sampling down woody materials but those results are not being presented here.) Two corners of each quadrat are permanently marked at 4.6 and 5.6 m, horizontal distance, from the subplot center for future relocation and remeasurement. On the quadrats, species presence/absence data were collected for all vascular plants rooted in the quadrat or with overhanging foliage or live material within 2 m above-the-ground above the quadrat. Species nomenclature was based on U.S. Department of Agriculture Natural Resource Conservation Service (NRCS) PLANTS database January 2000 version (U.S. Department of Agriculture Natural Resources Conservation Service 2000). Voucher samples of unknown specimens were collected when necessary for later identification in the laboratory.

After the quadrats were assessed, a time-constrained (45 minutes) search of all species on the subplot was conducted. Total canopy cover of each individual species was estimated, and then canopy cover within each of three height layers (0–1.8 m, >1.8–4.9 m, and >4.9 m) was estimated on each subplot. There were no height limits for vegetation overhanging the subplot boundary; trees and shrubs that are rooted outside the subplot were included if they overhang the subplot. Epiphytes (Spanish moss, bromeliads, ferns, orchids, etc.) were recorded as well as possible as seen from the ground level.

The month of April, when the plots were installed, was one of the driest months of 2008 (Rojas-Sandoval and Meléndez-Ackerman 2011) and was not ideal for the collection of vegetation cover data. There appeared to have been some dry season leaf loss in the overstory trees, particularly for the common overstory tree *Bursera simaruba* (L.) Sarg. Instead of attempting to reconstruct missing leaf area, we estimated what was present at the time. Mid- and understory-vegetation cover estimates did not appear to be appreciably affected by the dry season.

Plant species richness and diversity was estimated for each plot. Alpha diversity (the average species richness per plot), Beta diversity (ratio of the total number of species found to the average species richness per plot), and Gamma diversity (the landscape/island-wide diversity estimated from all plots) were calculated. Two diversity indices were also calculated, Shannon`s and Simpson's, with the following formulae.

Simpson`s diversity index (*D*) for an infinite population represents the ubiquity of a species across the sample; that is, the likelihood that two randomly chosen individuals will be the same species (McCune and Grace 2002)

$$D = -\frac{1}{\sum_{i}^{S} p_i^2}$$

Seasonal leaf loss on almácigo, gumbo limbo (*Bursera simaruba*) trees. (photo by Thomas Brandeis, USDA Forest Service)

where

p_i = proportion of individuals belonging to species i

S = number of species.

Shannon`s diversity index (H) expresses the information content of a species across the sample (McCune and Grace 2002), or put in other terms, the rarity and commonness of species by calculating the likelihood that one species has an equal probability of being represented as all the other species:

$$H = \log(D) = -\sum_{i}^{S} p_i \log p_i$$

To help assess how well the forest vegetation assessment plots captured the total number of plant species to be found on Mona Island, species area curves were generated using 500 subsampling iterations and the Sorenson (Bray-Curtis) distance measure using the PC-Ord software, as were first- and second-order jackknife estimates of species richness (McCune and Mefford 1999).

Results

Forest vegetation cover characteristics—Table 1 presents the mean, minimum, and maximum values for tree density (trees per hectare), basal area per hectare, and aboveground biomass per hectare for all trees with d.b.h. ≥2.5 cm. Also presented in this table are the mean values for canopy height of the codominant and dominant trees and average tallest tree found on the plot. For this site, the average canopy height was only 4.6 m, and the tallest tree found on the forest vegetation assessment plots was 9.8 m tall.

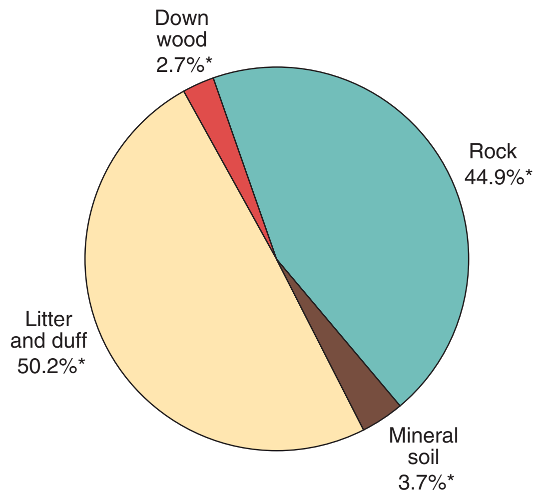
Subtropical dry forest on Mona Island, Puerto Rico. (photo by Thomas Brandeis, USDA Forest Service)

Table 1—Mean, standard error, minimum and maximum values for stem density, basal area, aboveground biomass, canopy height, and tallest tree on the subplot, for stems with d.b.h. ≥2.5 cm on Mona Island, Puerto Rico, 2008

Characteristic	Mean	SE	Minimum	Maximum
TPH (*number/ha*)	3,408.5	358.2	0.0	7,741.3
BAH (m^2/ha)	8.7	0.9	0.0	16.2
AGBH (*Mg/ha*)	28.8	3.4	0.0	59.0
Canopy height (*m*)	4.6	0.2	1.8	5.6
Tallest tree (*m*)	6.6	0.3	2.5	9.8

SE = standard error; d.b.h. = diameter at breast height; ha = hectare; m = meter; Mg = Mega gram; TPH = minimum and maximum values for stem density; BAH = basal area; AGBH = aboveground biomass.

Island-wide, the forest floor was covered primarily with a layer of duff/litter or bare rock, with minor coverage in mineral soil and woody material (fig. 3). Above the forest floor, the vegetation cover was highest in the lower two vertical strata, that is, in the 0–0.6 m and >0.6–1.8 m layers (fig. 4). The dominance of woody vegetation cover from 0–1.8 m is evident in figure 5.



* Percentages may not sum to 100 due to rounding.

Figure 3—Mean percent ground cover, Mona Island, Puerto Rico, 2008.

Subtropical dry forest on Mona Island, Puerto Rico. (photo by Thomas Brandeis, USDA Forest Service)

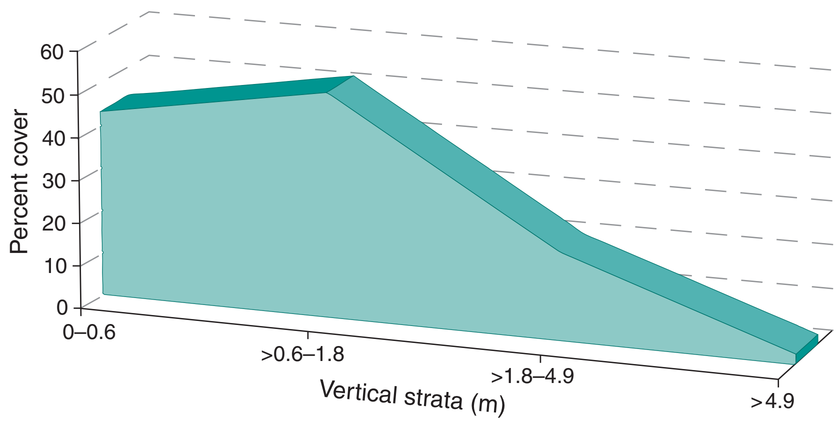


Figure 4—Mean percent vegetation cover by vertical strata for vegetation, Mona Island, Puerto Rico, 2008.

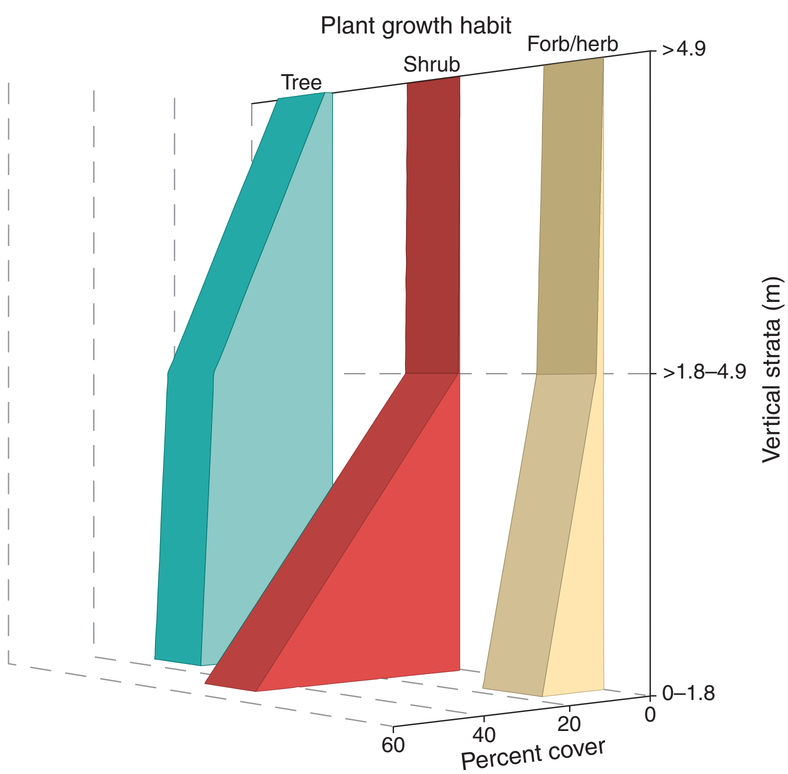


Figure 5—Mean percent vegetation cover by plant growth habit and vertical strata, Mona Island, Puerto Rico, 2008.

Sparse leaf litter over extremely shallow, rocky soil as often encountered on the plateau of Mona Island, Puerto Rico. (photo by Terry Riley, USDA Forest Service)

Species composition—A total of 104 vascular plot species were found on the forest vegetation assessment plots, plus unknowns (table 2). There were 35 species of forb/herbs, 26 of shrubs, and 43 tree species, but the total sampling area was greater for tree species, consisting of all 4 subplots on a plot. The sampling area for forb/herbs and shrubs was only 2 subplots per plot. Table 2 also presents the frequency of occurrence on all 26 forested plots, the species constancy (i.e., the percentage of plots where the species was recorded), as well as each species' total cover, subplot frequency, and quadrat frequency on plots where the species was encountered. Twenty-nine species were encountered on only 1 plot, and 18 species were encountered on only 2 plots. There were only three introduced species found on Mona Island, *Cereus hildmannianus* K. Schum., *Crotalaria berteriana* DC., and *Ipomoea batatas* (L.) Lam., and these were each found on <10 percent of the plots (table 2).

Table 2—Frequency and mean percent cover of native and introduced plant species found on 26 forest inventory plots on Mona Island, Puerto Rico, 2008

Number of plots	Growth habit[a]	Scientific name	Common name	Family	Origin	Constancy over all forested plots[b]	Plot where species present: Mean cover	Subplot frequency	Quadrat frequency
8	Tree	*Amyris elemifera* L.	Sea torchwood	Rutaceae	N	29.63	1.44	0.17	0.07
23	Tree	*Antirhea acutata* (DC.) Urb.	Placa chiquitu	Rubiaceae	N	85.19	8.50	0.74	0.56
1	Shrub	*Ayenia insulicola* Cristobal	Dwarf ayenia	Sterculiaceae	N	3.70	0.01	0.02	0.02
1	Shrub	*Bastardia bivalvis* (Cav.) Kunth	Escoba babosa	Malvaceae	N	3.70	0.01	0.02	0.02
17	Tree	*Bourreria succulenta* Jacq.	Bodywood	Boraginaceae	N	62.96	4.03	0.43	0.33
24	Tree	*Bursera simaruba* (L.) Sarg.	Gumbo limbo	Burseraceae	N	88.89	5.48	0.74	0.48
1	Tree	*Byrsonima lucida* (Mill.) DC.	Long Key locustberry	Malpighiaceae	N	3.70	0.01	0.02	0.00
3	Forb/herb	*Callisia repens* (Jacq.) L.	Creeping inchplant	Commelinaceae	N	11.11	2.50	0.09	0.09
1	Tree	*Calyptranthes pallens* Griseb.	Pale lidflower	Myrtaceae	N	3.70	5.00	0.02	0.02
2	Tree	*Canella winterana* (L.) Gaertn.	Wild cinnamon	Canellaceae	N	7.41	2.00	0.06	0.06
2	Tree	*Capparis flexuosa* (L.) L.	Falseteeth	Capparaceae	N	7.41	0.01	0.06	0.04
12	Forb/herb	*Centrosema virginianum* (L.) Benth.	Spurred butterfly pea	Fabaceae	N	44.44	0.30	0.39	0.35
2	Shrub	*Cereus hildmannianus* K. Schum.	Hedge cactus	Cactaceae	I	7.41	0.75	0.04	0.04
1	Forb/herb	*Chamaecrista* (L.) Moench	Sensitive pea	Fabaceae	N	3.70	0.01	0.02	0.02
7	Shrub	*C. lineata* (Sw.) Greene	Narrowpod sensitive pea	Fabaceae	N	25.93	5.43	0.22	0.20
17	Shrub	*C. nictitans* (L.) Moench	Partridge pea	Fabaceae	N	62.96	4.38	0.56	0.33
1	Forb/herb	*Chamaesyce cowellii* Millsp. ex Britton	Cowell's sandmat	Euphorbiaceae	N	3.70	0.01	0.02	0.00
1	Tree	*Chrysophyllum pauciflorum* Lam.	Camito de perro	Sapotaceae	N	3.70	0.01	0.02	0.00
3	Forb/herb	*Cissus trifoliata* (L.) L.	Sorrelvine	Vitaceae	N	11.11	0.01	0.06	0.02
3	Tree	*Coccoloba diversifolia* Jacq.	Tietongue	Polygonaceae	N	11.11	2.67	0.09	0.07
23	Tree	*C. microstachya* Willd.	Puckhout	Polygonaceae	N	85.19	10.26	0.80	0.59
3	Forb/herb	*Commelina diffusa* Burm. f.	Climbing dayflower	Commelinaceae	N	11.11	0.51	0.07	0.06
3	Forb/herb	*C. erecta* L. var. erecta	Whitemouth dayflower	Commelinaceae	N	11.11	0.17	0.09	0.09
19	Tree	*Comocladia dodonaea* (L.) Urb.	Poison ash	Anacardiaceae	N	70.37	0.64	0.41	0.22
21	Tree	*Consolea moniliformis* (L.) Britton	Tuna	Cactaceae	N	77.78	0.67	0.59	0.37
11	Shrub	*Corchorus hirsutus* L.	Jackswitch	Tiliaceae	N	40.74	1.73	0.31	0.22
2	Shrub	*Cordia globosa* (Jacq.) Kunth	Curaciao bush	Boraginaceae	N	7.41	2.25	0.06	0.06
8	Tree	*Crossopetalum rhacoma* Crantz	Maidenberry	Celastraceae	N	29.63	0.50	0.19	0.13
1	Shrub	*Crotalaria berteriana* DC.	Berteron's rattlebox	Fabaceae	I	3.70	2.00	0.04	0.04
19	Shrub	*Croton betulinus* Vahl	Beechleaf croton	Euphorbiaceae	N	70.37	6.03	0.61	0.56
23	Shrub	*C. discolor* Willd.	Lechecillo	Euphorbiaceae	N	85.19	6.83	0.78	0.63
23	Shrub	*C. lucidus* L.	Firebush	Euphorbiaceae	N	85.19	28.28	0.83	0.81
2	Forb/herb	*Cuscuta umbellata* Kunth	Flatglobe dodder	Cuscutaceae	N	7.41	1.25	0.04	0.02
1	Forb/herb	*Cyperus filiformis* Sw.	Wiry flatsedge	Cyperaceae	N	3.70	0.50	0.02	0.02
2	Forb/herb	*C. nanus* Willd.	Indian flatsedge	Cyperaceae	N	7.41	0.26	0.06	0.02
1	Tree	*Dodonaea viscosa* (L.) Jacq.	Florida hopbush	Sapindaceae	N	3.70	0.01	0.04	0.02
11	Forb/herb	*Domingoa haematochila* (Rchb. f.) Carabia	Mona	Orchidaceae	N	40.74	1.14	0.30	0.17
1	Forb/herb	*Ernodea littoralis* Sw.	Coughbush	Rubiaceae	N	3.70	0.01	0.02	0.00

continued

Table 2—Frequency and mean percent cover of native and introduced plant species found on 26 forest inventory plots on Mona Island, Puerto Rico, 2008 (continued)

							Plot where species present		
Number of plots	Growth habit[a]	Scientific name	Common name	Family	Origin	Constancy over all forested plots[b]	Mean cover	Subplot frequency	Quadrat frequency
1	Tree	*Erythroxylum areolatum* L.	Swamp-redwood	Erythroxylaceae	N	3.70	7.50	0.04	0.04
13	Tree	*Eugenia foetida* Pers.	Boxleaf stopper	Myrtaceae	N	48.15	2.39	0.39	0.30
1	Tree	*E. monticola* (Sw.) DC.	Birdcherry	Myrtaceae	N	3.70	0.51	0.04	0.04
22	Tree	*Euphorbia petiolaris* Sims	Manchineel berry	Euphorbiaceae	N	81.48	0.96	0.67	0.35
10	Tree	*Exostema caribaeum* (Jacq.) Schult.	Caribbean princewood	Rubiaceae	N	37.04	1.20	0.24	0.17
6	Tree	*Ficus citrifolia* Mill.	Wild banyantree	Moraceae	N	22.22	1.50	0.15	0.07
1	Shrub	*Furcraea tuberosa* (Mill.) W.T. Aiton	Female karata	Agavaceae	N	3.70	20.01	0.04	0.04
12	Forb/herb	*Galactia dubia* DC.	West Indian milkpea	Fabaceae	N	44.44	0.67	0.39	0.35
4	Tree	*Guettarda elliptica* Sw.	Hammock velvetseed	Rubiaceae	N	14.81	0.75	0.07	0.06
3	Tree	*G. pungens* Urb.	Roseta	Rubiaceae	N	11.11	3.67	0.09	0.09
2	Tree	*Gyminda latifolia* (Sw.) Urb.	West Indian false box	Celastraceae	N	7.41	0.01	0.04	0.02
1	Tree	*Gymnanthes lucida* Sw.	Oysterwood	Euphorbiaceae	N	3.70	0.01	0.02	0.02
13	Tree	*Harrisia portoricensis* Britton	Puerto Rico applecactus	Cactaceae	N	48.15	0.04	0.31	0.15
3	Tree	*Helicteres jamaicensis* Jacq.	Screwtree	Sterculiaceae	N	11.11	0.84	0.09	0.04
7	Tree	*Hypelate trifoliata* Sw.	Inkwood	Sapindaceae	N	25.93	3.22	0.17	0.11
1	Forb/herb	*Ipomoea batatas* (L.) Lam.	Sweetpotato	Convolvulaceae	I	3.70	0.01	0.02	0.00
2	Forb/herb	*I.* L.	Morning-glory	Convolvulaceae	N	7.41	0.01	0.06	0.02
2	Forb/herb	*I. microdactyla* Griseb.	Calcareous morning-glory	Convolvulaceae	N	7.41	0.01	0.04	0.00
4	Forb/herb	*Jacquemontia pentanthos* (Jacq.) G. Don	Skyblue clustervine	Convolvulaceae	N	14.81	0.13	0.13	0.06
1	Shrub	*Jacquinia armillaris* Jacq.	Braceletwood	Theophrastaceae	N	3.70	0.01	0.02	0.00
3	Tree	*Krugiodendron ferreum* (Vahl) Urb.	Leadwood	Rhamnaceae	N	11.11	2.67	0.06	0.04
5	Tree	*Lantana involucrata* L.	Buttonsage	Verbenaceae	N	18.52	0.60	0.11	0.11
1	Shrub	*Malvastrum americanum* (L.) Torr.	Indian Valley false mallow	Malvaceae	N	3.70	0.01	0.04	0.02
1	Shrub	*Mammillaria nivosa* Link ex N.E. Pfeiffer	Woolly nipple cactus	Cactaceae	N	3.70	17.50	0.04	0.04
3	Shrub	*Melocactus intortus* (Mill.) Urb.	Turk's cap	Cactaceae	N	11.11	0.01	0.09	0.02
2	Shrub	*Melochia tomentosa* L.	Teabush	Sterculiaceae	N	7.41	0.01	0.06	0.04
10	Tree	*Metopium toxiferum* (L.) Krug & Urb.	Florida poisontree	Anacardiaceae	N	37.04	4.40	0.28	0.15
19	Tree	*Myrcianthes fragrans* (Sw.) McVaugh	Twinberry	Myrtaceae	N	70.37	4.84	0.54	0.44
22	Shrub	*Opuntia repens* Bello	Roving pricklypear	Cactaceae	N	81.48	0.32	0.65	0.41
4	Forb/herb	*Paspalum blodgettii* Chapm.	Blodgett's crowngrass	Poaceae	N	14.81	2.00	0.13	0.11
1	Forb/herb	*P. caespitosum* FlueggT	Blue crowngrass	Poaceae	N	3.70	3.00	0.04	0.04
3	Forb/herb	*P.* L.	Crowngrass	Poaceae	N	11.11	1.17	0.07	0.04
4	Forb/herb	*P. laxum* Lam.	Coconut paspalum	Poaceae	N	14.81	1.13	0.13	0.09
2	Forb/herb	*Passiflora suberosa* L.	Corkystem passionflower	Passifloraceae	N	7.41	0.01	0.04	0.02

continued

Table 2—Frequency and mean percent cover of native and introduced plant species found on 26 forest inventory plots on Mona Island, Puerto Rico, 2008 (continued)

							Plot where species present		
Number of plots	Growth habit[a]	Scientific name	Common name	Family	Origin	Constancy over all forested plots[b]	Mean cover	Subplot frequency	Quadrat frequency
1	Shrub	*Pentalinon luteum* (L.) B.F. Hansen & Wunderlin	Hammock viper's-tail	Apocynaceae	N	3.70	0.01	0.02	0.00
3	Forb/herb	*Peperomia humilis* A. Dietr.	Polynesian peperomia	Piperaceae	N	11.11	3.34	0.07	0.07
13	Shrub	*Phyllanthus epiphyllanthus* L.	Swordbush	Euphorbiaceae	N	48.15	14.04	0.44	0.39
1	Shrub	*Pilea margarettiae* Britton	Margarett's clearweed	Urticaceae	N	3.70	0.01	0.04	0.04
1	Forb/herb	*P. tenerrima* Miq.	Musgo	Urticaceae	N	3.70	1.00	0.02	0.02
7	Tree	*Pilosocereus royenii* (L.) Byles & Rowley	Royen's tree cactus	Cactaceae	N	25.93	0.65	0.19	0.09
4	Tree	*Pisonia albida* (Heimerl) Britton ex Standl.	Corcho bobo	Nyctaginaceae	N	14.81	2.50	0.09	0.06
1	Tree	*Plumeria alba* L.	Nosegaytree	Apocynaceae	N	3.70	2.51	0.04	0.00
24	Tree	*P. obtusa* L.	Singapore graveyard flower	Apocynaceae	N	88.89	2.40	0.83	0.52
1	Forb/herb	*Portulaca caulerpoides* Britton & P. Wilson ex Britton	Puerto Rico purslane	Portulacaceae	N	3.70	0.01	0.02	0.02
2	Forb/herb	*Prestonia agglutinata* (Jacq.) Woodson	Babeiro	Apocynaceae	N	7.41	0.01	0.04	0.02
23	Forb/herb	*Psychilis monensis* Sauleda	Royal peacock orchid	Orchidaceae	N	85.19	1.92	0.81	0.54
2	Tree	*Psychotria nervosa* Sw.	Seminole balsamo	Rubiaceae	N	7.41	0.01	0.07	0.04
12	Tree	*Randia aculeata* L.	White indigoberry	Rubiaceae	N	44.44	0.75	0.28	0.09
2	Shrub	*R. portoricensis* (Urb.) Britton & Standl.	Puerto Rico indigoberry	Rubiaceae	N	7.41	0.01	0.04	0.00
2	Shrub	*Rauvolfia viridis* Roem. & Schult.	Milkbush	Apocynaceae	N	7.41	0.25	0.04	0.04
26	Tree	*Reynosia uncinata* Urb.	Sloe	Rhamnaceae	N	96.30	9.08	0.87	0.67
1	Forb/herb	*Rhynchosia minima* (L.) DC.	Least snoutbean	Fabaceae	N	3.70	0.01	0.02	0.02
6	Forb/herb	*R. reticulata* (Sw.) DC.	Habilla	Fabaceae	N	22.22	0.84	0.15	0.11
2	Tree	*Schaefferia frutescens* Jacq.	Florida boxwood	Celastraceae	N	7.41	0.01	0.04	0.02
21	Forb/herb	*Setaria utowanaea* (Scribn. ex Millsp.) Pilg.	Caribbean bristlegrass	Poaceae	N	77.78	4.41	0.72	0.65
1	Shrub	*Sida glabra* Mill.	Smooth fanpetals	Malvaceae	N	3.70	0.01	0.02	0.02
3	Shrub	*Sidastrum multiflorum* (Jacq.) Fryxell	Manyflower sandmallow	Malvaceae	N	11.11	0.01	0.06	0.04
1	Shrub	*Solanum racemosum* Jacq.	Berengena de playa	Solonaceae	N	3.70	0.01	0.02	0.00
2	Forb/herb	*Spermacoce confusa* Rendle	River false buttonweed	Rubiaceae	N	7.41	0.50	0.04	0.02
21	Forb/herb	*Stigmaphyllon emarginatum* (Cav.) A. Juss.	Monarch Amazonvine	Malpighiaceae	N	77.78	1.31	0.56	0.35
24	Tree	*Tabebuia heterophylla* (DC.) Britton	White cedar	Bignoniaceae	N	88.89	5.42	0.83	0.61
1	Tree	*Thrinax morrisii* H. Wendl.	Key thatch palm	Arecaceae	N	3.70	0.01	0.02	0.00
21	Forb/herb	*Tillandsia recurvata* (L.) L.	Small ballmoss	Bromeliaceae	N	77.78	3.62	0.70	0.52
22	Forb/herb	*T. utriculata* L.	Spreading airplant	Bromeliaceae	N	81.48	2.46	0.74	0.44
2	Forb/herb	*Tournefortia volubilis* L.	Twining soldierbush	Boraginaceae	N	7.41	0.01	0.04	0.00
4	Tree	*Ziziphus taylorii* (Britton) M.C. Johnst.	Taylor's jujube	Rhamnaceae	N	14.81	3.88	0.07	0.02
16	NA	Unknown	NA	NA	N	59.26	4.16	0.43	0.31

N = native plants species; I = introduced plant species.

[a] Growth habit and all nomenclature from the USDA NRCS PLANTS database, downloaded on February 2011. Note that growth habit has been simplified to forb/herb, shrub, and tree classes.

[b] Constancy is the percentage of plots where recorded (plot frequency x 100).

The endemic higo chumbo, Puerto Rico applecactus, (*Harrisia portoricensis*) on Mona Island, Puerto Rico. (photo by Terry Riley, USDA Forest Service)

Alpha diversity, the average species richness per plots, was 29.1 species. Beta diversity (the ratio of the total number of species found to the average species richness per plot) was 3.6 and Gamma diversity was 104 species. Species diversity indices, species richness, Simpson's diversity index (average = 0.96), and Shannon's diversity index (average = 3.35) are presented in table 3. The species-area curve for the FIA plots on Mona Island did not quite reach an asymptote and thus the observed number of species (104) is lower than the expected number of species (first-order jackknife estimate = 140.8 and second-order jackknife estimate = 153.5, fig. 6).

Table 3—Species diversity indices for forest inventory plots, Mona Island, Puerto Rico, 2008

Number	Plot	Mean	Standard deviation	S	H	D
1	502	0.373	0.486	41	3.714	0.9756
2	506	0.273	0.447	30	3.401	0.9667
3	510	0.245	0.432	27	3.296	0.9630
4	512	0.327	0.471	36	3.584	0.9722
5	518	0.236	0.427	26	3.258	0.9615
6	519	0.291	0.456	32	3.466	0.9688
7	520	0.264	0.443	29	3.367	0.9655
8	501	0.409	0.494	45	3.807	0.9778
9	504	0.282	0.452	31	3.434	0.9677
10	505	0.245	0.432	27	3.296	0.9630
11	511	0.309	0.464	34	3.526	0.9706
12	513	0.236	0.427	26	3.258	0.9615
13	514	0.209	0.409	23	3.135	0.9565
14	515	0.273	0.447	30	3.401	0.9667
15	516	0.309	0.464	34	3.526	0.9706
16	521	0.227	0.421	25	3.219	0.9600
17	522	0.227	0.421	25	3.219	0.9600
18	524	0.218	0.415	24	3.178	0.9583
19	525	0.227	0.421	25	3.219	0.9600
20	526	0.227	0.421	25	3.219	0.9600
21	527	0.227	0.421	25	3.219	0.9600
22	528	0.291	0.456	32	3.466	0.9688
23	529	0.218	0.415	24	3.178	0.9583
24	530	0.191	0.395	21	3.045	0.9524
25	507	0.245	0.432	27	3.296	0.9630
26	509	0.300	0.460	33	3.497	0.9697
Average	NA	0.265	0.440	29	3.355	0.9645

Note: Alpha diversity = 29.1 Average species richness per plot; Beta diversity = 3.6 Ratio of the total number of species found to the average species richness per plot; Gamma diversity = 104.0 Landscape/island-wide diversity estimated from all plots.

S = species richness = number of nonzero elements in row;
H = Shannon`s diversity index = - sum (Pi*ln(Pi));
D = Simpson`s diversity index for infinite population = 1 - sum (Pi*Pi) where Pi = importance probability in element i (element i relativized by row total).

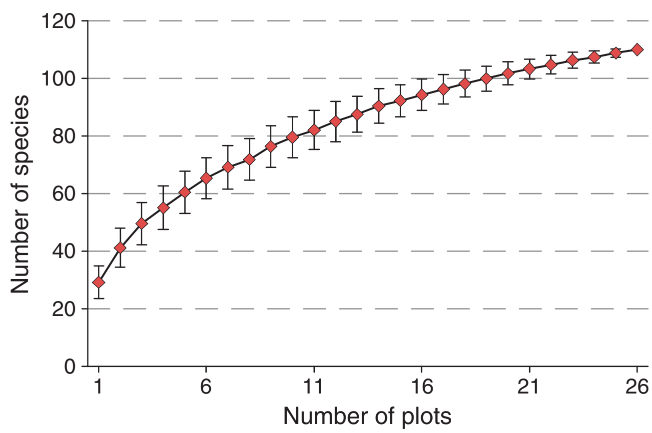


Figure 6—Species area, Mona Island, Puerto Rico, 2008. Curve generated using 500 subsampling iterations and the Sorenson (Bray-Curtis) distance measure. Data points represent the mean number of plant species found by the number of forest inventory plots, with error bars representing the standard deviations from the mean.

Discussion

The installation of these long-term forest vegetation assessment and monitoring plots on Mona Island completes an east-west sampling gradient over 360 km long, with Mona Island on the western end and St. Croix, U.S. Virgin Islands, to the east. Stem densities and basal areas on Mona Island, averaging 3,408 and 8.7 m^2 per ha, respectively, are typical of Caribbean subtropical dry forests at the drier end of the moisture gradient. The dry forests of mainland Puerto Rico, and its outlying islands of Vieques and Culebra, averaged 3,001 stems per ha with d.b.h. ≥12.5 cm and 8.2 m^2 per ha of basal area (Brandeis and others 2007). Dry forests of the U.S. Virgin Islands averaged 4,008 stems per ha and 9.7 m^2 per ha of basal area (Brandeis and Oswalt 2007). Aboveground live tree biomass was notably less on Mona Island, averaging 29 Mg per ha, when compared to the subtropical dry forests on the outer islands of Puerto Rico (41.74 Mg per ha) and the U.S. Virgin Islands (47.65 Mg per ha) (Brandeis and others 2007, Brandeis and Oswalt 2007). The forests on Mona Island are less dense, shorter, and have smaller diameters.

Cactus "forest" on Mona Island, Puerto Rico. (photo by Thomas Brandeis, USDA Forest Service)

The forest vegetation assessment plots fell in what is described by Cintrón and Rogers (1991) as plateau forest, which covers 80 percent of the island. High constancy values for the trees *Bursera simaruba* (L.) Sarg., *Plumeria obtusa* L., *Tabebuia heterophylla* (DC.) Britton, *Coccoloba microstachya* Willd., *Euphorbia petiolaris* Sims, *Bourreria succulenta* Jacq., as well as small tree/shrubs *Reynosia uncinata* Urb., *Antirhea acutata* (DC.) Urb., *Croton* spp., and *Opuntia repens* Bello correspond closely to the dominant species they described for plateau forest.

Sampling was not intensive enough to differentiate between the 10 vegetation types identified by Cintrón and Rogers (1991). The computer-generated systematic sample did not place any forest vegetation assessment plots directly into any of the distinct karst depressions that dot the surface of Mona Island. However, many of the species that dominate the depression forests were encountered in the sample, though not as dominants, including *Pisonia albida* (Heimerl) Britton ex Standl., *Ficus citrifolia* Mill., and *Schaefferia frutescens* Jacq. (Cintrón and Rogers 1991). These depressions have greater soil accumulation that results in forest patches with species composition and stand development that differs from the drier, more exposed plateau (Cintrón and Rogers 1991). The largest trees and densest, most variable stands on the island are found in these depressions, so it must be noted that the results of this study, while capturing some characteristics of the depression forests, are skewed toward the plateau forests where tree heights and diameters are slightly less and the composition more dominated by species with greater drought tolerance.

Notably absent due to the sampling design are the distinct coastal, cliffside, mangrove, and plantation forests that exist in very limited areas on the island that are described by Cintrón and Rogers (1991) and Warren (2000). None of the forest vegetation assessment plots fell on the lowland coastal shelf along the southwestern portions of the island where lowland, mangrove, and plantation forests are found.

Blue-footed booby (*Sula nebouxii*) nesting in a wild banyantree (*Ficus citrifolia*) tree.
(photo by Humfredo Marcano, USDA Forest Service)

Cliff-side vegetation on Mona Island, Puerto Rico.
(photo by Iván Vicéns, USDA Forest Service)

The intent of this study was to produce an estimate of average forest structure along with the composition of common species. As such, we did not detect all of the species that a botanical survey of Mona Island might have. Our study encountered 104 vascular plant species; Woodbury (1973) states there are 393 vascular plant species on Mona Island. Cintrón and Rogers' (1991) admirably comprehensive study encountered 150 species, but they noted that many species had a scattered distribution. The species area curve from this survey indicates the capture rate of additional species with more sampling is leveling off. Scattered distributions and uncommon or rare occurrence of many species on Mona Island would make capturing all of them difficult with any vegetation sample.

Other subtropical dry forests in Puerto Rico are similarly species rich or even more so. It is estimated that there are 253 plant species in the Punta Guaniquilla Natural Reserve, Cabo Rojo (Vázquez and Kolterman 1998) and around 500 plant species in the Guánica Commonwealth Forest (Quevedo and Silander 1990). The 42 tree species encountered by this study on Mona Island was considerably less than observed in other subtropical dry forests in Puerto Rico. In Guánica there were 167 tree species reported by Chinea (1990), 161 tree species were found on the La Tinaja Tract of the Cartagena Lagoon National Wildlife Refuge (Weaver and Chinea 2003), and 89 tree species were found in the Punta Guaniquilla Natural Reserve (Vázquez and Kolterman 1998). Further afield but still within the Caribbean, there were 105 species of woody plants in what the author describes as "old growth" subtropical dry forest and 56 species in secondary "scrub" dry forest in the Dominican Republic (Roth 1999). However, Mona is much smaller than the areas mentioned above. Also, unlike the above-mentioned areas and other subtropical dry forests in Puerto Rico, those on Mona Island do not have the significant numbers of nonnative species found in the more heavily disturbed forests on the other islands of Puerto Rico (Brandeis and others 2007, Brandeis and others 2009, Molina Colón and others 2011).

This forest vegetation assessment and monitoring plot network provides landscape-level information based on extensive survey of the forest characteristics, complementing smaller-scale, more intensive studies on vegetation phenology, wildlife habitat, biogeochemical cycling, etc. in two ways. First, it places the results of those smaller-scale studies into an island-wide context. Second, the plot network creates a framework for extrapolating the findings from more intensive studies out across the entire island. The detailed information on canopy height and vegetation structural profiles on each of these plots will also support research on vegetation description using remotely-sensed imagery or lidar data.

The true value of these plots and their data will be realized with remeasurement and trend assessment over time. The vegetation cover information collected can be used as a baseline from which trends can be monitored. In the longer term, the effects of climatic change on Caribbean subtropical dry forest vegetation can be tracked using these plots' data. In the shorter term, the need for and effectiveness of management activities can be assessed. For example, we can safely assume that the vegetation of Mona Island is currently showing the impact of feral goat and pig browsing. This browsing has been shown to have a detrimental effect on Mona ground iguana habitat (Meléndez-Ackerman and others 2008). Mona ground iguanas primarily forage on fruits and leaves on the ground, but they sometimes climb 2–3 m into the shrubs (Wiewandt 1977 as cited in Díaz 1984).

Another consideration is that goat grazing could affect forest succession on Mona Island after natural disturbances like hurricanes or wildfire. In dry limestone forests of Eleuthera, The Bahamas, Larkin and others (2012) compared forest succession after clearing, wildfire, or clearing followed by managed goat grazing. They found that goat grazing keeps nonwoody ground cover low. In doing so, grazing may accelerate forest succession in the ground layer. At the same time, grazing on Eleuthera was associated with reduced or inhibited growth of dominant forest tree species, mainly coppice there, particularly *Bursera simaruba.* Goat grazing could be contributing to the low herbaceous ground cover observed on Mona Island.

If management activities directed toward feral animal control or exclusion are undertaken, the effectiveness of those activities could be assessed by observing changes in the vegetation in the lower vertical strata, particularly in those species known to be preferential forage. For example, four species of critical conservation value, being endangered, endemic, rare, or threatened, are frequently consumed by goats (Melendez-Ackerman and others 2008). All four of these species were encountered on the plots. The U.S. federally endangered cactus, *Harrisia portorricensis*, was found in 23 plots. Goats mainly consume the fruits of this species, but they do not contribute to its dispersal (Melendez-Ackerman and others 2008). The other 3 species were the endemic orchid *Psychilis monensis,* which was found in 23 plots, *Ziziphus taylorii* Britton was found on 4 plots and *Plumeria obtuse* L. was found on 24 plots.

Feral goat browsing impacts vegetation and critical Mona Island ground iguana habitat. (photo by Lewis Zimmerman, USDA Forest Service)

Vegetation seasonality needs to be carefully considered before remeasurement. As noted previously, the initial plot installation took place at a time of year where there had been some seasonal leaf loss in the overstory trees. One option would be for remeasurement to take place on the same dates for the fullest comparability between the two points in time. Another option would be to make the next measurement and all future remeasurements nearer the end of the wet season, (typically November or December according to Rojas-Sandoval and Meléndez-Ackerman 2011) when the vegetation is fully flushed. Comparisons between the first two points in time might have to be adjusted to account for possible underestimation of overstory leaf cover in this first dry season measurement. However, results from similar Caribbean dry forests on limestone substrate in Eleuthera, The Bahamas (Wunderle and others 2010) suggest that the differences in vegetative cover may not be large. They collected foliage height profile data when leaf loss was high for *B. simaruba*, a dominant species in both forests. Foliage height profiles based on estimates of "missing" foliage cover did not differ significantly between those measured and those estimated when including estimates of the dropped foliage cover.

Despite the challenges of plot installation and remeasurement in this somewhat remote location, the information gained creates a unique dataset of Caribbean subtropical dry forest species composition and structural parameters. Natural resource managers and other stakeholders faced with the task of making multiple, intertwined management decisions on critical wildlife habitat protection, feral animal control, hunting permitting, infrastructure development, and ecotourism opportunities will benefit from this information.

Resource management on Mona Island must balance the needs of wildlife habitat conservation, recreation, and protection of historic structures. (photo by Thomas Brandeis, USDA Forest Service)

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Mona ground iguana (*Cyclura cornuta stejnegeri*).
(photo by Humfredo Marcano, USDA Forest Service)

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Permanent plots were installed on the Mona Island natural reserve as part of the U.S. Department of Agriculture Forest Service's forest vegetation assessment and monitoring efforts in the Commonwealth of Puerto Rico. In addition to tree, sapling, and seedling measurements, the data collected included detailed descriptions of percent cover of vascular plants in four height layers (0–0.6 m, >0.6–1.8 m, >1.8–4.9 m, and >4.9 m) and percent ground cover. Based on these data we provide the first description of the structural characteristics, species composition, and vegetative cover of plant associations that stems from a systematic sample extending across the entire Mona Island plateau. We encountered 104 vascular plant species, however, suggesting that our surveys missed less common and sparsely distributed species. Though we also describe depression forests, they were represented by only a few sites in our systematic sample design. These data plus those that will come from future plot remeasurement will provide baseline information otherwise lacking for Caribbean subtropical dry forest ecosystems and will be of value to stakeholders and resource managers charged with management decisionmaking on this unique island.

Keywords: Caribbean, FIA, Mona Island, species diversity, subtropical dry forest, vegetation.

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