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Structure and composition of vegetation along an elevational gradient in Puerto Rico

Gould, W.A.*; González, G. & Carrero Rivera, G.

International Institute of Tropical Forestry, USDA Forest Service, Río Piedras, PR 00926-1119, USA;
**Corresponding author; Fax +1 7877666302; E-mail wgould@fs.fed.us*

Abstract

Question: What are the composition, conservation status, and structural and environmental characteristics of eight mature tropical forest plant communities that occur along an elevational gradient.

Location: Northeastern Puerto Rico.

Methods: We quantified the species composition, diversity, conservation status, and ecological attributes of eight mature tropical forest plant communities in replicated plots located to sample representative components of important forest types occurring along an elevational gradient. A suite of environmental and vegetation characteristics were sampled at each plot and summarized to characterize communities and analyse trends along the elevational gradient.

Results: The set of communities included 374 species; 92% were native, 14% endemic, and 4% critical elements (locally endangered) to the island. All communities, occurring within a wide range of patch sizes and degree of conservation protection, showed a high percentage of native species (> 89% per plot). The lowland moist forest communities, occurring within a matrix of urbanization, agriculture, and disturbance, had the highest degree of invasion by exotics. Community descriptions were nested within a variety of hierarchies to facilitate extrapolation of community characteristics to larger ecosystem units. Basal area, above-ground biomass, canopy heights, and mean species richness peaked at mid elevations.

Conclusions: It is significant that all of these forest communities continue to be dominated by native species while existing in a matrix of human and natural disturbance, species invasion, and forest regeneration from widespread agriculture. The lowland moist and dry forest types represent a minority of the protected forested areas in Puerto Rico, serve as unique genetic reservoirs, and should be protected.

Keywords: Detrended Correspondence Analysis; Exotics; Gradient analysis; Land management; Native species; Phytosociology; Puerto Rico.

Nomenclature: Liogier & Martorrell (1999).

Abbreviations: AB = above-ground; BA = Basal area; DCA = Detrended Correspondence Analysis; CE = Critical element; I = Introduced; MAP = Mean annual precipitation; MAT = Mean annual temperature; N = Native.

Introduction

Vegetation composition in Puerto Rico is controlled by four key factors: climate, substrate, topography and human and natural disturbance (Britton & Wilson 1924; Dansereau 1966; Weaver 1991; Lugo 2005). Climatic gradients are related to an elevational rise from sea level up to 1340 m on the central cordillera of the island, the northeasterly trade winds, and the rain shadow effect of the mountains. Diverse geologic substrates include volcanic, limestone, and serpentine bedrock and colluvial, alluvial, and marine quaternary deposits. Within these broad landscape features community composition is controlled by topographic effects on soil moisture and development (slope position). Disturbance regimes (e.g. land use, flooding, fire, landslides, and hurricanes) induce effects on the subsequent succession of secondary vegetation. The resulting landscape in Puerto Rico is a mosaic of (1) primary forests that have not experienced deforestation – according to Wadsworth (1951) and Birdsey & Weaver (1982) < 1% of the landscape supported climax vegetation by 1950; (2) mature secondary forests (< 10% cover of the island); (3) young secondary forests and shrublands (> 30%); (4) agriculture, grasslands and pastures, (> 30%); and (5) developed areas and urban forests, (> 15%). The mature upland forests are primarily found in the upland forest reserves which occupy ca. 4% of the island. These protected areas harbour our greatest wealth of native, endemic, and endangered plant species (Figueroa & Woodbury 1996). There are over 2800 species of native and exotic flowering plants in Puerto Rico and 9% of these are endemic to the island (Liogier & Martorrell 1999). Understanding the floristic composition of mature forest communities is important for biodiversity conservation and land management planning as these serve as both reservoirs of species and provide important ecosystem functions.

Community-level descriptions of plant associations form the basis of hierarchical phytosociological classification (Braun-Blanquet 1964; Mueller-Dombois & Ellenberg 2002). This approach has been more prevalent in temperate than tropical vegetation studies. A few recent studies place tropical plant communities within the Braun-Blanquet framework (Borhidi 1996; Bussmann 2001; Sánchez-Sánchez & Islebe 2002). While many of the major forest formations and alliances in Puerto Rico have been described floristically and structurally (Birdsey & Weaver 1987; Scatena et al. 1993; Chinea 2002; Thompson et al. 2002; Lugo 2005), the description and classification of plant community composition within these alliances has not been well documented.

This study has three objectives: (1) describe the composition of eight tropical forest plant communities within a hierarchy related to the primary controls on vegetation, i.e. climate, substrate, topographic position, and disturbance; (2) evaluate the conservation status species within these communities; and (3) relate the variation in diversity, structure, and site environmental characteristics of these communities to gradients of climate and soil characteristics; which are correlated to elevation.

Methods

Study sites

This study was developed in Northeastern Puerto Rico and focused on plant communities within eight older forest types (> 60 years old) that are representative of Lowland subtropical dry, Lowland subtropical moist, Subtropical wet, Subtropical rain, Lower montane wet, and Lower montane rain forest life zones in Puerto Rico (Ewel & Whitmore 1973). The sites occur along an elevational gradient from sea level to over 1000 m. Four of the forest types are located in the Luquillo Experimental Forest (LEF) and include Elfin woodland, Sierra palm, Palo colorado, and Tabonuco forest alliances (Wadsworth 1951; Weaver 1994). Four additional forest types include Lowland moist and dry forests, and flooded *Pterocarpus* and mangrove forests. The latter four are located on federal, state, and private managed and unmanaged lands. All sites are on non calcareous material derived from volcanic bedrock (montane and lowland sites) or Quaternary deposits (coastal sites).

Field sampling

We selected 24 sampling sites throughout northeastern Puerto Rico, three of each of the eight forest types. Within these sites, 10 m × 10 m plots were sampled for a total of nine replicates per forest type. Sampling was done during 2001-2002. Replicate plots were located away from forest edges and ecotones to represent homogeneous stands of vegetation. The sampling methodology was based on *a priori* knowledge of compositional differences between communities. The plot size, while smaller than typically used to characterize tropical forest alliances, served well to characterize homogeneous stands of these plant communities. Additionally, we tested whether plot sizes of 10 m × 10 m, 10 m × 20 m, or 10 m × 30 m added a significant number of species and found that not to be the case at our sites. The high degree of β-diversity between the eight forest types and the *a priori* site selection based on compositional homogeneity within each forest type resulted in the selection of repeatable occurrences of these communities as replicates.

Environmental and vegetation characteristics were sampled at each plot including location, elevation, slope, and aspect. Six soil volumes were taken from 0-10 cm depths at each plot and combined to form a composite sample, which was ground with a Foss Tecator Cyclotec (model 1093) mill through a 1 mm stainless steel sieve. Total N, C and S were determined using the dry combustion method by means of a LECO CNS-200 analyzer (St. Joseph, MI, USA). Elemental P, Ca, K, Al, Fe, Mn, and Mg were determined from digestions using a Beckman plasma emission spectrometer (Spectra V) (Luh Huang & Schulte 1985). Mean annual precipitation was sampled bimonthly from July 2001 to July 2004 and mean annual air temperature was determined from shaded stations placed at 1 m height. All plant species were identified following Liogier and Martorrell (1999). Species cover was estimated using the Braun-Blanquet cover scale (Westhoff & van der Maarel 1978). Percent cover and height estimates were made for each vegetation layer (canopy trees, understorey trees, shrub layer, and herbaceous layer). Percent cover estimates were made for non vegetation layers including bare soil, root, rock, litter, and water. Tree diameters were measured at breast height (DBH) for all trees over 2 cm.

Data analyses

All species were classified as either native or non native (Little & Wadsworth 1964). Native species were classified as endemic and/or critical elements using the classification developed by the Puerto Rico Department of Natural and Environmental Resources for conservation purposes (Quevedo 1999). Species were identified by growth form as trees, shrubs, lianas, forbs, graminoids, or epiphytes. For trees, we determined the number of stems per species per plot and forest type and the basal area per species per plot. We calculated biomass per species per plot using DBH and regression equations from Brown (1997) for lowland subtropical dry forests and Scatena et al. (1993) for all other forests. Tree species were ranked by importance values (IV) calculated per forest type using relative frequency (RF) (occurrence within nine plots per forest type), relative dominance (RDOM) (based on basal area from D_{BH} measurements), and relative density (RDEN) (based on number of stems) in the following relationship

$$IV = (RF \times RDOM \times RDEN) / 3) \quad (1)$$

(Kent & Coker 1996). We determined the percent constancy (or relative frequency) of all herbaceous and woody species per community type as the percent of plots in which it occurred in that community type. The percent fidelity was calculated as the percent of occurrences within a community relative to all occurrences.

Two tree species, the characteristic (high constancy and importance value (*IV*) and diagnostic (high fidelity and constancy) species within the data set, were used to name the community types (except in the mono-specific *Pterocarpus* forest). Each community is nested in a series of hierarchical crosswalk tables to place the community within a phytosociological class and order (Braun-Blanquet 1964) and within a vegetation alliance or an equivalent designation and formation (Anon. 1998; Ahern et al. 1999; Areces-Mallea et al. 1999; Dansereau 1966). Communities were hierarchically nested within life zone (Ewel & Whitmore 1973), vegetation zone (Dansereau 1966), forest region (Wadsworth 1964), and mapped units (Helmer et al. 2002). These include descriptions consistent with global forest cover classes used by the Food and Agriculture Organization (Anon. 1998) and the Global Observations of Forest Cover (Ahern et al. 1999).

Ordinations were performed on the 54 non wetland samples using PCORD 4.0 (McCune & Medford 1999), including all species and using Braun-Blanquet cover estimates from each plot as abundance measures (Westhoff & van der Maarel 1978). Univariate analysis of means and Student-Newman-Keuls (S-N-K) (α = 0.05) were used to determine whether the community types differed significantly in the numbers of native, introduced, endemic, and endangered species, soil attributes, and structural characteristics (Anon. 2002).

Table 1. Number and percent of all species and of subgroups by growth form, stem size, and conservation status for all sites.

	Nr	% all species	% by subgroups
Plant species	374	100	
Woody species	263	70	
Tree species	172	46	65 of woody spp.
Trees ≥ 10 cm	76	20	44 of tree spp.
Trees > 2 cm DBH	131	35	76 of tree spp.
Trees < 2 cm DBH (saplings)	147	39	85 of tree spp.
Shrub species	21	6	8 of woody spp.
Woody vines (lianas)	70	19	27 of woody spp.
Herbaceous species	111	30	
Forbs	57	14	52 of herbaceous spp.
Graminoids	12	3	11 of herbaceous spp.
Epiphytes	42	11	38 of herbaceous spp.
Native species	347	93	
Non endemic	296	79	85 of native spp.
Endemic	51	14	15 of native spp.
Critically endangered	14	4	4 of native spp.
Exotic species	**27**	**7**	

Results

Composition

Flora

We found 374 plant species from 98 families within the plots. The majority were woody plants. The woody component was primarily composed tree species, followed by woody vines (lianas) and shrub species. Nearly half of all tree species were found with diameters greater than 10 cm. Over 75% of all tree species were found with diameters greater than 2 cm and 85% of all tree species were found with diameters less than 2 cm (saplings). Over half of the herbaceous component was made up of forbs, followed by lesser numbers of epiphytes, and graminoids (Table 1).

Of the species sampled 93% were native. Endemics make up 14% of the species sampled and 4% are critical elements (Quevedo 1999). Exotic species include 13 introduced tree species with diameters > 2 cm and most (with the exception of *Hura crepitans* in the Lowland moist forest) were minor elements within the communities (App. 1).

Community classification

Eight plant community types will now be described and as far as possible phytosociologically identified on the basis of the vegetation description of Cuba by Borhidi (1996).

1. The *Tabebuia rigida-Eugenia borinquensis* community (App. 1a, Tables 2-5)

This is a closed broad-leaved evergreen forest (Anon. 1998; Ahern et al. 1999) found within the Elfin woodland forest type or alliance (Weaver 1994) and Montane subtropical cloud forest formation (Table 2). It is within the class *Cyrillo-Weinmannietae pinnatae*, order *Cyrillo-Weinmannietalia pinnatae* (Borhidi 1996) of tropical cloud forest vegetation (Table 2). The community is found within both the Lower montane wet and rain Holdridge life zones (Ewel & Whitmore 1973, Table 3) on azonal sites including exposed slopes and ridges (Lyford 1969; Weaver 1990, 1991,1994; Weaver et al. 1986). It is a gnarled, epiphyte-laden, and dense forest type characterized by closely spaced, stunted trees. The soils are commonly saturated with moisture as the forest is frequently enveloped in clouds. Seven of the ten tree species with DBH > 2 cm are endemic. Rare endemics include *Ardisia luquillensis* and *Ilex sintenissi*. The endemic shrub *Miconia foveolata* was found in 44% of the plots. The lianas *Marcgravia sintenissi* and *Mikania cordifolia* are characteristic of the community, as are the endemic forbs *Cyathea borinquena* and *Pilea yunquensis*. The grass *Isachne angustifolia* occurred at most sites as did endemic epiphytes *Selaginella krugii, Hohenbergia attenuata* and native epiphytic fern *Blechnum fragile*.

2. The *Prestoea montana-Cecropia schreberiana* community (App. 1b, Tables 2-5)

This is a closed broad-leaved evergreen forest (Anon. 1998; Ahern et al. 1999) found within the Sierra palm forest type or alliance (Weaver 1991, 1994) and Montane subtropical rain forest formation (Table 2). It is provisionally placed within the class *Ocoteo-Cyrilletea racemiflorae* and order *Ocotea-Magnolietalia* (Borhidi 1996) of montane tropical rainforests (Table 2). The Sierra palm forest type is found in the Lower montane wet and subtropical rain Holdridge life zones (Ewel & Whitmore 1973, Table 3). The communities are found on azonal (although common) steeply sloping sites and dominated by *Prestoea montana* (Sierra palm) and an abundance of epiphytes. The abundance of *Cecropia schreberiana* in this community is indicative of past hurricane disturbance. Five endemic tree species with DBH > 2 cm occur at the sites, the most abundant being *Henrietta squamulosa, Eugenia borinquensis* and *Cyathea arborea*. Two endemic lianas characterize the community including *Macgravia sintenissi* and *Ipomoea krugii*. Eleven forbs were consistently found within the community including two endemics *Cyathea borinquena* and *Begonia decandra*. The grass species *Ichnanthus pallens* and epiphytes *Guzmania berteriana* and *Selaginella krugii* were also characteristic.

3. The *Cyrilla racemiflora-Micropholis garciniifolia* community (App. 1c, Tables 2-5)

This is a closed broad-leaved evergreen forest (Anon. 1998; Ahern et al. 1999) found within the Palo colorado forest type or alliance (Weaver 1986, 1991, 1994) and Montane subtropical rain forest formation (Table 2). It is within the class *Ocoteo-Cyrilletea racemiflorae* and order *Ocotea-Magnolietalia* (Borhidi 1996) of montane tropical rainforests (Table 2). It is characterized by the presence of *Cyrilla racemiflora* (Palo colorado) and occurs in the Lower montane wet Holdridge life zone and is considered the zonal vegetation of this life zone (Ewel & Whitmore 1973, Table 3). The sites included 14 endemic tree species and 6 rare native species with DBH > 2 cm. Saplings of *Prestoea montana, Psychotria maleolens, Myrcia fallax* and *Hirtella rugosa* were present in most sites. The endemic liana *Marcgravia sintenissi* was present in most sites, as were the ferns *Thelypteris deltoides, Cyathea borinquena,* and *Nephrolepis rivularis,* the grass *Ichnanthus pallens*, and epiphytes *Anthurium dominicense* and *Polypodium dissimile*.

4. The *Dacryodes excelsa-Manilkara bidentata* community (App. 1d, Tables 2-5)

This is a closed broad-leaved forest (Anon. 1998; Ahern et al. 1999) found within the Tabonuco forest type or alliance (Weaver 1989, 1994; Basnet 1992) and Submontane subtropical rain forest formation (Table 2). It is provisionally placed within the class *Swietenio-Calophylletea calabae* and order *Dipholi-Calyphylletalia calabae* (Borhidi 1996) of submontane tropical rain forests (Table 2). It is characterized by the presence of *Dacryodes excelsa* (Tabonuco) and occurs in the Subtropical wet Holdridge life zone (Ewel & Whitmore 1973, Table 3). *Tetragastris balsamifera* is also common and was found in over 40% of the plots in the overstorey and as saplings in 78% of the plots. The community includes five endemic tree species, three considered rare (App. 1d). Twelve species occurred as saplings in > 50% of the plots, two of these restricted to the tabonuco plots include *Myrcia leptocladia* and *Eugenia stahlii*. Four lianas occurred in most plots, including *Rourea surinamensis* in all but one tabonuco plot. The ferns *Cyathea borinquena* and *Thelypteris deltoides* occurred in all plots and the grass *Ichnanthus pallens* occurred in nearly all plots.

5. The *Manilkara bidentata-Ocotea leucoxylon* community (App. 1e, Tables 2-5)

This is a closed broad-leaved forest (Anon. 1998; Ahern et al. 1999) found within the Lowland rain forest alliance (Dansereau 1966) and Lowland subtropical seasonal evergreen forest formation (Table 2). It is placed within the class *Swietenio-Calophylletea calabae* and order *Dipholi-Calophylletalia calabae* (Borhidi 1996) of submontane tropical rainforests (Table 2). It is likely similar to formerly extensive moist lowland forests converted to agriculture in the preceding century. It occurs in the Lowland subtropical moist Holdridge life zone (Ewel and Whitmore 1973, Table 3). *Manilkara bidentata* is dominant in the overstorey of most plots, *Faramea occidentalis* is the most abundant understorey species and *Inga laurina* was common in all plots. The lowland moist plots were more variable than the montane plots and *Ocotea leucoxylon* and *Hymenaea courbaril* shared dominance with or replaced *Manilkara bidentata* in some plots. One rare endemic tree species, *Thespesa grandiflora*, occurred as well as one rare native, *Byrsonima spicata*. Four lianas occurred at most sites including *Macfadyena unguis-cati, Paullinia pinnata, Hippocratea volibis* and *Rourea surinamensis*. The fern *Adiantum latifolium* occurred in all plots and the grasses *Ichnanthus pallens* and *Lasiacis divaricata* occurred in most plots.

6. The *Bucida buceras-Guapira fragrans* community (App. 1f, Tables 2-5)

This is a closed mixed-evergreen deciduous forest (Anon. 1998; Ahern et al. 1999) found within the *Bucida buceras* (Ucar) forest alliance (Dansereau 1966) and Lowland subtropical semideciduous woodland formation (Table 2). It is placed within the class *Guazumo-Ceibetea pentandrae* and order *Oxandro-Burseretalia* (Borhidi 1996) of semideciduous mesophytic forests (Table 2). It occurs on non calcareous substrates in the Lowland subtropical dry Holdridge life zone (Ewel & Whitmore 1973, Table 3). *Bursera simaruba* and *Bourreria succulenta* also occurred and were abundant in most plots. The rare native *Maytenus cymosa* occurred in one plot and the saplings *Capparis cynophallophora, Erythroxylum brevipes, Neea buxifolia*, and *Eugenia biflora* occurred in most plots. The lianas, *Macfadyena unguis-cati, Tragia volubilis, Serjania polyphylla*, and *Chioccocca alba* occurred in most plots as did the grass *Ichnanthus pallens*.

7. The *Pterocarpus officinalis-Acrostichum aureum* community (App. 1g, Tables 2-5)

This is a closed flooded forest (Anon. 1998, Ahern et al. 1999) found within the *Pterocarpus officinalis* forest alliance (Dansereau 1966) and Subtropical seasonally flooded rain forest formation (Table 2). It is placed within the class *Chrysobalano-Annonetea glabrae* and order *Chrysobalano-Annonetalia glabrae* (Borhidi 1996) of freshwater swamp forests (Table 2). It occurs in relict patches within the Lowland subtropical moist Holdridge life zone (Ewel and Whitmore 1973, Table 3) and was likely much more extensive on the coastal plain and riparian corridors prior to deforestation for agriculture (Alvárez 1982, Eusse & Aide 1999). It is found on undisturbed freshwater seasonally flooded non calcareous alluvial substrates. It is typically a monoculture of *Pterocarpus* trees in the overstory with the fern *Acrostichum aureum* in the understory. The lianas *Paullinia pinnata, Hippocratea volubilis,* and *Ipomoea triloba* were found on most plots.

8. The *Avicennia germinans-Laguncularia racemosa* community (App. 1h, Tables 2-5)

This is a closed flooded forest (Anon. 1998; Ahern et al. 1999) found in the Mixed mangrove alliance (Dansereau 1966) and the Tidally flooded evergreen sclerophyllous (mangrove) forest formation (Table 2). It is placed within the class *Rhizophoro-Avicennietea germinantris* and order *Avicennietalia* (Borhidi 1996) of mangrove forests (Table 2). Mangrove forest types occur within the Lowland subtropical dry and moist Holdridge life zones (Ewel & Whitmore 1973, Table 3) in Puerto Rico and are typically found as *Rhizophora mangle* dominated stands on coastal and estuarine fringes and in basins as pure or mixed stands of *Avicennia germinans* and *Laguncularia racemosa*. Nearly all plots of this community had both *Avicennia germinans* and *Laguncularia racemosa,* with *Avicennia germinans* typically being the dominant. The shrub *Suriana maritima* occurred in most plots.

Table 2. Hierarchical structure of forest communities (associations), alliances (or equivalent), and formations. Characteristics for communities are found in Tables 3-5, App. 1, characteristics for alliances are found in cited literature, and characteristics of formations are from Dansereau (1966) and Areces-Mallea et al. (1999). Communities are nested within the phytosociological classes and orders described by Borhidi (1996) for subtropical forests of Cuba.

Class Order *Community* (provisional association)	Alliance (Dansereau 1966; Weaver 1994)	Formation (Anon. 1998; Ahern et al. 1999; Areces–Mallea et al. 1999)
Class: *Cyrillo-Weinmannietea pinnatae* Borhidi 1991Cloud forests of the Antillean high mountains (Borhidi 1996).		
Order: *Cyrillo-Weinmannietalia pinnatae* Borhidi (Borhidi 1996).		Closed, broadleaf evergreen,
1. *Tabebuia rigida-Eugenia borinquensis* comm.	Elfin woodland	montane subtropical cloud forest.
Class: *Ocoteo-Cyrilletea racemiflorae* Borhidi 1991Montane rainforests of the Caribbean (Borhidi 1996).		
Order: *Ocoteo-Magnolietalia* Borhidi (Borhidi 1996).		Closed, broadleaf evergreen,
2. *Prestoea montana-Cecropia schreberiana* comm.	Sierra palm forest	montane subtropical rain forest.
3. *Cyrilla racemiflora-Micropholis garciniifolia* comm.	Palo colorado forest	Closed, broadleaf evergreen, montane subtropical rain forest.
Class: *Swietenio-Calophylletea calabae* Borhidi 1991Lowland and submontane rainforests of the Caribbean (Borhidi 1996).		
Order: *Dipholi-Calophylletalia calabae* Borhidi 1991 (Borhidi 1996).		Closed, broadleaf evergreen,
4. *Dacryodes excelsa-Manilkara bidentata* comm.	Tabonuco forest	submontane subtropical rain forest.
5. *Manilkara bidentata-Ocotea leucoxylon* comm.	Lowland moist forest	Closed, broadleaf evergreen, lowland subtropical seasonal evergreen forest. Lowland rainforest (Dansereau 1996).
Class: *Guazumo-Ceibetea pentandrae* Borhidi 1991Lowland seasonal evergreen and semi deciduous mesophytic forests of the Caribbean (Borhidi 1996).		
Order: *Oxandro-Burseretalia* Borhidi & Muñiz 1991 (Borhidi 1996).		Closed, broadleaf mixed, lowland
6. *Bucida buceras-Guapira fragrans* comm.	Ucar (Bucaro) forest	subtropical semi-deciduous woodland.
Class: *Chrysobalano-Annonetea glabrae* Borhidi and Muñiz 1991Evergreen and deciduous freshwater swamps of the Caribbean (Borhidi 1996).		
Order: *Chrysobalano-Annonetalia glabrae* Borhidi and Del-Risco 1991 (Borhidi 1996).		Closed, flooded, subtropical
7. *Pterocarpus officinalis-Acrostichum aureum* comm.	*Pterocarpus* forest	seasonally flooded rainforest.
Class: *Rhizophoro-Avicennietea germinantris* Borhidi and Del-Risco 1991Mangrove vegetation (Borhidi 1996)		
Order: *Avicennietalia* Cuatrecasas 1958 (Borhidi 1996).		Closed, flooded, tidally
8. *Laguncularia racemosa-Avicennia germinans* comm.	Mixed mangrove forest	flooded evergreen sclerophyllous forest.

Table 3. Location of communities and forest types (equivalent to alliance) within Holdridge lifezone (Ewel & Whitmore 1973), Vegetation zone (Dansereau 1966), Forest Region (Little & Wadsworth 1964), and mapped formations in Puerto Rico (Helmer et al. 2002).

Community	Forest type	Holdridge Lifezone	Vegetation zone	Forest Region	Mapped formations
Tabebuia rigida-Eugenia borinquensis	Elfin woodland	Lower montane wet and rain forest	Montane forest	Upper Luquillo forest	Lower montane wet evergreen forest – elfin cloud forest
Prestoea montana-Cecropia schreberiana	Sierra palm forest	Lower montane wet and subtropical rain forests	Montane forest	Upper Luquillo forest	Lower montane wet evergreen forest – palm and elfin cloud forest
Cyrilla racemiflora-Micropholis garciniifolia	Palo Colorado forest	Lower montane wet forest	Montane forest	Upper Luquillo forest	Lower montane wet evergreen forest – tall cloud forest
Dacryodes excelsa-Manilkara bidentata	Tabonuco forest	Subtropical wet forest	Lower montane rain forest	Lower Luquillo forest	Submontane wet evergreen forest
Manilkara bidentata-Ocotea leucoxylon	Lowland moist forest	Lowland subtropical moist forest	Lowland rainforest	Moist coastal forest	Lowland moist seasonal evergreen forest
Bucida buceras-Guapira fragrans	Dry forest	Lowland subtropical dry	Semideciduous forest	Dry coastal forest	Lowland dry semi-deciduous forest
Pterocarpus officinalis-Acrostichum aureum	Pterocarpus forest	Lowland subtropical moist	Littoral forest	Moist coastal forest	Seasonally flooded evergreen forest
Laguncularia racemosa-Avicennia germinans	Mixed mangrove forest	Lowland subtropical dry and moist	Littoral forest	Dry and moist coastal forest	Tidally and semi permanently flooded evergreen sclerophyllous forest

Table 4. Forest community characteristics including Importance Value (IV) of characteristic species, site numbers, mean site elevation in meters, average daily mean annual temperatures (MAT) in ºC and total annual precipitation (measured at 21 climate stations along the elevational gradient), mean slope per plot ± S.E. and the range of aspects, mean plot maximum canopy heights (m) ± S.E., stem densities (mean stems/ha per plot for stems ≥ 10 cm and for 2 cm ± S.E.), basal area (BA) (mean m^2/ha per plot ± S.E.), aboveground biomass (a.g. biomass) (mean Mg/ha per plot ± S.E.), and total number of tree and plant species from all plots within each forest type. Lower case letters indicate significant differences between forest types ($n = 9$, $\alpha = 0.05$) (Anon. 2002).

Community	IV	Site	El. (m)	MAT (°C)	MAP (mm)	Slope (º)	Aspect (wind-ward)	Mean/ max can. ht. (m)	Stems /ha (≥10 cm)	Stems /ha (≥2 cm)	BA (m^2/ ha)	a.g. biomass (Mg/ha)	Tree spp. richness	Plant ssp. richness
Tabebuia rigida- *Eugenia borinquensis*	31.3 22.6	1, 2, 3	1010	19.5	3908	27±2	NE-E	6±0.3	687	$6678±950^{d}$	$27±4.8^{ab}$	$100±2^{*a}$	10	53
Prestoea montana- *Cecropia schreberiana*	59.813.8	7, 8, 9	835	20.7	3956	19±3	S-SSW	15±0.5	1171	$2156±142^{a}$	$39±3.0^{abc}$	$177±14^{*ab}$	13	78
Cyrilla racemiflora- *Micropholis garciniifolia*	18.4 10.7	4, 5, 6	751	20.3	2932	14±3	SE-W	14±0.6	1200	$2956±258^{abc}$	$61±8.6^{c}$	$364±62^{*b}$	38	85
Dacryodes excelsa- *Manilkara bidentata*	30.1 6.6	10, 11, 12	380	23.0	3060	30±3	NE-SE	22±1.7	1022	$2911±405^{abc}$	$58±10.9^{c}$	$356±83^{*b}$	40	86
Manilkara bidentata- *Ocotea leucoxylon*	8.7 8.9	13,14, 15	47	26.2	1712	10±3	NE-SE	26±2.8	633	$4389±165^{cb}$	$50±11.1^{bc}$	$330±99^{*b}$	38	98
Bucida buceras- *Guapira fragrans*	15.5 14.4	16, 17, 18	17	27.5	1262	15±2	NE-NW	13±0.7	478	$4767±689^{c}$	$26±6.1^{ab}$	$163^{\#}$ $95±31^{*a}$	34	99
Pterocarpus officinalis- *Acrostichum aureum*	100	19, 20, 21	3	26.4	1685	0	NA	34±1.2	700	$2422±370^{ab}$	$na^{\dagger}$	$na^{\dagger}$	1	15
Laguncularia racemosa - *Avicennia germinans*	49.7 46.2	22, 23, 24	5	27.3	1414	0	NA	12±1.3	344	$4578±754^{b}$	$15±3.9^{a}$	$57±19^{*a}$	4	8

* Calculated using Scatena et al. 1993.
# Calculated using Brown 1997.
† Not calculated as D_{BH} measured below buttress roots invalidated basal area and biomass estimates.

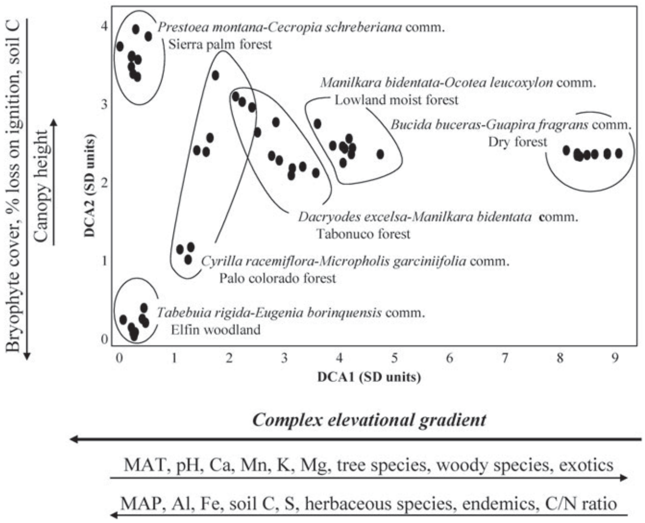

Fig. 1. Ordination of all non-wetland sites using Detrended Correspondence Analysis with PCORD (McCune & Medford 1999) indicates that sites separate primarily along the elevational gradient that correlates with DCA axis 1. Mean annual temperature (MAT), pH, total soil calcium (CA), magnesium (Mn), potassium (K), manganese (Mg), the number of tree species, the number of woody species, and the number of exotics all decrease with elevation. Mean annual precipitation (MAP), total soil aluminum (Al), iron (Fe), carbon (C) sulfur (S), the carbon nitrogen ratio (C/N), the number of herbaceous species, and the number of endemic species all increase with elevation. DCA2 separates high elevation Elfin woodland, Sierra palm, and Palo colorado sites with canopy height decreasing and bryophyte cover, % loss on ignition and soil carbon increasing in the Elfin woodland sites.

Ordination

An ordination of the non wetland sites using detrended correspondence analysis indicates a high degree of beta diversity (DCA1) and a number of environmental and structural characteristics that increase or decrease along the complex elevational gradient (Fig. 1). Ninety percent of the variation expressed by the ordination is explained by the first axis (r^2 = 0.228) and this axis explains about 23% of the variability in the data set. The second DCA axis separates three high elevation communities with increasing bryophyte cover, total soil carbon, greater % loss on ignition and decreasing canopy height in the Elfin woodland communities relative to the Palo Colorado and Palm communities (Fig. 1).

Conservation status

We found significant differences among all forest types in the numbers of native, non native, endemic, critical, and introduced species (one-way ANOVAs, p < 0.001, r^2 > 0.356). The highest number of native species were found in the *Cyrilla racemiflora-Micropholis garciniifolia* community (Palo colorado) and *Dacryodes excelsa-Manilkara bidentata* community (Tabonuco) plots, followed by the Sierra palm, Dry forest, and Elfin woodland plots. High percentages of native species were found in the mangrove and *Pterocarpus* forest plots. The percent of native species within plots in these seven forest types are all over 96%. The Lowland moist forest plots, located within a matrix of urban, agricultural, and forest land cover in the most disturbed and unprotected landscapes, are made up of nearly 90% native species (Fig. 2a-d).

We observed an increase in the number and percentage of endemic and critical elements along the altitudinal gradient (Fig. 3a-d). Over 50% of the species in the Elfin woodland forest plots were endemic and 5% of the species in the Elfin woodland and Palo colorado forest plots have critical conservation status. The Lowland moist, Dry, *Pterocarpus* and Mangrove forest plots had low numbers and percentages of endemics and critical species (Fig. 3a-d). These are sites that are outside the limits of the LEF and subject to higher levels of disturbance and human manipulation.

Structure, diversity, and environmental characteristics

Forest structure

Within the non wetland forests there were a number of unimodal trends that had high or low points at mid elevation. Mean maximum canopy heights ranged from 5.8 to 25.5 meters and peaked in Lowland moist and Tabonuco forest types (for the non wetland forest types). Mean canopy heights ranged from 5 to 17 meters and were also greatest in these mid elevation forests (r^2 = 0.602, p = 0.000) (Table 4). The greatest and least canopy heights were in the coastal flooded forests. The freshwater *Pterocarpus* communities had mean maximum canopy heights of over 34 m. The mangrove communities were similar to the dry forest communities with a mean maximum height of 12 m. Mean basal area peaked at mid elevations and ranged from 15 m^2/ha (Mangrove) to 61 m^2/ha (Palo colorado). Mean above-ground biomass expressed as dry weight estimated from diameter at breast height (D_{BH}) ranged from 57 Mg/ha (Mangrove) to 364 Mg/ha (Palo colorado) and also

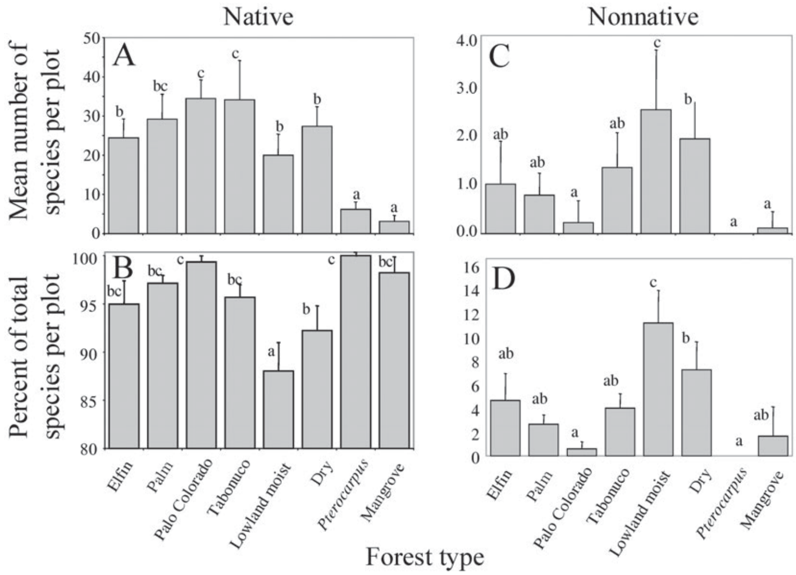

Fig. 2a-d. Distribution of native (**A**, **B**) and non native (**C**, **D**) species in eight tropical forest types in Puerto Rico, plotted as mean number of species per 10 m × 10 m plot (n = 9) (**A**, **C**) and as a percent of plot total species richness (**B**, **D**). Error bars = +/– 1 SE, letters indicate significant differences in means using univariate analysis of means and SNK test (α = 0.05) (Anon. 2002).

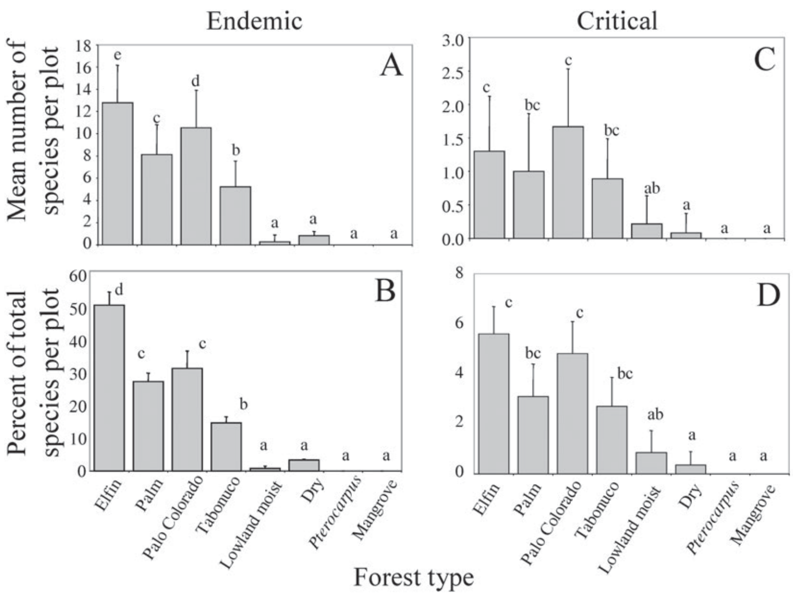

Fig. 3a-d. Distribution of endemic (**A**, **B**) and critical (Quevedo 1999) (**C**, **D**) species in eight tropical forest types in Puerto Rico, plotted as mean number of species 10m × 10m plot (n = 9) (**A**, **C**) and as a percent of plot total species richness (**B**, **D**). Error bars = +/- 1 SE, letters indicate significant differences in means using univariate analysis of means and SNK test (α = 0.05) (Anon. 2002).

peaked at mid elevations. Mean stem densities ranged from 2156 stems/ha (Sierra palm) to 6678 stems/ha (Elfin woodland) for stems > 2 cm and from 256 stems/ha (Mangrove) to 1422 stems/ha (Sierra palm) for stems > 10 cm, peaking at uppermost and lowermost elevations (Table 4).

Species diversity

Species richness for each community ranged from 8 to 99 species for all plots (Table 4) with a mean number of species ranging from 3 to 35 per plot. The mangrove communities were the most species poor (8 species) and the Lowland moist and Dry communities, with the greatest variability between plots, were the most species rich as a group (99 and 98 species, respectively). The Palo colorado and Tabonuco plots had the highest mean number of species per plot (34-35 species). Tree species richness ranged from 1 (*Pterocarpus* forest) to 40 (Tabonuco) for all plots within a forest type with mean tree species richness ranging from 1 (*Pterocarpus* forest) to 23 (Palo colorado) per plot (Table 4). Tree species are the most abundant growth form in most of the forest types and range from 78% of all species in the Mangrove plots to 19.5% of all species in the *Pterocarpus* plots. Mid elevation forest types have an even mix of tree species versus other growth forms. The highest numbers of non tree species are found in the *Prestoea montana-Cecropia schreberiana* community with high numbers of forb and epiphyte species. The growth form with the highest numbers of native and endemic components was trees, except for the Sierra palm forests, with higher values and percentages native forbs.

Environmental gradients

Mean annual temperatures decreased with increasing elevation (27.5 °C to 19.5 °C) while mean annual rainfall increased from 1262 mm to 3908 mm (Table 4). The *Bucida buceras-Guapira fragrans* dry forest communities have the lowest rainfall and highest temperatures. Rainfall increased and temperatures decreased slightly in the Mangrove and *Pterocarpus* forest types (Table 4). Soils become increasingly acidic with increasing elevation and range from 5.32 to 6.56 in the coastal communities to a low of 4.08 in the *Tabebuia rigida-Eugenia borinquensis* Elfin woodland community (Table 5). Total soil carbon is highest in saturated soils from upper and lower ends of the elevational gradient, i.e. the *Tabebuia rigida-Eugenia borinquensis* and *Pterocarpus officinalis-Acrostichum aureum* communities. Some of this carbon is in the form of calcium carbonate and calcium levels are high in the both the lowland dry and flooded communities (Table 5). The percent loss on ignition (LOI) ranged from 13.52% in the *Manilkara bidentata-Ocotea leucoxylon* community to 29.18% in the *Pterocarpus officinalis-Acrostichum aureum* communities and was not significantly different in the non wetland communities (Table 5).

Within the lowland and montane moist and wet forest communities, elevation was positively correlated with mean annual precipitation (MAP), the number of endemic species (END), total soil C, N, S, C/N, and LOI. Elevation was negatively correlated with mean annual temperature (MAT), the number of exotic species (EX), above-ground biomass (AB), tree species richness (TSP) and pH. Above-ground biomass was positively correlated with basal area (BA), TSP and negatively correlated with elevation (EL), MAP, END, total soil C, N, and S, and LOI (App. 2).

Discussion

The eight plant communities described here form important elements in a matrix of habitats making up each forest alliance. The high percentage of native species within these communities is characteristic across all plots. Tree species make up less than 50% of the plant species diversity sampled. Variation in forest composition along the elevational gradient can be divided in three components, the coastal forested wetlands where salinity gradients are the most important control on species composition, the subtropical dry climate of the coastal hills with a more pronounced seasonality controlling species composition, and the broad-leaved evergreen forests of the moist lowland and montane areas, with gradients in rainfall and soil characteristics affecting species composition. The three montane communities (*Tabebuia rigida-Eugenia borinquensis* comm., *Prestoea montana-Cecropia schreberiana* comm., *Cyrilla racemiflora-Micropholis garciniifolia* comm.) and one submontane community (*Dacryodes excelsa-Manilkara bidentata* comm.) are found within the protected LEF and serve as reservoirs of native species. The *Pterocarpus* and mangrove communities in this study are a limited forest resource and vulnerable to loss through land use change. They occur in the most heavily populated coastal plain and are subject to disturbance from changes in the hydrologic regime, particularly as related to development. Coastal saline wetlands include communities composed of nearly pure stands of *Rhizophora mangle, Avicennia germinans,* and *Laguncularia racemosa*, as well as sparsely vegetated mudflats and mixed *Avicennia germinans-Laguncularia racemosa* stands. The *Bucida buceras-Guapira fragrans* community on coastal dry hills share most affinities with the dry forests on the southern limestone hills, serpentine outcrops, and the communities found on haystack hilltops or 'mogotes' in the northern moist limestone region. The Lowland moist *Manilkara*

Table 5. Soil nutrients and chemistry including percent (by weight) of macronutrients Sulfur (S), total Nitrogen (N), and total Carbon (C); Carbon to nitrogen ratio (C/N); Loss on ignition (LOI of organic carbon); micronutrients (mg/g soil) Calcium (Ca), Phosphorus (P), Aluminum (Al), Iron (Fe), Manganese (Mn), Potassium (K), Magnesium (Mg); and pH from eight community types along an elevational gradient. Mean percent derived from 3 samples per plot, nine plots per forest type (*n* = 27). Significant differences in means determined using Student-Newman-Keuls (S-N-K) test (Anon. 2002) are shown with lower case letters.

	Macronutrients					Micronutrients							
Community type	%S	%N	%C	C/N	%LOI	CA	P	Al	Fe	Mn	K	Mg	pH
Tabebuia rigida-Eugenia borinquensis	0.11 [a]	0.30 [ab]	15.49 [c]	22.2 [c]	15.49 [a]	0.27 [a]	0.30 [b]	57.38 [c]	75.62 [a]	0.03 [a]	1.04 [b]	0.94 [a]	4.08 [a]
Prestoea montana-Cecropia schreberiana	0.07 [a]	0.48 [a]	7.86 [ab]	16.2 [b]	23.18 [a]	1.73 [a]	0.53 [c]	80.92 [d]	34.61 [a]	0.39 [a]	1.03 [b]	2.83 [a]	4.52 [a]
Cyrilla racemiflora-Micropholis garciniifolia	0.05 [a]	0.48 [a]	7.29 [ab]	16.2 [b]	19.34 [a]	0.34 [a]	0.19 [a]	33.36 [ab]	43.29 [b]	0.46 [a]	0.66 [b]	0.63 [a]	4.12 [a]
Dacryodes excelsa-Manilkara bidentata	0.49 [a]	0.35 [a]	4.92 [a]	14.2 [b]	20.69 [a]	0.25 [a]	0.30 [b]	59.56 [c]	64.49 [b]	0.87 [abc]	0.95 [b]	1.71 [a]	4.38 [ab]
Manilkara bidentata-Ocotea leucoxylon	0.04 [a]	0.37 [a]	4.18 [a]	11.4 [a]	13.52 [a]	1.02 [a]	0.32 [b]	14.72 [a]	27.98 [b]	1.06 [bc]	0.80 [b]	0.69 [a]	4.82 [bc]
Bucida buceras-Guapira fragrans	0.06 [a]	0.61 [ab]	6.34 [ab]	10.4 [a]	19.34 [a]	9.26 [b]	0.48 [c]	33.05 [ab]	45.98 [b]	1.37 [ac]	2.91 [a]	6.12 [c]	6.51 [d]
Pterocarpus officinalis-Acrostichum aureum	0.20 [a]	0.81 [b]	12.25 [bc]	14.2 [b]	29.18 [b]	5.49 [c]	0.56 [c]	26.32 [ab]	28.91 [b]	0.60 [ab]	1.59 [b]	4.51 [b]	5.32 [c]
Avicennia germinans-Laguncularia racemosa	0.57 [b]	0.40 [a]	7.34 [ab]	16.1 [b]	22.64 [b]	9.03 [b]	0.33 [b]	40.20 [b]	31.82 [b]	0.36 [a]	3.36 [a]	9.30 [d]	6.56 [d]

bidentata-Ocotea leucoxylon community is found in a small number of patchy remnants in a primarily disturbed landscape dominated by active and abandoned agricultural areas and development. Each of these community types deserve consideration as landscape elements in need of continued conservation.

The increase in percent of native and endemic species along the elevational gradient is a function of both the protected nature of the montane sites and the isolation of mountain peak habitats. The *Cyrilla racemiflora-Micropholis garciniifolia* community (Palo colorado forest alliance), considered the zonal vegetation for the Lower montane wet Holdridge life zone, and the *Dacryodes excelsa-Manilkara bidentata* community (Tabonuco forest alliance), considered zonal vegetation for the Subtropical wet forest Holdridge life zone, had the highest species richness and number of native species. More surprising was the dominance and percentage of native species in the moist lowland sites, a region of high human disturbance.

Structural characteristics such as stem densities, basal area, and aboveground biomass are a function of the forest type, edaphic conditions, and the age and degree of disturbance of each stand. These ecosystem characteristics are integrated components of the plant community and the distribution of these can be used to extrapolate these properties spatially. The Lowland moist, Tabonuco, and Palo colorado forest plots have the highest standing crop (greater than 300 Mg/ha) and the highest tree species diversity per type. The Lowland moist and dry communities have the highest overall plant diversity. Stand characteristics of these forest types will be useful for comparison with the less mature secondary forests currently dominating the lowland and montane Puerto Rican landscape. The correlations of vegetation, soil, and abiotic characteristics with a complex elevational gradient indicate that a number of these characteristics are correlated to rainfall and temperature and that conservation elements are not independent of elevation. The elevation gradient represents variation in measured properties such as temperature and rainfall but also variation in disturbance, degree of conservation protection, and degree of isolation that affect species distribution.

Conclusions

This study shows that mature forest stands in protected higher elevation sites continue to serve as a reservoir of native, endemic, and critically endangered species. The unprotected but mature secondary lowland forest communities described here are also dominated by native species and remarkably few non native species have colonized the herbaceous, subcanopy, or canopy layers. Invasive plant species are abundant on the island as a whole, and most common in young secondary low elevation moist forests. Lowland moist forest sites in this study had the highest number of introduced species but maintain a remarkably high number of native species. The structural, functional, and compositional characteristics of these communities can serve as a baseline against which to measure the dynamics of younger secondary forests. The detailed structural and compositional information, nested within a hierarchy of vegetation and land cover descriptions, can be spatially extrapolated in mapping and analyses of land cover composition and change.

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App. 1a. Composition and conservation status of the *Tabebuia rigida-Eugenia borinquensis* comm. in Elfin woodland vegetation. Importance values (IV) range up to 100 and are the sum of relative density, relative dominance, and relative frequency divided by three. Tree species in bold had individuals equal to or greater than 10 cm DBH. Stems per hectare are given for all species with stems equal to or greater than 10 cm DBH. Basal area (BA) for all tree species with DBH greater than 2 cm is given in m^2 per hectare. Constancy is the percent of Elfin woodland plots in which a species occur. Fidelity is percent of occurrences within Elfin woodland plots relative to all plots. Percent cover is field estimate of cover in 7 classes (r = rare, one or 2 individuals, + < 1%, 1 = 1-6%, 2 = 6-25%, 3 = 25-50%, 4 = 50-75%, 5 = > 75%). Conservation status: N = native, EN = endemic, CE = critical elements, I = introduced (Little & Wadsworth 1964; Quevedo 1999).

Species	IV	Stems/ha	BA m^2/ha	% Cons.	%Fid.	% Cover	Status
Trees (DBH > 2 cm)							
Tabebuia rigida	31.34	456	12.80	100	75	3	EN
Eugenia borinquensis	22.57	122	5.85	100	60	2	EN
Ocotea spathulata	12.31	11	1.73	100	69	1	N
Cyathea bryophila	10.94		2.14	78	100	1	EN
Micropholis garciniifolia	8.40	67	3.24	44	40	1	EN
Calyptranthes krugii	7.00		0.56	78	100	1	EN
Henriettea squamulosum	4.46	33	0.86	67	43	2	EN
Ardisia luquillensis	1.38		0.05	11	50	+	EN, CE
Clusia clusioides	0.96		0.09	11	25	1	N
Henriettea macfadyenii	0.64		0.01	11	100	+	N
Saplings (DBH < 2 cm)							
Prestoea montana				89	24	+	N
Calyptranthes krugii				78	100	1	EN
Cyathea bryophila				78	88	2	EN
Gesneria sintenisii				67	75	2	EN
Ocotea spathulata				67	75	+	N
Tabebuia rigida				56	100	+	EN
Miconia pachyphylla				44	67	+	EN
Hedyosmum arborescens				44	57	+	N
Eugenia borinquensis				44	57	+	EN
Ilex sintenissi				33	100	+	N
Ardisia luquillensis				33	75	+	EN, CE
Henriettea squamulosa				33	38	1	EN
Wallenia yunquensis				22	67	+	EN
Torralbasia cuneifolia				22	50	+	N
Miconia pycnoneura				22	40	+	EN, CE
Psychotria berteriana				22	22	+	N
Psychotria maleolens				22	10	+	EN
Micropholis garciniifolia				11	50	+	EN
Symplocos micrantha				11	50	+	EN
Mecranium latifolium				11	13	+	N
Trichilia pallida				11	8	+	N
Shrubs							
Miconia foveolata				44	100	+	EN
Clidemia cymosa				33	100	+	N
Clibadium erosum				11	50	+	N
Lianas							
Marcgravia sintenissi				89	31	+	EN
Mikania cordifolia				67	50	+	N
Dioscorea alata				22	100	+	N
Mikania pachyphylla				22	67	+	EN
Ipomoea repanda				11	50	+	N
Symphysia racemosa				11	25	+	N
Mikania odoratissima				11	20	+	N
Rajania cordata				11	7	+	N
Forbs							
Cyathea borinquena				78	23	+	EN
Trimezia martinicensis				67	100	+	I
Pilea yunquensis				56	100	+	EN
Trichomanes hymenophylloides				44	33	+	N

App. 1a, cont.

Species	IV	Stems/ha	BA m²/ha	% Cons.	%Fid.	% Cover	Status
Grammitis hessii				33	100	+	N
Pilea semidentata				33	75	+	N
Asplenium auriculatum				33	60	+	N
Impatiens walleriana				33	30	+	I
Trichomanes rigidum				22	50	+	N
Nephrolepis rivularis				22	13	+	N
Cyathea portoricensis				11	100	+	EN
Pilea parietaria				11	17	+	N
Diplazium centripetale				11	14	+	N
Graminoids							
Isachne angustifolia				89	62	+	N
Scleria canescens				11	11	+	EN
Epiphytes							
Blechnum fragile				78	100	+	N
Polystichum calderonense				33	100	+	EN, CE
Anthurium scandens				22	100	+	N
Hohenbergia attenuata				56	83	+	EN
Blechnum divergens				33	60	+	N
Dilomilis montana				33	60	+	N
Selaginella krugii				100	45	+	EN
Polypodium loriceum				22	40	+	N
Psychotria guadalupensis				22	33	+	N
Grammitis seminuda				22	29	+	N
Guzmania berteriana				56	28	+	N
Oleandra articulata				22	20	+	N
Polytaenium feei				11	20	+	N
Columnea ambigua				11	14	+	EN
Anthurium dominicense				11	10	+	N

App. 1b. Composition and conservation status of the *Prestoea montana-Cecropia schreberiana* comm. in Sierra palm forest vegetation. Importance values (IV) range up to 100 and are the sum of relative density, relative dominance, and relative frequency divided by three. Tree species in bold had individuals equal to or greater than 10 cm DBH. Stems per hectare are given for all species with stems equal to or greater than 10 cm DBH. Basal area (BA) for all tree species with DBH greater than 2 cm is given in m2 per hectare. Constancy is the percent of Sierra palm forest plots in which a species occur. Fidelity is percent of occurrences within Sierra palm forest plots relative to all plots. Percent cover is field estimate of cover in 7 classes (r = rare, one or 2 individuals, + < 1%, 1 = 1-6%, 2 = 6-25%, 3 = 25-50%, 4 = 50-75%, 5 = > 75%). Conservation status: N = native, EN = endemic, CE = critical elements, I = introduced (Little & Wadsworth 1964; Quevedo 1999).

Species	IV	Stems/ha	BA m^2/ha	% Cons.	%Fid.	% Cover	Status
Trees							
Prestoea montana	59.82	1467	33.32	100	53	5	N
Cecropia schreberiana	13.81	133	3.56	78	58	+	N
Henriettea squamulosa	6.75	33	0.78	44	29	+	EN
Eugenia borinquensis	6.38	33	0.52	56	33	+	EN
Cyathea arborea	2.40	22	0.26	33	100	+	N
Clibadium erosum	2.36		0.02	11	50	+	N
Haenianthus salicifolius	1.66	11	0.68	11	33	+	N
Citharexylum caudatum	1.27		0.01	11	100	+	N
Croton poecilanthus	1.21	11	0.15	11	50	+	EN
Cestrum macrophyllum	1.10		0.02	11	100	+	N
Sapium laurocerasus	1.09		0.01	11	100	+	EN
Saplings (D_{BH} < 2 cm)							
Prestoea montana				100	26	1	N
Psychotria berteriana				67	30	+	N
Henriettea squamulosa				56	63	+	EN
Mecranium latifolium				56	63	+	N
Cordia borinquensis				44	33	+	EN
Guarea glabra				44	57	+	N
Cecropia schreberiana				33	50	+	N
Cestrum macrophyllum				33	43	+	N
Croton poecilanthus				33	50	+	EN
Miconia pycnoneura				33	60	+	EN, CE
Ocotea leucoxylon				33	12	+	N
Miconia racemosa				22	22	+	N
Trichilia pallida				22	17	+	N
Alchornea latifolia				11	14	+	N
Citharexylum caudatum				11	100	+	N
Cyathea bryophila				11	13	+	EN
Cyathea horrida				11	100	+	N
Eugenia borinquensis				11	14	+	EN
Lasianthus lanceolatus				11	14	+	N
Lobelia portoricensis				11	100	+	EN
Miconia tetrandra				11	25	+	N
Ocotea spathulata				11	13	+	N
Shrubs							
Piper blattarum				44	80	+	EN
Gesneria sintenisii				22	25	+	EN
Piper hispidum				22	100	+	N
Lepianthes peltata				11	50	+	N
Ruellia coccinea				11	100	+	N
Lianas							
Marcgravia sintenissi				78	27	+	EN
Ipomoea krugii				67	75	+	EN, CE
Mikania cordifolia				33	25	+	N
Mikania odoratissima				22	40	+	EN
Hillia parasitica				11	100	+	N
Matelea variifolia				11	100	+	EN
Forbs							
Cyathea borinquena				89	27	+	EN
Thelypteris deltoidea				89	33	+	N

App. 1b, cont.

Species	IV	Stems/ha	BA m^2/ha	% Cons.	%Fid.	% Cover	Status
Begonia decandra				78	100	+	EN
Impatiens walleriana				78	70	+	I
Polybotrya cervina				78	100	+	N
Diplazium centripetale				67	86	+	N
Erythrodes plantaginea				67	86	+	N
Nephrolepis rivularis				56	31	+	N
Pilea parietaria				56	83	+	N
Trichomanes hymenophylloides				56	42	+	N
Blechnum occidentale				44	40	+	N
Danaea nodosa				44	100	+	N
Dennstaedtia bipinnata				33	100	+	N
Asplenium auriculatum				22	40	+	N
Bolbitis nicotianifolia				22	100	+	N
Commelina diffusa				22	50	+	N
Diplazium striatum				11	100	+	N
Hemidictyum marginatum				11	100	+	N
Lobelia assurgens				11	100	+	N
Lycopodium taxifolium				11	100	+	N
Pilea semidentata				11	25	+	N
Tectaria incisa				11	100	+	N
Tectaria trifoliata				11	100	+	N
Thelypteris reticulata				11	100	+	N
Blechnum divergens				22	40	+	N
Conyza apurensis				11	100	+	N
Graminoids							
Ichnanthus pallens				78	24	+	N
Paspalum conjugatum				22	67	+	N
Scleria canescens				11	11	+	EN
Epiphytes							
Guzmania berteriana				89	44	+	N
Selaginella krugii				67	30	+	EN
Elaphoglossum simplex				44	67	+	N
Oleandra articulata				44	40	+	N
Polytaenium feei				44	50	+	N
Elaphoglossum longifolium				33	38	+	N
Polypodium dissimile				33	38	+	N
Columnea ambigua				22	29	+	EN
Grammitis seminuda				22	29	+	N
Grammitis taxifolia				22	100	+	N
Polypodium crassifolium				22	50	+	N
Polypodium dispersum				22	100	+	N
Polypodium piloselloides				22	29	+	N
Anthurium dominicense				11	10	+	N
Grammitis flabelliformis				11	33	+	N
Grammitis suspensa				11	100	+	N
Lepanthes woodburyana				11	100	+	EN
Peperomia emarginella				11	100	+	N
Peperomia rotundifolia				11	100	+	N
Pleurothallis aristata				11	100	+	N
Polypodium polypodioides				11	100	+	N
Psychotria guadalupensis				11	17	+	N

App. 1c. Composition and conservation status of the *Cyrilla racemiflora-Micropholis garciniifolia* comm. in Palo colorado forest vegetation. Importance values (IV) range up to 100 and are the sum of relative density, relative dominance, and relative frequency divided by three. Tree species in bold had individuals equal to or greater than 10 cm DBH. Stems per hectare are given for all species with stems equal to or greater than 10 cm DBH. Basal area (BA) for all tree species with DBH greater than 2 cm is given in m2 per hectare. Constancy is the percent of Palo colorado forest plots in which a species occur. Fidelity is percent of occurrences within Palo colorado forest plots relative to all plots. Percent cover is field estimate of cover in 7 classes (r = rare, one or 2 individuals, + < 1%, 1 = 1-6%, 2 = 6-25%, 3 = 25-50%, 4 = 50-75%, 5 = > 75%). Conservation status: N = native, EN = endemic, CE = critical elements, I = introduced (Little & Wadsworth 1964; Quevedo 1999).

Species	IV	Stems/ha	BA m^2/ha	% Cons.	%Fid.	% Cover	Status
Trees							
Cyrilla racemiflora	18.37	333	20.04	100	100	2	N
Micropholis garciniifolia	10.74	167	4.30	67	60	2	EN
Clusia clusioides	7.84	111	9.33	33	75	1	N
Matayba domingensis	7.07	78	8.18	44	100	1	N
Prestoea montana	5.39	178	3.01	44	24	1	N
Henriettea squamulosa	5.02	56	2.33	33	21	1	EN
Cordia borinquensis	4.24	44	0.71	44	57	+	EN
Cecropia schreberiana	3.45	22	1.13	44	31	+	N
Chrysophyllum argenteum	3.45	33	1.83	11	11	+	N
Daphnopsis philippiana	3.28		1.13	78	100	+	EN
Tabebuia rigida	2.21	22	0.75	33	25	+	EN
Ocotea leucoxylon	2.14		0.15	11	6	+	N
Eugenia stahlii	1.96		0.07	33	75	+	EN
Ocotea spathulata	1.72		0.10	44	31	+	N
Palicourea croceoides	1.55		0.02	22	67	+	N
Inga laurina	1.42	22	1.41	22	15	+	N
Myrcia fallax	1.31		0.05	22	67	+	N
Hirtella rugosa	1.24		0.15	33	60	+	EN
Byrsonima wadsworthii	1.20		0.09	33	60	+	EN, CE
Coccoloba diversifolia	1.19	22	0.76	11	33	+	N
Croton poecilanthus	1.04		0.03	11	50	+	EN
Schefflera morototonii	1.03		0.02	22	67	+	N
Micropholis guyanensis	1.02	11	0.21	33	100	+	N
Magnolia splendens	0.72		0.14	11	100	+	EN, CE
Ixora ferrea	0.70		0.11	11	25	+	I
Haenianthus salicifolius	0.66	11	0.28	22	67	+	N
Eugenia borinquensis	0.65		0.02	11	7	+	EN
Miconia pachyphylla	0.65		0.01	11	100	+	EN
Miconia tetrandra	0.64	11	0.24	11	20	+	I
Ditta myricoides	0.58	11	0.13	11	100	+	N, CE
Ardisia luquillensis	0.53		0.03	11	50	+	EN, CE
Cassipourea guianensis	0.53		0.03	11	100	+	N
Ilex sideroxyloides	0.52		0.02	11	50	+	N
Psychotria berteriana	0.52		0.02	11	33	+	N
Cybianthus sintenisii	0.51		<0.01	11	100	+	N
Saplings (D_{BH} < 2 cm)							
Prestoea montana				78	21	+	N
Psychotria maleolens				78	35	+	EN
Myrcia fallax				67	60	+	N
Hirtella rugosa				56	50	+	EN
Adenanthera pavonina				44	57	1	I
Lasianthus lanceolatus				44	57	+	N
Miconia prasina				44	18	+	N
Pterocarpus officinalis				44	67	+	N
Cestrum macrophyllum				33	43	+	N
Cordia borinquensis				33	25	+	EN
Croton poecilanthus				33	50	+	EN
Daphnopsis philippiana				33	100	+	EN
Ocotea leucoxylon				33	12	+	N
Palicourea crocea				33	75	+	N, CE
Palicourea croceoides				33	60	+	N
Trichilia pallida				33	25	+	N
Byrsonima wadsworthii				22	50	+	EN, CE

App. 1c, cont.

Species	IV	Stems/ha	BA m²/ha	% Cons.	%Fid.	% Cover	Status
Cecropia schreberiana				22	33	+	N
Chrysophyllum argenteum				22	12	+	N
Drypetes glauca				22	67	+	N
Eugenia eggersii				22	100	+	EN, CE
Hedyosmum arborescens				22	29	+	N
Mecranium latifolium				22	25	+	N
Miconia pachyphylla				22	33	+	EN
Schefflera morototonii				22	18	+	N
Tabebuia heterophylla				22	20	+	N
Torralbasia cuneifolia				22	25	+	N
Antirhea obtusifolia				11	25	+	EN
Casearia arborea				11	20	+	N
Chrysophyllum oliviforme				11	100	+	N
Comocladia glabra				11	33	+	N
Cyrilla racemiflora				11	100	+	N
Eugenia borinquensis				11	14	+	EN
Guarea glabra				11	14	+	N
Haenianthus salicifolius				11	100	+	N
Inga laurina				11	14	+	N
Mangifera indica				11	100	+	I
Matayba domingensis				11	100	+	N
Miconia racemosa				11	11	+	N
Miconia tetrandra				11	25	+	N
Micropholis garciniifolia				11	50	+	EN
Micropholis guyanensis				11	100	2	N
Myrcia deflexa				11	17	+	N
Ocotea portoricensis				11	100	+	EN
Ocotea spathulata				11	13	+	N
Sapium laurocerasus				11	33	+	EN
Sloanea berteriana				11	25	+	N
Solanum erianthum				11	100	+	
Symplocos micrantha				11	50	+	EN
Wallenia yunquensis				11	33	+	EN
Shrubs							
Urera baccifera				22	100	+	N
Lepianthes peltata				11	50	+	N
Lianas							
Marcgravia sintenissi				78	27	+	EN
Smilax coriacea				56	71	+	N
Rajania cordata				44	27	+	N
Mikania cordifolia				33	25	+	N
Cissampelos pareira				22	67	+	N
Neorudolphia volubilis				22	67	+	EN
Mikania odoratissima				22	40	+	EN
Ipomoea krugii				22	25	+	EN, CE
Gonocalyx portoricensis				22	100	+	EN
Passiflora rubra				22	100	+	N
Melothria pendula				11	50	+	N
Macfadyena unguis-cati				11	3	+	N
Symphysia racemosa				11	25	+	N
Piptocarpha tetrantha				11	100	+	EN
Forbs							
Thelypteris deltoidea				78	29	+	N
Cyathea borinquena				67	20	1	EN
Nephrolepis rivularis				56	31	+	N
Trichomanes hymenophylloides				33	25	+	N
Trichomanes rigidum				22	50	+	N
Odontosoria aculeata				11	100	+	N
Blechnum occidentale				11	10	+	N

App. 1c, cont.

Species	IV	Stems/ha	BA m^2/ha	% Cons.	%Fid.	% Cover	Status
Graminoids							
Ichnanthus pallens				67	21	1	N
Scleria canescens				33	33	+	EN
Panicum trichoides				11	100	+	N
Isachne angustifolia				11	8	+	N
Epiphytes							
Anthurium dominicense				78	70	+	N
Polypodium dissimile				56	63	+	N
Columnea ambigua				44	57	+	EN
Guzmania berteriana				44	22	+	N
Selaginella krugii				44	20	+	EN
Grammitis serrulata				33	100	+	N
Lephanthes veleziana				33	100	+	EN
Grammitis flabelliformis				33	67	+	N
Polypodium loriceum				33	60	+	N
Psychotria guadalupensis				33	50	+	N
Grammitis seminuda				33	43	+	N
Polypodium piloselloides				33	43	+	N
Oleandra articulata				33	30	+	N
Vittaria remota				22	100	+	N
Polypodium astrolepis				22	50	+	N
Dilomilis montana				22	40	+	N
Elaphoglossum longifolium				22	33	+	N
Maxillaria coccinea				11	100	+	N
Elaphoglossum simplex				11	17	+	N
Hohenbergia attenuata				11	17	+	EN

App. 1d. Composition and conservation status of the *Dacryodes excelsa-Manilkara bidentata* comm. in Tabonuco forest vegetation. Importance values (IV) range up to 100 and are the sum of relative density, relative dominance, and relative frequency divided by three. Tree species in bold had individuals equal to or greater than 10 cm DBH. Stems per hectare are given for all species with stems equal to or greater than 10 cm DBH. Basal area (BA) for all tree species with DBH greater than 2 cm is given in m2 per hectare. Constancy is the percent of Tabonuco forest plots in which a species occur. Fidelity is percent of occurrences within Tabonuco forest plots relative to all plots. Percent cover is field estimate of cover in 7 classes (r = rare, one or 2 individuals, + < 1%, 1 = 1-6%, 2 = 6-25%, 3 = 25-50%, 4 = 50-75%, 5 = > 75%). Conservation status: N = native, EN = endemic, CE = critical elements, I = introduced (Little & Wadsworth 1964; Quevedo 1999).

Species	IV	Stems/ha	BA m^2/ha	% Cons.	%Fid.	% Cover	Status
Trees							
Dacryodes excelsa	30.11	389	37.44	100	100	3	N
Tetragastris balsamifera	10.33	78	6.64	44	50	1	N
Manilkara bidentata	6.57	89	1.82	56	29	1	N
Prestoea montana	5.20	167	2.56	44	24	1	N
Miconia tetrandra	4.70	22	0.56	44	80	+	N
Ormosia krugii	4.66	56	1.80	44	100	+	N
Myrcia leptoclada	2.64		0.06	44	100	+	N
Meliosma herbertii	3.61	11	0.38	33	100	+	N
Drypetes glauca	2.16		0.01	33	100	+	N
Cordia borinquensis	1.77		0.05	33	43	+	EN
Ocotea leucoxylon	1.45	11	0.33	33	17	+	N
Psychotria berteriana	2.30	56	1.18	22	67	+	N
Rondeletia portoricensis	1.94	22	0.36	22	100	+	EN
Hirtella rugosa	1.66		0.10	22	40	+	EN
Byrsonima wadsworthii	1.61	11	1.08	22	40	+	EN, CE
Buchenavia tetraphylla	1.32	11	1.45	22	20	3	N
Andira inermis	1.22	11	0.40	22	33	+	N
Faramea occidentalis	1.13		0.03	22	11	+	N

App. 1d, cont.

Species	IV	Stems/ha	BA m²/ha	% Cons.	%Fid.	% Cover	Status
Ilex sideroxyloides	1.52		0.08	11	50	+	N
Eugenia stahlii	1.38	11	0.47	11	25	+	EN
Schefflera morototonii	1.32	22	0.34	11	17	+	N
Miconia prasina	1.12		0.02	11	33	+	N
Tetrazygia urbanii	0.72	11	0.17	11	100	+	EN
Calophyllum calaba	0.63		0.02	11	100	+	N
Guettarda valenzuelana	0.63		0.02	11	100	+	N
Byrsonima spicata	0.61	11	0.20	11	50	+	N, CE
Metastelma leptocladon	0.60	11	0.18	11	100	+	N
Guatteria caribaea	0.57	11	0.13	11	100	+	N
Alchornea latifolia	0.55	11	0.10	11	100	+	N
Casearia sylvestris	0.51		0.02	11	20	+	N
Citharexylum fruticosum	0.50		0.02	11	100	+	N
Dendropanax arboreus	0.50		<0.01	11	100	+	N
Maytenus elongata	0.50		0.01	11	100	+	EN, CE
Miconia serrulata	0.50		0.01	11	100	+	N
Myrcia fallax	0.50		<0.01	11	33	+	N
Palicourea croceoides	0.50		0.01	11	33	+	N
Casearia guianensis	0.50		0.01	11	8	+	N
Saplings (DBH < 2 cm)							
Prestoea montana				78	21	+	N
Myrcia leptoclada				67	100	+	N
Miconia racemosa				67	67	+	N
Tabebuia heterophylla				67	60	+	N
Miconia prasina				67	27	+	N
Eugenia stahlii				56	100	+	EN
Tetragastris balsamifera				56	63	+	N
Hirtella rugosa				56	50	+	EN
Schefflera morototonii				56	45	+	N
Cordia borinquensis				56	42	+	EN
Psychotria berteroana				56	25	+	N
Ocotea leucoxylon				56	20	+	N
Chionanthus domingensis				44	100	+	N
Byrsonima spicata				44	80	+	N, CE
Ixora ferrea				44	44	+	I
Myrcia fallax				44	40	+	N
Meliosma herbertii				33	100	+	N
Swietenia macrophylla				33	100	+	I
Sloanea berteroana				33	75	+	N
Casearia arborea				33	60	+	N
Myrcia deflexa				33	50	+	N
Andira inermis				33	27	+	N
Trichilia pallida				33	25	+	N
Guettarda valenzuelana				22	100	+	N
Homalium racemosum				22	100	+	N
Psychotria brachiata				22	100	+	N
Sapium laurocerasus				22	67	+	EN
Byrsonima wadsworthii				22	50	+	EN, CE
Miconia tetrandra				22	50	+	N
Calophyllum calaba				22	40	+	N
Alchornea latifolia				22	29	+	N
Guarea glabra				22	29	+	N
Lasianthus lanceolatus				22	29	+	N
Manilkara bidentata				22	15	+	N
Antirhea obtusifolia				11	100	+	EN
Cassipourea guianensis				11	100	+	N
Cinnamomum elongatum				11	100	+	N
Ilex sideroxyloides				11	100	+	N
Miconia mirabilis				11	100	+	N
Ormosia krugii				11	100	+	N
Rondeletia portoricensis				11	100	+	EN
Symplocos martinicensis				11	100	+	N

App. 1d, cont.

Species	IV	Stems/ha	BA m²/ha	% Cons.	%Fid.	% Cover	Status
Mangifera indica				11	50	+	I
Comocladia glabra				11	33	+	N
Drypetes glauca				11	33	+	N
Buchenavia tetraphylla				11	25	+	N
Palicourea croceoides				11	20	+	N
Cecropia schreberiana				11	17	+	N
Cestrum macrophyllum		11	14	+	N		
Casearia sylvestris		11	10	+	N		
Faramea occidentalis		11	5	+	N		
Lianas							
Rourea surinamensis		89	40	+	N		
Rajania cordata	67	40	+	N			
Securidaca virgata		67	35	+	N		
Hippocratea volubilis		56	15	+	N		
Marcgravia sintenissi		44	15	+	EN		
Philodendron scandens		33	100	+	N		
Ipomoea indica	22	50	+	N			
Paullinia pinnata	22	7	+	N			
Philodendron angustatum		22	40	+	N		
Smilax coriacea	22	29	+	N			
Symphysia racemosa		22	50	+	N		
Vigna luteola	22	100	+	N			
Vigna vexillata	22	50	+	N			
Acacia retusa	11	100	+	N			
Chioccocca alba	11	8	+	N			
Ipomoea repanda	11	50	+	N			
Marcgravia brittoniana		11	50	+	N		
Mimosa ceratonia		11	33	+	N		
Neorudolphia volubilis		11	33	+	EN		
Forbs							
Cyathea borinquena		100	30	+	EN		
Thelypteris deltoidea		100	38	+	N		
Blechnum occidentale		56	50	+	N		
Oeceoclades maculata		33	25	+	N		
Diodia sarmentosa		11	100	+	N		
Elephantopus mollis		11	100	+	N		
Erythrodes plantaginea		11	14	+	N		
Gleichenia bifida	11	100	+	N			
Psilotum nudum	11	100	+	N			
Sauvagesia erecta		11	100	+	N		
Graminoids							
Ichnanthus pallens		78	24	+	N		
Scleria canescens		44	44	+	EN		
Isachne angustifolia		22	15	+	N		
Epiphytes							
Polypodium lycopodioides			44	80	+	N	
Polypodium crassifolium		22	50	+	N		
Polypodium piloselloides		22	29	+	N		
Anthurium dominicense		11	10	+	N		
Elaphoglossum longifolium			11	17	+	N	
Elaphoglossum rigidum		11	100	+	N		
Elaphoglossum simplex		11	17	+	N		
Guzmania berteroniana		11	6	+	N		
Oleandra articulata		11	10	+	N		
Polypodium astrolepis		11	25	+	N		
Polypodium aureum		11	100	+	N		
Polypodium phyllitidis		11	100	+	N		
Polystachya foliosa		11	100	+	N		
Selaginella krugii		11	5	+	EN		

App. 1e. Composition and conservation status of the *Manilkara bidentata-Ocotea leucoxylon* comm. of Lowland moist forest vegetation. Importance values (IV) range up to 100 and are the sum of relative density, relative dominance, and relative frequency divided by three. Tree species in bold had individuals equal to or greater than 10 cm DBH. Stems per hectare are given for all species with stems equal to or greater than 10 cm DBH. Basal area (BA) for all tree species with DBH greater than 2 cm is given in m2 per hectare. Constancy is the percent of Lowland moist forest plots in which a species occur. Fidelity is percent of occurrences within Lowland moist forest plots relative to all plots. Percent cover is field estimate of cover in 7 classes (r = rare, one or 2 individuals, + < 1%, 1 = 1-6%, 2 = 6-25%, 3 = 25-50%, 4 = 50-75%, 5 = > 75%). Conservation status: N = native, EN = endemic, CE = critical elements, I = introduced (Little & Wadsworth 1964; Quevedo 1999).

Species	IV	Stems/ha	BA m^2/ha	% Cons.	%Fid.	% Cover	Status
Hymenaea courbaril	12.64	133	14.75	44	100	2	N
Faramea occidentalis	10.32		0.95	78	78	2	N
Manilkara bidentata	8.72	44	7.69	67	55	2	N
Ocotea leucoxylon	8.86	111	3.12	56	56	3	N
Buchenavia tetraphylla	6.74	22	8.84	22	67	2	N
Hura crepitans	5.56	22	1.07	44	100	2	I
Pouteria multiflora	3.92	22	1.78	44	100	1	N
Inga laurina	3.91	22	0.71	78	78	+	N
Tetragastris balsamifera	3.45	11	0.45	33	43	2	N
Schefflera morototonii	3.40	89	3.12	11	20	2	N
Casearia guianensis	2.76		0.29	44	67	+	N
Chrysophyllum argenteum	2.46		0.07	44	80	+	N
Spathodea campanulata	2.42	56	1.57	22	100	1	I
Guarea guidonia	2.38	11	1.25	22	100	+	N
Andira inermis	2.26	33	0.68	44	67	+	N
Quararibea turbinata	2.13		0.12	33	100	+	N
Guapira fragrans	1.48	11	0.07	11	13	+	N
Miconia prasina	1.33		0.07	22	67	+	N
Trichilia pallida	1.31		0.03	22	100	+	N
Byrsonima spicata	1.23	11	1.20	11	50	2	N, CE
Nectandra turbacensis	1.22	22	0.81	11	50	2	N
Casearia sylvestris	1.09		0.09	22	67	+	N
Inga vera	1.06		0.04	22	100	+	N
Myrcia splendens	0.90		0.06	22	100	+	N
Syzygium jambos	0.90		0.05	22	100	+	I
Swietenia macrophylla	0.89		0.05	22	100	+	I
Adenanthera pavonina	0.88		0.03	22	100	+	I
Ixora ferrea	0.88		0.02	22	67	+	I
Casearia arborea	0.58	11	0.23	22	100	2	N
Mangifera indica	0.56		0.06	11	100	2	I
Casearia decandra	0.53		0.02	11	33	+	N
Casearia aculeata	0.52		0.01	11	100	+	N
Coccoloba diversifolia	0.46		0.04	11	50	+	N
Cecropia schreberiana	0.46		0.05	11	8	+	N
Thespesia grandiflora	0.45		0.03	11	100	+	EN, CE
Tabebuia heterophylla	0.45		0.03	11	50	+	N
Genipa americana	0.44		0.02	11	100	+	N
Hirtella triandra	0.44		0.01	11	100	+	N
Saplings (DBH < 2 cm)							
Faramea occidentalis				89	89	1	N
Syzygium jambos				89	100	+	I
Miconia prasina				78	41	+	N
Ocotea leucoxylon				67	35	+	N
Casearia guianensis				56	50	+	N
Manilkara bidentata				56	71	2	N
Chrysophyllum argenteum				44	67	1	N
Andira inermis				33	50	+	N
Casearia sylvestris				33	75	+	N
Hymenaea courbaril				33	100	+	N
Quararibea turbinata				33	100	+	N
Samyda dodecandra				33	38	+	N
Casearia decandra				22	67	+	N
Hura crepitans				22	100	+	I
Pouteria multiflora				22	100	+	N

App. 1e, cont.

Species	IV	Stems/ha	BA m^2/ha	% Cons.	%Fid.	% Cover	Status
Roystonea borinquena				22	100	+	N
Schefflera morototonii				22	22	+	N
Trichilia pallida				22	18	+	N
Buchenavia tetraphylla				11	50	+	N
Byrsonima spicata				11	20	+	N, CE
Calophyllum calaba				11	33	+	N
Casearia aculeata				11	100	+	N
Casearia arborea				11	20	+	N
Citharexylum fruticosum				11	25	+	N
Coccoloba diversifolia				11	100	+	N
Coffea arabica				11	100	+	I
Comocladia glabra				11	33	+	N
Eugenia borinquensis				11	14	+	EN
Genipa americana				11	100	r	N
Guapira fragrans				11	14	+	N
Guarea guidonia				11	100	+	N
Inga laurina				11	50	+	N
Ixora ferrea				11	20	+	I
Miconia impetiolaris				11	100	+	N
Myrcia deflexa				11	20	+	N
Palicourea croceoides				11	20	+	N
Parathesis crenulata				11	100	+	N
Prestoea montana				11	3	+	N
Tetragastris balsamifera				11	17	2	N
Shrubs							
Gonzalagunia hirsuta				33	50	r	N
Piper blattarum				11	20	+	EN
Dalbergia monetaria				11	100	r	N
Lianas							
Macfadyena unguis-cati				89	42	+	N
Paullinia pinnata				67	35	+	N
Hippocratea volubilis				56	25	+	N
Rourea surinamensis				56	38	+	N
Syngonium auritum				33	100	1	N
Cissus verticillata				22	67	+	N
Heteropterys laurifolia				22	100	+	N
Passiflora edulis				22	100	+	I
Rajania cordata				22	15	+	N
Securidaca virgata				22	17	+	N
Vigna vexillata				22	50	+	N
Chioccocca alba				11	10	+	N
Cordia polycephala				11	100	+	N
Cydista aequinoctialis				11	50	+	N
Dalbergia monetaria				11	50	+	N
Dioclea hexandra				11	100	+	N,CE
Dioscorea altissima				11	100	+	I
Dioscorea polygonoides				11	100	+	N
Ipomoea tiliacea				11	50	+	N
Mikania pachyphylla				11	33	+	EN
Philodendron angustatum				11	25	+	N
Senna nitida				11	100	+	N
Syngonium podophyllum				11	100	+	I
Forbs							
Adiantum latifolium				100	75	1	N
Pharus lappulaceus				67	100	+	N
Oeceoclades maculata				33	38	+	N
Adiantum pyramidale				22	100	+	N
Adiantum obliquum				11	100	+	N
Arthrostylidium sarmentosum				11	100	1	N
Desmodium wydlerianum				11	100	r	N

App. 1e, cont.

Species	IV	Stems/ha	BA m²/ha	% Cons.	%Fid.	% Cover	Status
Dieffenbachia seguine				11	100	+	N
Nephrolepis rivularis				11	6	+	N
Pharus latifolius				11	100	+	N
Xanthosoma sagittifolium				11	100	+	I
Graminoids							
Ichnanthus pallens				56	19	+	N
Lasiacis divaricata				56	31	+	N
Isachne angustifolia				22	15	+	N
Lithachne pauciflora				22	100	+	N
Lasiacis maculata				11	100	+	N
Paspalum conjugatum				11	33	+	N
Epiphytes							
Polypodium astrolepis				11	25	+	N
Polypodium lycopodioides				11	20	+	N
Tillandsia utriculata				11	100	r	N

App. 1f. Composition and conservation status of the *Guapira fragrans-Bourreria succulenta* comm. of Dry forest vegetation. Importance values (IV) range up to 100 and are the sum of relative density, relative dominance, and relative frequency divided by three. Tree species in bold had individuals equal to or greater than 10 cm DBH. Stems per hectare are given for all species with stems equal to or greater than 10 cm DBH. Basal area (BA) for all tree species with DBH greater than 2 cm is given in m² per hectare. Constancy is the percent of Dry forest plots in which a species occur. Fidelity is percent of occurrences within Dry forest plots relative to all plots. Percent cover is field estimate of cover in 7 classes (r = rare, one or 2 individuals, + < 1%, 1 = 1-6%, 2 = 6-25%, 3 = 25-50%, 4 = 50-75%, 5 = > 75%). Conservation status: N = native, EN = endemic, CE = critical elements, I = introduced (Little & Wadsworth 1964; Quevedo 1999).

Species	IV	Stems/ha	BA m²/ha	% Cons.	%Fid.	% Cover	Status
Trees							
Bucida buceras	15.49	178	8.16	56	67	3	N
Guapira fragrans	14.43	144	4.71	56	63	3	N
Bourreria succulenta	8.37	22	1.73	67	75	1	N
Erythroxylum brevipes	7.39		0.54	89	89	1	N
Leucaena leucocephala	6.80		0.76	33	100	2	N
Capparis amplissima	4.33		0.49	67	86	+	N
Gymnanthes lucida	4.13	22	1.11	22	67	1	N
Eugenia biflora	4.04		0.16	67	86	+	N
Bursera simaruba	3.88	44	0.63	56	83	+	N
Flueggea acidoton	3.65		0.45	22	100	+	N
Pictetia aculeata	3.53		0.71	22	67	+	N
Eugenia monticola	2.74		0.17	44	80	+	N
Ginoria rohrii	2.54	33	0.59	22	100	+	I
Exostema caribaeum	2.01		0.39	22	100	2	N
Randia aculeata	1.69		0.04	33	100	+	N
Casearia decandra	1.56		0.07	22	67	+	N
Eugenia procera	1.33		0.06	22	100	+	N
Zanthoxylum monophyllum	1.25	11	0.17	11	50	+	N
Peltophorum pterocarpum	1.07		0.19	22	40	+	I
Samanea saman	0.98	11	0.34	11	100	+	I
Eugenia cordata	0.95		0.02	22	100	+	N
Guettarda elliptica	0.95		0.02	22	50	+	N
Poitea florida	0.94		0.01	22	100	+	N
Capparis indica	0.63		0.06	11	100	+	N
Samyda dodecandra	0.59		0.03	11	50	+	N
Eugenia ligustrina	0.56		0.01	11	100	+	N
Krugiodendron ferreum	0.56		0.02	11	100	+	N
Maytenus cymosa	0.54	11	0.05	11	100	+	N, CE

App. 1f, cont.

Species	IV	Stems/ha	BA m²/ha	% Cons.	%Fid.	% Cover	Status
Capparis hastata	0.51		0.03	11	100	r	N
Tamarindus indica	0.49		0.02	11	100	+	N
Elaeodendron xylocarpum	0.48		0.01	11	100	+	N
Pithecellobium unguis-cati	0.48		0.01	22	100	+	N
Coccoloba microstachya	0.46		<0.01	11	100	+	N
Saplings (D_{BH} < 2 cm)							
Capparis cynophallophora				67	100	+	N
Erythroxylum brevipes				67	86	1	N
Neea buxifolia				67	67	+	EN
Eugenia biflora				56	63	1	N
Capparis amplissima				44	67	+	N
Casearia guianensis				44	40	+	N
Eugenia monticola				44	100	+	N
Guapira fragrans				44	57	2	N
Randia aculeata				44	57	+	N
Eugenia pseudopsidium				33	50	+	N
Peltophorum pterocarpum				33	60	+	I
Samyda dodecandra				33	38	+	N
Amyris elemifera				22	67	+	N
Bourreria succulenta				22	67	+	N
Bursera simaruba				22	67	+	N
Citharexylum fruticosum				22	50	+	N
Eugenia cordata				22	67	+	N
Eugenia ligustrina				22	67	+	N
Jacquinia berteroi				22	67	+	N
Krugiodendron ferreum				22	100	+	N
Leucaena leucocephala				22	100	+	N
Pithecellobium unguis-cati				22	67	+	N
Rauvolfia viridis				22	100	+	N
Bucida buceras				11	33	+	N
Capparis hastata				11	100	+	N
Capparis indica				11	100	+	N
Casearia decandra				11	33	+	N
Cestrum diurnum				11	50	+	N
Coccoloba microstachya				11	50	+	N
Coccoloba venosa				11	50	+	N
Comocladia dodonaea				11	100	+	N
Daphnopsis americana				11	100	+	N
Flueggea acidoton				11	100	+	N
Guettarda elliptica				11	50	+	N
Gymnanthes lucida				11	50	+	N
Margaritaria nobilis				11	100	+	I
Poitea florida				11	50	+	N
Schaefferia frutescens				11	50	+	N
Tabebuia heterophylla				11	10	+	N
Shrubs							
Triphasia trifolia				33	75	1	I
Chamaesyce articulata				22	100	+	N
Lantana camara				22	100	+	N
Argythamnia stahlii				22	67	+	N
Cestrum laurifolium				11	100	+	N
Psychotria brownei				11	100	+	N
Psychotria domingensis				11	100	+	N
Iresine diffusa				11	50		N
Melochia nodiflora				11	50	+	N
Lianas							
Macfadyena unguis-cati				89	42	+	N
Tragia volubilis				78	78	+	N
Serjania polyphylla				67	67	+	N
Chioccocca alba				67	60	+	N

App. 1f, cont.

Species	IV	Stems/ha	BA m²/ha	% Cons.	%Fid.	% Cover	Status
Passiflora suberosa				44	67	+	N
Capparis flexuosa				33	60	+	N
Securidaca virgata				33	25	+	N
Abrus precatorius				22	67	+	N
Gouania lupuloides				22	67	+	N
Jaquemontia pentathos				22	67	+	N
Rhynchosia reticulata				22	67	+	N
Heteropterys purpurea				22	50	+	N
Ipomoea indica				22	50	+	N
Stigmaphyllon emarginatum				22	50	+	N
Distictis lactiflora				22	100	+	N
Galactia dubia				22	100	+	N
Hippocratea volubilis				22	10	+	N
Metastelma parviflorum				11	50	1	N
Cissus verticillata				11	33	+	N
Mimosa ceratonia				11	33	+	N
Trichostigma octandrum				11	33	+	N
Centrosema pubescens				11	100	+	N
Centrosema virginianum				11	100	+	N
Cissus trifoliata				11	100	+	N
Pisonia borinquena				11	100	3	EN
Prestonia agglutinata				11	100	r	N
Stigmaphyllon floribundum				11	100	+	N
Tournefortia volubilis				11	100	+	N
Vigna hosei				11	100	+	I
Forbs							
Commelina erecta				33	100	+	N
Opuntia repens				33	100	+	N
Justicia sphaerosperma				22	67	+	N
Celosia nitida				22	100	+	N
Thephrosia senna				22	100	+	N
Rivina humilis				11	50	r	N
Commelina diffusa				11	25	+	N
Oeceoclades maculata				11	13	+	N
Bromelia pinguin				11	100	+	N
Iresine angustifolia				11	100	+	N
Mirabilis jalapa				11	100	+	I
Graminoids							
Ichnanthus pallens				89	50	+	N
Urochloa maxima				22	67	+	I
Scleria melaleuca				11	50	r	N
Scleria lithosperma				11	100	+	N
Epiphytes							
Tillandsia recurvata				11	100	1	N
Tolumnia variegata				11	100	r	N

App. 1g. Composition and conservation status of the *Pterocarpus officinalis-Acrostichum aureum* comm. of *Pterocarpus* forest vegetation. Importance values (IV) range up to 100 and are the sum of relative density, relative dominance, and relative frequency divided by three. Tree species in bold had individuals equal to or greater than 10 cm DBH. Stems per hectare are given for all species with stems equal to or greater than 10 cm DBH. Basal area (BA) for all tree species with DBH greater than 2 cm is given in m^2 per hectare. Constancy is the percent of *Pterocarpus* forest plots in which a species occur. Fidelity is percent of occurrences within *Pterocarpus* forest plots relative to all plots. Percent cover is field estimate of cover in 7 classes (r = rare, one or 2 individuals, + < 1%, 1 = 1-6%, 2 = 6-25%, 3 = 25-50%, 4 = 50-75%, 5 = > 75%). Conservation status: N = native, EN = endemic, CE = critical elements, I = introduced (Little & Wadsworth 1964; Quevedo 1999).

Species	IV	Stems/ha	BA m^2/ha	% Cons.	%Fid.	% Cover	Status
Trees							
Pterocarpus officinalis	100	700	NA	100	100	4	N
Saplings (D_{BH} < 2 cm)							
Pterocarpus officinalis				100	100	1	N
Prestoea montana				11	3	+	N
Shrubs							
Pluchea odorata				11	100	+	N
Lianas							
Paullinia pinnata				100	53	+	N
Hippocratea volubilis				89	40	+	N
Ipomoea triloba				56	100	+	N
Cydista aequinoctialis				11	50	+	
Dalbergia monetaria				11	50	+	N
Marcgravia brittoniana				11	50	+	N
Philodendron angustatum				11	25	+	N
Forbs							
Acrostichum aureum				67	86	2	N
Thelypteris kunthii				33	100	+	N
Adiantum latifolium				33	25	+	N
Nephrolepis rivularis				33	19	+	N
Graminoids							
Paspalum plicatulum				22	100	+	N
Epiphytes							
Anthurium crenatum				33	100	+	N

App. Ih. Composition and conservation status of the *Avicennia germinans-Laguncularia racemosa* comm. of Mangrove vegetation Importance values (IV) range up to 100 and are the sum of relative density, relative dominance, and relative frequency divided by three. Tree species in bold had individuals equal to or greater than 10 cm DBH. Stems per hectare are given for all species with stems equal to or greater than 10 cm DBH. Basal area (BA) for all tree species with DBH greater than 2 cm is given in m2 per hectare. Constancy is the percent of Mangrove forest plots in which a species occur. Fidelity is percent of occurrences within Mangrove forest plots relative to all plots. Percent cover is field estimate of cover in 7 classes (r = rare, one or 2 individuals, + < 1%, 1 = 1-6%, 2 = 6-25%, 3 = 25-50%, 4 = 50-75%, 5 = > 75%). Conservation status: N = native, EN = endemic, CE = critical elements, I = introduced (Little & Wadsworth 1964; Quevedo 1999).

Species	IV	Stems/ha	BA m^2/ha	% Cons.	%Fid.	% Cover	Status
Trees							
Avicennia germinans	49.71	22	5.19	89	100	2	N
Laguncularia racemosa	46.19	32	10.08	89	100	2	N
Bontia daphnoides	2.05		<0.01	11	100	+	N
Conocarpus erectus	2.05		<0.01	11	100	+	N
Saplings (D_{BH} < 2 cm)							
Avicennia germinans				89	100	3	N
Laguncularia racemosa				89	100	1	N
Rhizophora mangle				33	100	+	N
Conocarpus erectus				22	100	+	N
Bontia daphnoides				11	100	+	N
Shrubs							
Suriana maritima				56	100	2	N
Lianas							
Jasminum multiflorum				11	100	+	I
Capparis flexuosa				11	20	+	N
Forbs							
Acrostichum aureum				11	14	+	N

App. 2. Pearson correlation (R) matrix of composition, structure, and soil characteristics from plots within five moist broadleaf evergreen tropical forest types along the elevational gradient (n = 45). EL = elevation, MAT = mean annual temperature, MAP = mean annual precipitation, TSP = Tree species richness, ST = stems per hectare, BA = basal area per hectare, AB = aboveground live biomass, NAT = native, END = endemic, EX = exotic, C/N = soil carbon to nitrogen ratio, C = total soil carbon, S = total soil sulfur, N = total soil nitrogen, LOI = loss on ignition, pH = soil pH. Significant relationships are shown in **bold**.

		EL	MAT	MAP	TSP	ST	BA	AB	NAT	END	EX	C/N	C	S	N	LOI	PH
EL	R	1	-.982**	.892**	-.494**	.145	-.259	-.352*	.008	.828**	-.587**	.823**	.735**	.666**	.592**	.711**	-.503**
	Sig.	.	.000	.000	.001	.343	.085	.018	.959	.000	.000	.000	.000	.000	.000	.000	.000
MAT		-.982**	1	-.844**	.420**	-.077	.186	.281	-.108	-.840**	.664**	-.786**	-.669**	-.595**	-.572**	-.660**	.550**
		.000	.	.000	.004	.613	.220	.061	.482	.000	.000	.000	.000	.000	.000	.000	.000
MAP		.892**	-.844**	1	-.657**	.081	-.301*	-.403**	-.021	.671**	-.501**	.737**	.656**	.657**	.523**	.723**	-.367*
		.000	.000	.	.000	.597	.038	.006	.889	.000	.000	.000	.000	.000	.000	.000	.013
TSP	R	-.494**	.420**	-.657**	1	.034	.297*	.340*	.251	-.284	.235	-.391**	-.427**	-.451**	-.429**	-.440**	.206
	Sig.	.001	.004	.000	.	.824	.047	.022	.096	.059	.121	.008	.003	.002	.003	.003	.174
ST	R	.145	-.077	.081	.034	1	-.031	-.054	-.326*	.142	.215	.355*	.568**	.421**	.516**	.506**	-.221
	Sig.	.343	.613	.597	.824	.	.839	.723	.029	.353	.156	.017	.000	.004	.000	.000	.145
BA	R	-.259	.186	-.301*	.297*	-.031	1	.978**	.136	-.282	.063	-.280	-.338*	-.335*	-.305*	-.329*	.110
	Sig.	.085	.220	.038	.047	.839	.	.000	.372	.061	.681	.063	.023	.025	.042	.027	.474
AB	R	-.352*	.218	-.403**	.340*	-.054	.978**	1	.154	-.329*	.130	-.340*	-.408**	-.405**	-.377*	-.404**	.165
	Sig.	.018	.061	.006	.022	.723	.000	.	.313	.027	.394	.022	.005	.006	.011	.006	.278
NAT	R	.008	.108	-.021	.251	-.326*	.136	.154	1	.294*	-.194	-.026	-.249	-.229	-.294	-.172	-.037
	Sig.	.959	.482	.889	.096	.029	.372	.313	.	.050	.201	.865	.098	.130	.050	.258	.810
END	R	.828**	-.840**	.671**	-.284	.142	-.282	-.329*	.294*	1	-.582**	.783**	.625**	.515**	.462**	.534**	-.464**
	Sig.	.000	.000	.000	.059	.353	.061	.027	.050	.	.000	.000	.000	.000	.001	.000	.001
EX	R	-.587**	.664**	-.501**	.235	.215	.063	.130	-.194	-.582**	1	-.372*	-.165	-.093	-.060	-.177	.557**
	Sig.	.000	.000	.000	.121	.156	.681	.394	.201	.000	.	.012	.279	.544	.693	.245	.000
C/N	R	.823**	-.786**	.737**	-.391**	.355*	-.280	-.340*	-.026	.783**	-.372*	1	.846**	.764**	.615**	.788**	-.508**
	Sig.	.000	.000	.000	.008	.017	.063	.022	.865	.000	.012	.	.000	.000	.000	.000	.000
C	R	.735**	-.669**	.656**	-.427**	.568**	-.338*	-.408**	-.249	.625**	-.165	.846**	1	.907**	.930**	.938**	-.424**
	Sig.	.000	.000	.000	.003	.000	.023	.005	.098	.000	.279	.000	.	.000	.000	.000	.004
S	R	.666**	-.595**	.657**	-.451**	.421**	-.335*	-.405**	-.229	.515**	-.093	.764**	.907**	1	.850**	.893**	-.200
	Sig.	.000	.000	.000	.002	.004	.025	.006	.130	.000	.544	.000	.000	.	.000	.000	.187
N	R	.592**	-.572**	.593**	-.429**	.516**	-.305*	-.377*	-.294	.462**	-.060	.615**	.930**	.850**	1	.868**	-.318*
	Sig.	.000	.000	.000	.003	.000	.042	.011	.050	.001	.693	.000	.000	.000	.	.000	.033
LOI	R	.711**	-.660	.723**	-.440**	.506**	-.329*	-.404**	-.172	.534**	-.177	.788**	.938**	.893**	.868**	1	-.399**
	Sig.	.000	.000	.000	.003	.000	.027	.006	.258	.000	.245	.000	.000	.000	.000	.	.007
pH	R	-.503**	.550**	-.367*	.206	-.221	.110	.165	-.037	-.464**	.557**	-.508**	-.424**	-.200	-.318*	-.399**	1
	Sig.	.000	.000	.013	.174	.145	.474	.278	.810	.001	.000	.000	.004	.187	.033	.007	.

* is significant at the 0.05 level;
** is significant at the 0.01 level.