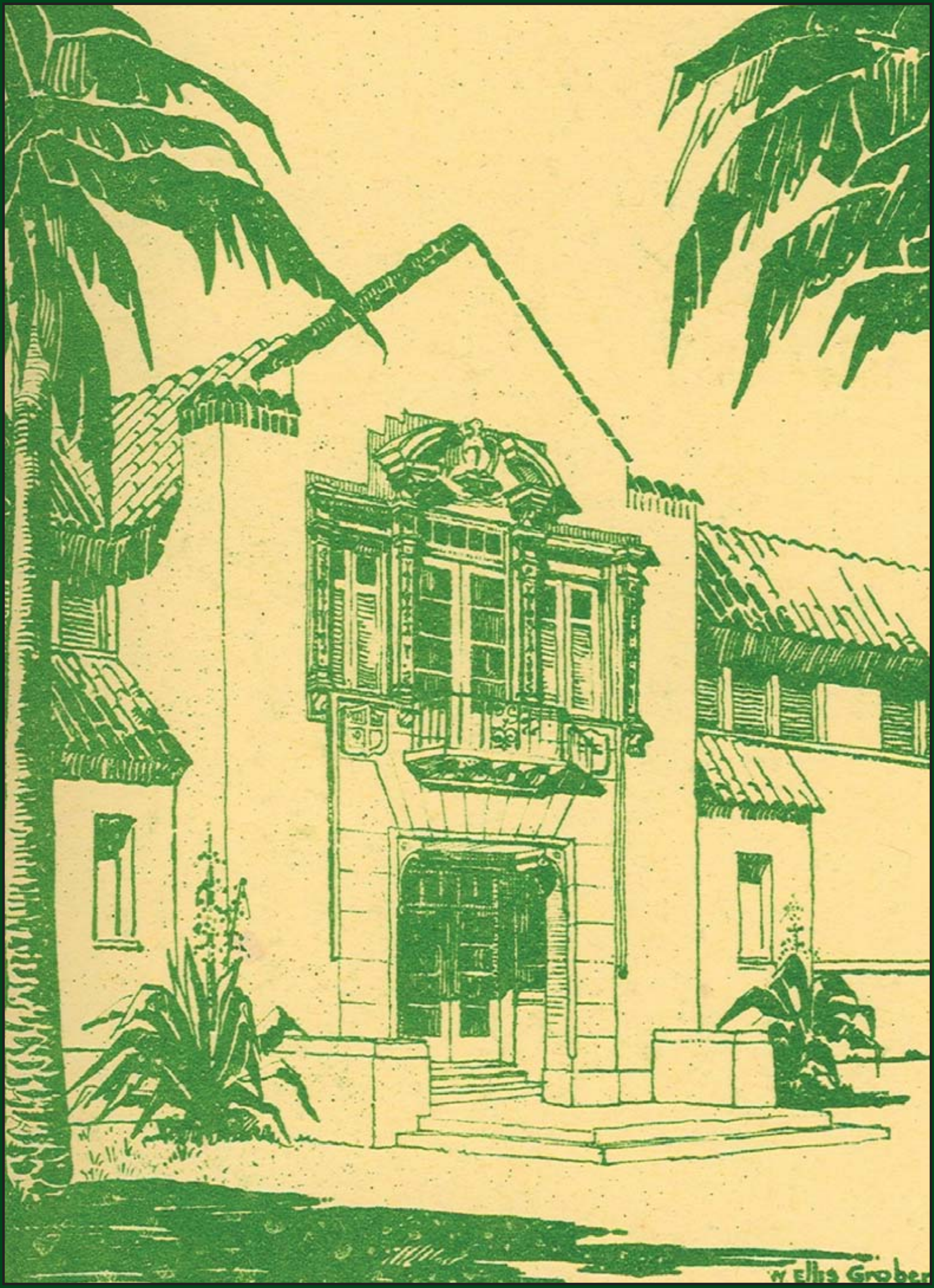
United States
Department of
Agriculture

Forest Service

International Institute
of Tropical Forestry

General Technical
Report
IITF-GTR-28
March 2005

Annual Letter 2000-2001



Cover: The cover is based on a drawing by W. Ellis Groben, Forest Service architect. He designed several Forest Service buildings including the one for the International Institute of Tropical Forestry. It depicts the front of the building from the northwest end.

Annual Letter 2000-2001

U.S. Department of Agriculture
Forest Service
International Institute of Tropical Forestry
San Juan, Puerto Rico 00926-1119
March 2005

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Puerto Rico's Forest Inventory: Adapting the USDA Forest Service Forest Inventory and Analysis Program to a Caribbean Island

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Forest Inventory in Puerto Rico

The mission of the USDA Forest Service's Forest Inventory and Analysis (FIA) Program is to "make and keep current a comprehensive inventory and analysis of the present and prospective conditions of and requirements for the renewable resources of the forest and rangelands of the United States." The program's responsibility extends to Puerto Rico as well. However, implementing a comprehensive forest inventory on a Caribbean island has called for innovation in modifying inventory techniques developed for temperate forest types.

The island's diverse forests, containing over 500 native species, reflect its equally diverse physiography (Little and Wadsworth 1995). Marked moisture and elevation gradients result in changes in forest species composition and structure over relatively short distances. Reversion to secondary forest followed widespread abandonment of agricultural lands during the latter half of the 20th century. These secondary forests contain an additional 117 naturalized exotic species whose ecological impacts are still unclear (Francis and Liogier 1991). The present day Puerto Rican landscape is a fragmented, dynamic mosaic of shifting land uses, predominately continued agricultural abandonment, reversion to secondary forest, and urban expansion. The USDA Forest Service inventories document these land use changes.

The objective of the first forest inventory in Puerto Rico, completed in 1980, was to assess the timber production potential of the island's forests (Birdsey and Weaver 1982). In all, 978 permanent sampling points were established along a systematic square grid at a 3-km spacing (Birdsey and Weaver 1982). An island-wide estimate of forest area for commercial and noncommercial areas was made from aerial photographs, although coverage was incomplete. Permanent plots were installed in two forest types that were considered to have the potential for commercial production: the subtropical moist and subtropical wet forests (Birdsey and Weaver 1982). Areas that were excluded from the survey included public forests, flood plains, urban areas, mangrove forests, areas with poorer soils, dry subtropical life zones, steep slopes, and critical watersheds with high rainfall.

Five years after the first inventory, a more complete estimate of forest area was made from newer, aerial photographs of the entire island. Forest types included in the aerial estimation of forest cover were expanded to include all present except the montane forests and plantations. A subsample of the 1980 inventory plots installed in commercial forest was revisited to update survey results (Birdsey and Weaver 1987). The data collected during the survey update were expanded to include erosion factors, hydrology, and operating conditions, as well as tree crown and branch measurements.

The island's forests were resurveyed in 1990 by using the 1985 survey update's method. Four hundred and thirty permanent plots were revisited to confirm their status, and the 167 forested plots were remeasured (Franco et al. 1997).

Adapting the Inventory to Puerto Rico's Unique Forests

The challenges of adapting the FIA Program's current method to the forests of Puerto Rico in 2001 include:

- **Expanding the inventory scope.** A sampling grid at the standard FIA intensity used in the continental United States would result in approximately 370 sampling points spread at equal distance across the island. A sampling grid that is three times as intense has been recommended for adequately sampling all the diverse forest types found on tropical islands.[1] For Puerto Rico, such a grid would give approximately 1,100 sampling points island-wide.

- **Maintaining continuity with previous inventories.** The previous forest surveys contain valuable data that give insight into long-term forest growth and changes in land use, so every effort will be made to remeasure the 167 forested plots installed in 1980 and 1990. Old plots will be relocated, and as many of the previously measured trees as possible will be remeasured.

[1] Willits, S.; Kelly, J.; Birdsey, R.; Czaplewski, R.; Ewel, J.; Lugo, A.E.; Stolte, K. 2000. Inventory needs and design for insular tropical forests of the United States. Unpublished report. On file with: (address)

- **Adding forest health monitoring.** Additional forest health monitoring data consisting of down woody debris measurements, tree crown condition assessment, and soil and erosion descriptions have been collected at a subset of the regular forest inventory plots. This information will be particularly important in Puerto Rico where the network of monitoring plots will serve for hurricane damage assessment.
- **Building a framework for additional inventories.** A flexible framework had to be built to accommodate present and future inventory questions. Composing and decomposing the hexagonal base grid to zoom in and zoom out in scale according to the demands of the data being collected is and will continue to be a vital part of the sampling framework's design. Inventory grids that are 3 and 12 times as dense as the standard FIA grid have been produced for additional inventories. Two inventory intensifications were initiated in 2001.
    - San Juan Bay Estuary urban forest inventory. The 250-km^2 San Juan Bay Estuary encompasses San Juan Bay, several large lagoons and channels, extensive wetlands, and mangrove forest, and is home to 622,000 people (Webb 1998, as cited in the Draft Comprehensive Conservation and Management Plan for the San Juan Bay Estuary, Villanueva et al. 1999). Based on experiences in continental U.S. cities (Nowak et al. 2001), a 12x grid was laid over the watershed, producing 109 sampling points that will be used to assess San Juan's urban forest.
    - Karst regional intensification. Land acquisition for expanding protected areas is underway in the karst region, making description of this biologically and historically unique area a priority. To adequately sample these forests, a 3x grid was used to generate 160 sampling points in the northern karst region.

Looking to the Future

Puerto Rico now has a forest inventory and monitoring framework with flexibility, longevity, and a statistically rigorous design. The systematic sampling grid in place allows researchers to better assess land use change in a dynamic landscape. Expanding the scope of the inventory effort recognizes the need for information on a broader suite of questions than those addressed in the past. However, maintaining continuity with the previous work allows the examination of long-term trends in forest growth and dynamics. Future challenges to the inventory program include incorporating sustainable forest criteria and indicators, better assessing the impact of urban encroachment into forested areas, and expanding the forest inventory into a true biodiversity inventory.

English Equivalent

1 kilometer (km) = 0.621 mile
1 square kilometer (km^2) = .386 square miles

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Big-Leaf Mahogany Growth Study: Year-3 Progress Report

Julio C. Figueroa Colón
Ecologist

Summary

This report documents fieldwork undertaken in the installation and mensuration of the fourth study site of the Big-Leaf Mahogany Growth study. With the completion of this site, 100 ha of natural mahogany forests have been tallied. The study site was located in karst landscape within natural tropical moist forest adjacent to Nuevo Becal, a land grant ejido[2] in the municipality of Xpujil in southeastern Campeche (Mexico). A 25-ha study block (500 by 500 m) was selected and gridded with plastic markers into 25 1-ha "permanent" globally referenced plots. All mahoganies with a diameter at breast height (d.b.h.) of 10.0 cm and larger within the block were measured, and their d.b.h., total height, crown canopy position, surrounding basal area, microtopography, and geographical positions were recorded. Saplings (d.b.h. 5.0 to 9.9 cm) within five randomly selected 1-ha plots within the block, and seedlings (d.b.h. 1.0 to 4.9 cm) within 25 randomly selected 0.04-ha subplots were assessed, 5 within each of the five selected 1-ha plots. Diameter at breast height, total height, and geographical positions also were recorded for all the saplings and seedlings tallied. One hundred forty-six mahoganies, with d.b.h. ≥ 10.0 cm, were tallied in the 25-ha area for an average of 5.8 trees per ha. Mean d.b.h. was 36.8 cm, and only 1 percent of the stems tallied as over 60 cm in d.b.h. Mean total height was 23.5 m. In all, of 35 mahoganies, 1 sapling (d.b.h. 5.0 to 9.9 cm) and 34 seedlings (d.b.h. 1.0 to 4.9 cm), were tallied in the regeneration plots for averages of 0.2 and 34 individuals per ha, respectively. Structurally, when compared to previous study sites in Bacalar, Quiringuicharo, and Capixaba, results from Nuevo Becal were second to those of Bacalar in mahoganies per ha (d.b.h. > 10 cm), and third in mean d.b.h. and total height after Quiringuicharo and Capixaba.

Results

What follows is a brief description of the Nuevo Becal study site and several simple, descriptive summary analyses of the plot data collected.

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[2]An ejido (ā hē thō) in Mexico is agricultural land expropriated from large holdings and redistributed to communal farms.

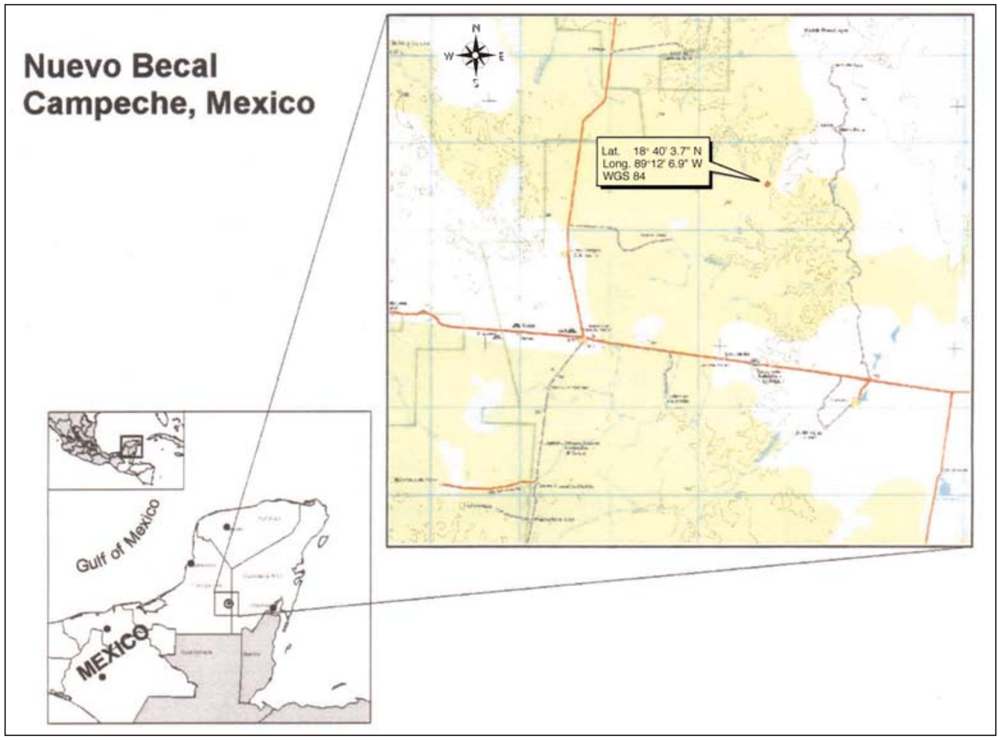

Figure 1—Location of the Nuevo Becal study site in Campeche, Mexico.

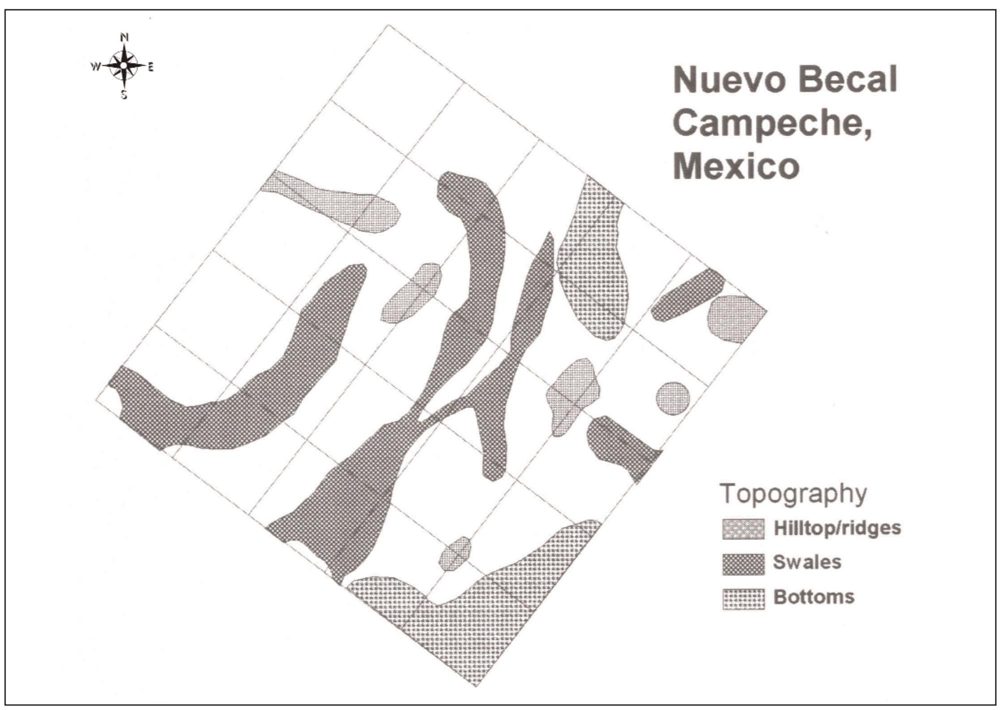

Figure 2—Prominent topographic features within the Nuevo Becal study block. The area was characterized by karst geomorphology made up by short, rounded hills jutting out of predominantly wet bottoms. Large areas of flat, wet, elevated swales were common. White areas represent slopes.

Study Site

The study area was located in karst landscape in a remote patch of lowland tropical dry forest within communal land grant property of the Nuevo Becal ejido in southeastern Campeche (fig. 1). The ejido controls 52 000 ha, 25 000 ha of which are designated "permanent forest area." The study site, although technically outside of the "permanent forest area," is within an area of 212 ha of protected natural forest set aside as a permanent seed source for mahogany. The study site is located within an area with a general topography of low, rolling karst hills. Area geomorphology is made up mainly by broad-based, rounded, dry rocky limestone hills set in damp low-lying areas. The prominent tree species on the dryer upper slopes and ridges was *Bursera simarouba* (almacigo), whereas the damp bottoms were predominantly covered with palms. Fieldwork was undertaken at the end of the 5- to 6-month dry season, yet there were numerous areas that showed signs of permanent water. The study site itself was made up mainly of slopes and level, elevated swales. There were some ridges and hilltops and two wide and poorly drained bottom areas (fig. 2). The highest ridge within the study block was 255 m.

Stand Density

One hundred forty-six mahoganies, ≥ 10 cm d.b.h., were found and tallied within the 25-ha study block (table 1). Average density of mahogany individuals within the study block was 5.8 trees per ha. Mean d.b.h. was 36.8 cm, and only 1 percent of the stems tallied were over 60 cm in d.b.h. Mean total height was 23.5 m. Structurally, when compared to previous study sites in Bacalar, Quiringuicharo,

Table 1—Summary of data collected on all mahoganies (d.b.h. ≥ 10 cm) within a 25-ha study block in Nuevo Becal, Campeche, Mexico

Diameter size class	N	Mean d.b.h.	Mean total height	Stocking rate	Forest basal area
cm	*No. (percent)*	*cm*	*m*	*No./ha*	*m^2/ha*
10.0-19.9	13 (9)	10.3	15.3	0.52	19.5
20.0-39.9	67 (46)	33.4	18.2	2.68	22.2
40.0-59.9	64 (44)	49	26.3	2.56	17.1
60.0-79.9	2 (1)	60.1	33.0	.08	16.3
80.0+	0	—	—	0	—
Total	146	36.8	23.5	5.8	15.8

— = no individuals found in this category.

D.b.h. = diameter at breast height.

and Capixaba, results from Nuevo Becal were second to those of Bacalar in mahoganies per ha (d.b.h. > 10 cm), and third in mean d.b.h. and total height after Quiringuicharo and Capixaba.

Regeneration

In all, 35 mahoganies, 1 sapling (d.b.h. 5.0 to 9.9 cm) and 34 seedlings (d.b.h. 1.0 to 4.9 cm), were tallied in the regeneration plots for averages of 0.2 and 34 individuals per ha, respectively (table 2).

Table 2—Summary of data collected in regeneration plots within a 25-ha study block in Nuevo Becal, Campeche, Mexico[a]

Diameter size class	Number	Stocking rate
cm		*No./ha*
1.0 – 4.9	34	34
5.0 – 9.9	1	.2
Total	35	34.2

[a] Saplings (d.b.h. 5.0 to 9.9 cm) were assessed within 5 randomly selected 1-ha plots within the block, and seedlings (d.b.h. 1.0 to 4.9 cm) within 25 randomly selected 0.04-ha subplots, 5 within each of the 5 selected 1-ha plots.

Distribution

Figure 3 shows the location, by diameter size class, of all 161 mahoganies tallied within the 25-ha study block. Average density of mahogany stem ≥ 10 cm d.b.h. was 5.8 per ha. Mahogany distributions showed a strong relationship to topography. Distribution was clumped, and individual isolated trees were rare. Mahoganies occurred in clumps throughout the area, although mainly in the wetter areas of bottoms and swales where occurrences were double those in the dryer drainages and hilltops and ridges. Owing to the highly dissected nature of the site, individual microtopographic values were assigned to each of the mahoganies tallied to determine possible trends (table 3). Twice as many mahoganies occurred on wet sites (swales and bottoms) versus dryer sites (drainages and ridges). Both mean d.b.h.'s and heights were greater on the dryer sites. Surrounding forest basal area showed no direct relationship. Tallied mahogany stems were very uniform in size, suggesting cohort development. Based on present average size, local records were investigated to try to identify catastrophic climatic events in the range of 40 to 70 years before present time. The search revealed that six major hurricanes have affected the region in the period between 1931 and 1955. Two hurricanes in 1931

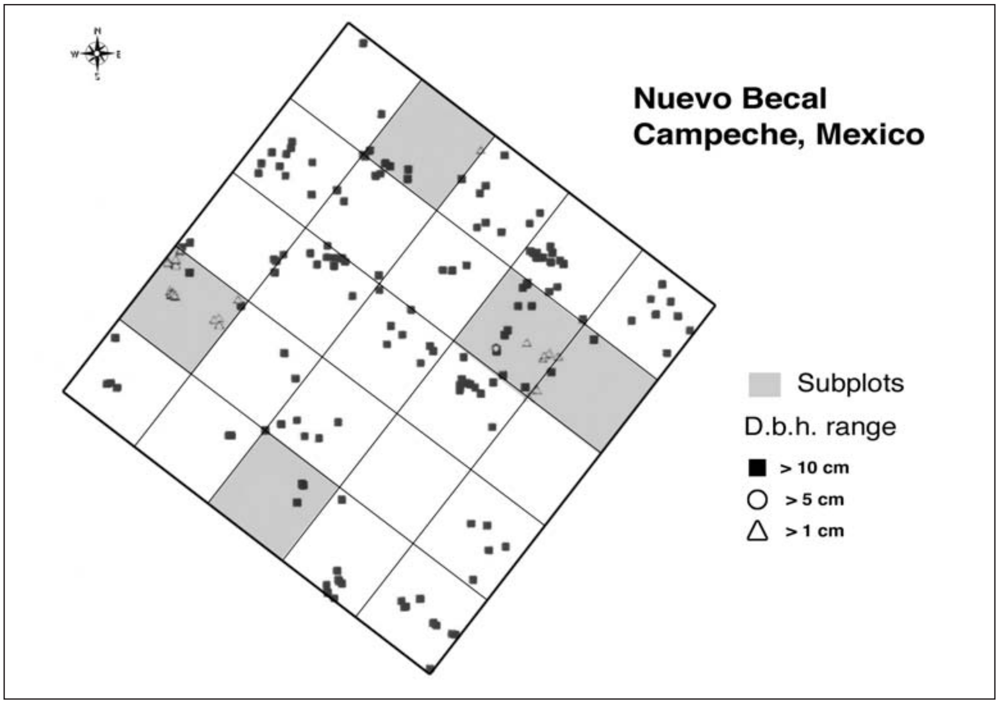

Figure 3—Distribution of all tallied mahogany individuals within the 25-ha study block in Nuevo Becal (Campeche, Mexico). Shaded areas represent randomly selected 1-ha regeneration plots.

(both category 3), one in 1932 (category 3), two in 1933 (categories 1 and 2), one in 1942 (category 2), and most significantly, two very strong hurricanes in 1955 (categories 3 and 5). These last two storms, Hurricanes Hilda and Janet, could have provided the conditions that resulted in the present-day composition of the forest.

Table 3—Distribution of all mahoganies ≥ 10 cm d.b.h. tallied within the 25-ha study block in Nuevo Becal by microtopography

	Microtopography				
	Bottom	**Drainage**	**Swale**	**Ridge**	**Total**
Number (%)	33(23)	27(18)	65(45)	21(14)	146
Mean d.b.h. (cm)	30.8	39.1	37.8	40.6	36.8
Mean height (m)	20.4	25.6	24.3	23.3	23.5
Forest basal area (m^2/ha)	18.0	16.2	18.0	18.9	17.8

Conclusions

The Nuevo Becal study site was located in karst landscape within natural tropical moist forest adjacent to a land grant ejido in the municipality of Xpujil in southeastern Campeche (Mexico). A total of 146 mahoganies, d.b.h. ≥ 10.0 cm, were tallied in the 25-ha area for an average of 5.8 trees per ha. Mean d.b.h. was 36.8 cm, and only 1 percent of the stems tallied was over 60 cm in d.b.h. Mean total height was 23.5 m. In all, of 35 mahoganies, 1 sapling (d.b.h. 5.0 to 9.9 cm) and 34 seedlings (d.b.h. 1.0 to 4.9 cm), were tallied in the regeneration plots for averages of 0.2 and 34 individuals per ha, respectively. Structurally, when compared to previous study sites in Bacalar, Quiringuicharo, and Capixaba, results from Nuevo Becal were second to those for Bacalar in mahoganies per ha (d.b.h. >10 cm), and third in mean d.b.h. and total height after Quiringuicharo and Capixaba. Although both of these sites are in relative proximity (<200 km) and similar in climate, Bacalar is on a coastal alluvial flood plain, whereas Nuevo Becal sits in dry, elevated karst hills. Results from Nuevo Becal seem to reflect those from Bacalar in having a high proportion of smaller individuals, whose similarity in size suggests possible same-age cohorts. Hurricanes, as in nearby Bacalar, would seem to be the driving force in stand-structure dynamics. Records from the area show that six major hurricanes affected the region from 1931 to 1955. The two strong hurricanes from 1955 could have provided the disturbance in the area's forest cover that promoted the development of the cohorts now in place.

English Equivalents

When you know:	Multiply by:	To get:
Centimeters (cm)	0.394	Inches
Meters (m)	3.28	Feet
Kilometers (km)	.6215	Miles
Hectares (ha)	2.47	Acres
Square meters (m^2)	10.76	Square feet

Shrubs

John K. Francis
Research Forester

Shrubs are a category or life form of plants generally intermediate in size between trees and herbs, perennial, and woody in at least some of their parts. They are extremely varied in their manifestations, from traditional, multistemmed shrubs to woody vines, to semisucculents, to suffruticose or half-shrubs, to parasitic epiphytes. There are approximately 3,000 species of shrubs in the United States and its territories (about 450 in Puerto Rico)—twice as many as tree species. Shrubs are often ignored because they contain much less biomass and have less economic value than trees, but they often are the dominant vegetation in harsh environments and are extremely important to wildlife for food and cover.

Did you know that a shrub (*Capsicum annuum*) found in Puerto Rico (and much of the American tropics) is the wild ancestor of most of the domestic pepper plants cultivated today? And did you know that a common shrub (*Ricinus communis*) contains one of the most potent poisons known to man? One of our shrubs (*Bixa orellana*) produces the world's second most important natural colorant. The benefits derived from coffee (*Coffea arabica*) and cotton (*Gossypium hirsutum*), both of which grow wild today in Puerto Rico, are well known. Several of our shrubs (e.g., *Calotropis procera, Capsicum annuum, Tecoma stans*) contain chemicals that hold great promise as drugs to treat such physical conditions as diabetes, chronic pain, and parasites. Several shrubs that are of little concern in Puerto Rico have become serious pests and even threaten forest ecosystems in other tropical and subtropical countries (*Jasminum fluminense, Lantana camara, Macfadyena unguiscati*).

For the last year, International Institute of Tropical Forestry scientists John Francis and John Parrotta have been collecting data on tropical shrubs and writing short monographs, called thamnic descriptions, about them. As of this writing (October 2001), descriptions of 8 species have been published and another 18 have been written and are currently being edited. The publication *Wildland Shrubs of the United States and Its Territories* can be viewed in its current extent at www.fs.fed.us/ global/iitf/wildland_shrubs.htm. As the title implies, the scope of the publication has been expanded to include the whole United States and its territories. A number of experts have volunteered to write descriptions for 179 additional species.

Although it may not be possible to describe all 3,000 species of shrubs, I hope that thamnic descriptions of the most important of them can be published within the next few years.

Do you have special knowledge of a shrub species in Puerto Rico or the United States and have a desire to publish it? You can be a contributor. Please contact John K. Francis to reserve the species and consult the format page and examples contained in the above publication before starting.

Mapping Forest Type and Land Use of a Biodiversity Hotspot

Eileen H. Helmer, Olga Ramos, Tania M. López,
Maya Quiñones, and Wilmaris Díaz

Introduction

Extinction risks for Caribbean island species are among the world's highest, where 11.3 percent of the region's remaining original habitat contains perhaps 2.3 and 2.9 percent of the world's endemic plants and vertebrates, respectively (Myers et al. 2000).

The only available vegetation maps for the region are land-cover maps derived from coarse-resolution satellite imagery or ecological zone maps. Neither is adequate for biodiversity conservation. Distributions of the Caribbean's most vulnerable endemic species are usually too small for coarse-resolution maps to display.

Caribbean islands have many ecological zones in small areas, presenting a major challenge to mapping the Caribbean's natural vegetation types. Finer resolution imagery is required.

We evaluated a stratified, supervised classification method for integrating Landsat Thematic Mapper (TM) imagery with ancillary data to map, for conservation planning, woody vegetation types across Puerto Rico. Puerto Rico contains forest types representative of many forests found in the region.

Methods

Landsat TM imagery underwent masking of water and cloud elements, stratification by geoclimatic classification zone (fig. 4), and supervised classification of each zone by using maximum-likelihood analysis. Digital-elevation data served as a fourth data band in supervised classification of the higher elevation zones.

The hierarchical classification system we used was collapsible to regional- and global-scale systems. It was derived by modifying the classification scheme of Areces-Mallea et al. (1999).

Classification training data consisted of 70 to 100 aerial-photo-derived point observations for each class within each zone. Forest/shrub zone included apparently abandoned agriculture/pasture, with 25 to 60 percent tree canopy cover, that codominated with small trees or shrubs as opposed to grass (Helmer et al. 2000), and, as indicated by a smoothly textured canopy, denser stands of small trees or shrubs. Woodland/shrubland also indicated 25 to 60 percent tree or shrub cover but included both active and inactive grazing lands.

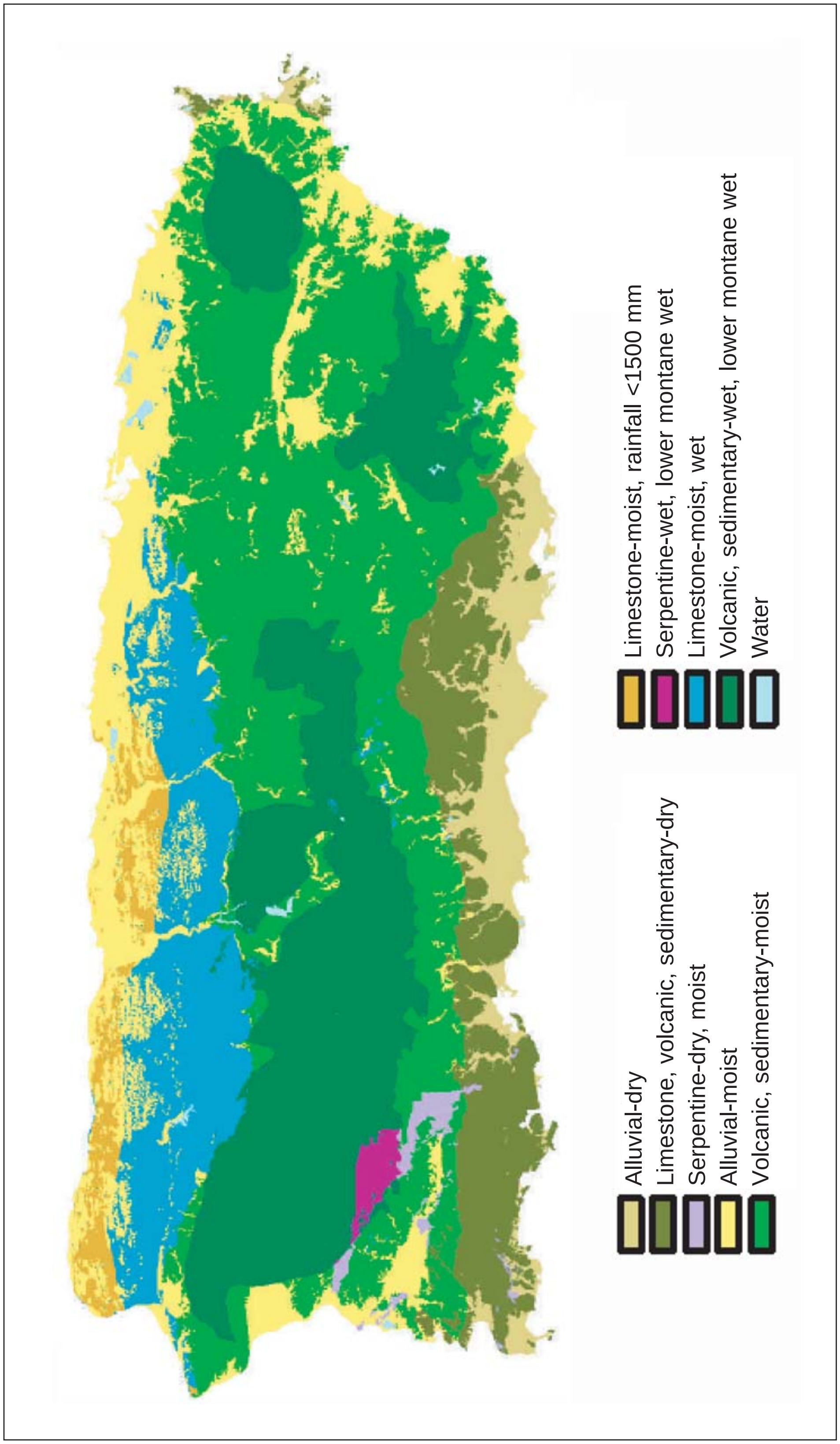

Figure 4—Geoclimatic classification zones of Puerto Rico.

A random sample of nine-pixel clusters, stratified by the class of each cluster's center pixel, provided data for accuracy assessment. We photointerpreted the natural vegetation or land use class of each pixel within each cluster, recording all possible classes that apparently mixed pixels reflected.

A digital overlay of life zone sensu Holdridge (1967) and generalized geology (Ewel and Whitmore 1973, Figueroa and Parks 1996, Krushensky 1995) yielded geoclimatic classification zones (fig. 4). Modifications included a rainfall-defined semideciduous moist forest zone and combined certain geologic classes.

Results and Discussion

Ancillary geographic data greatly enhanced our ability to produce the most detailed map of Puerto Rico's land use and natural vegetation ever developed (fig. 5).

Certain agriculture still required manual interpretation, including sugar cane, pineapple, and woody fruit crops. At higher elevations, forest/shrub included plantain, and sun and shade coffee. Because of their small patch sizes, we also manually demarcated the few larger coastal shrub areas, and we did not evaluate their mapped accuracy.

After combining all manually digitized agricultural lands, accuracy assessment data estimated a Kappa coefficient of agreement of 0.69 ± 0.01. After successional stages within each forest formation were combined, the Kappa estimate significantly improved to 0.77 ± 0.01, indicating substantial agreement.

Geology maps successfully indicated the unique forest formations developed on serpentine and karst substrates. Use of climate (1) distinguished semideciduous from evergreen forests and (2) prevented mapping of dry semideciduous forest as very young forest. Future work will investigate whether classification trees and continuous climate data improve mapping accuracy for forest successional stage.

Elevation as a classification band distinguished (1) cloud forest formations from disturbed forest at lower elevations and (2) dense-canopied submontane from lower montane wet forests.

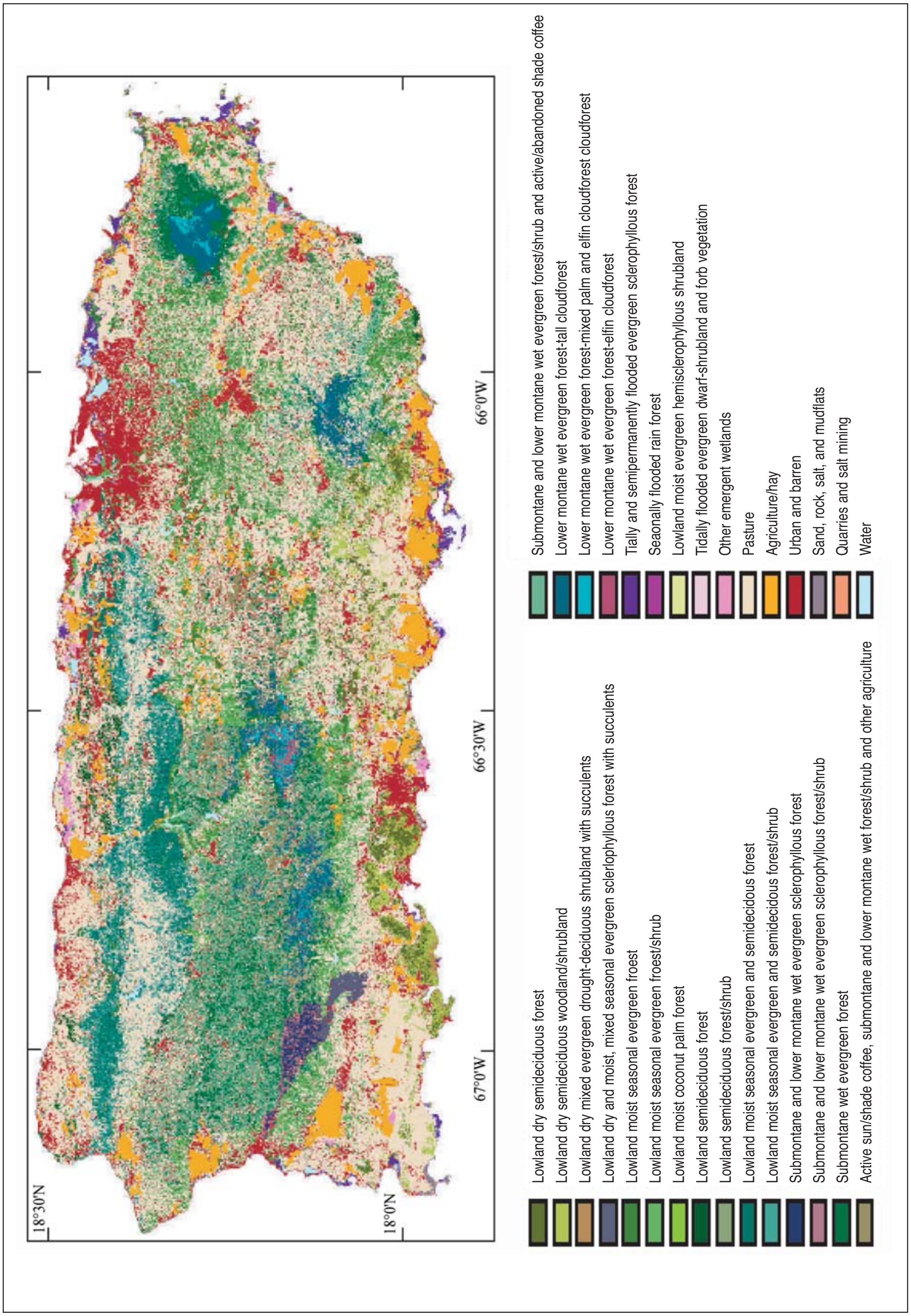

Figure 5—Forest types and land cover of Puerto Rico in 1991-92 as mapped from Landsat Thematic Mapper satellite imagery.

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Diatom Communities Along an Elevation Gradient in the Rio Mameyes

Brynne Bryan
Biological Technician

Surveys of the diatoms of Puerto Rico and other Caribbean islands have been conducted since the late 1800s (Bacon 1973, Cleve 1878, Greville 1857, Grunow 1877, Hagelstein 1938, Janisch and Rabenhorst 1863, Navarro 1989). Although the emphasis of these surveys was typically on marine diatoms, some freshwater forms were included (Bourelly and Manguin 1952, Foerster 1971, Foged 1984, Hagelstein 1938, Podzorski 1985). However, until now, no intensive study of freshwater diatom communities has been undertaken. As part of a larger water-quality study, periphytic diatoms—diatoms that grow on solid substrata—were collected along the Río Mameyes in northeastern Puerto Rico (fig. 6). The collection period started in May 1998 and has continued for 31 months, including the passage of Hurricane Georges in September 1998. Collection and analysis of samples are ongoing.

Additional information can be found on the Long-Term Ecological Research Web page at http://sunites.upr.clu.edu/sunceer/DATA/lterdb114/metadata/lterdb114.htm.

Sites

The five collection sites were chosen to represent a range of riverine environments that commonly occur in Caribbean streams that drain humid life zones (figs. 6 and 7). The highest elevation site, **Bisley Quebrada 3 (B3)** is a closed-canopy headwater drainage within the Luquillo Experimental Forest (LEF). This site drains mature tabonuco forest and is not subject to anthropogenic disturbances. The second site, **Puente Roto**, is an open-canopy midelevation reach of the Río Mameyes at the edge of the LEF. The site drains the entire elevation range of the LEF, including the four forest types that occur in the LEF. Although the drainage area of the site is relatively undisturbed forest within the LEF, the reach is heavily used for swimming and picnicking, especially on weekends and during summer. The next site downstream, called the **Intake**, is located at a municipal water intake and pumping station and drains an area of forest and urban to suburban land use. This water intake consists of a series of risers, installed in the riverbed, that withdraw river water without obstructing the flow or significantly changing channel or substratum morphology. The fourth site is located on the main channel where the river

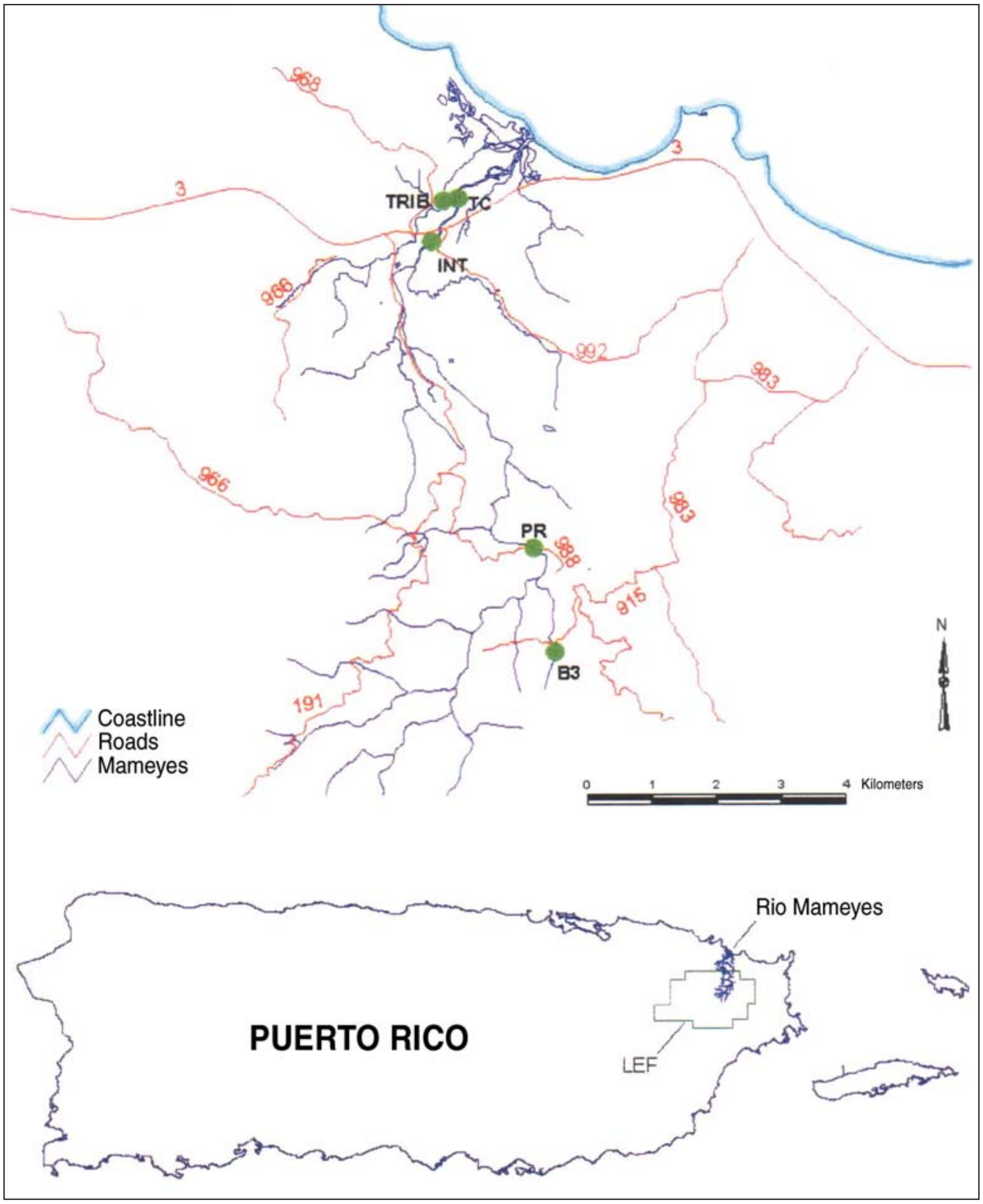

Figure 6—The Rio Mameyes watershed (inset). The diatom sampling sites are marked with green dots. The symbols for the sites are B3—Bisley Quebrada 3; PR—Puente Roto; INT—Intake; TRIB—urban tributary; TC—the main channel in the golf course, just downstream from the tributary.

passes through a golf course and is referred to as **Golf Course Channel**. This reach is the last freshwater, nontidal reach in the river. Immediately upstream of this sampling area is the last sampling spot, **urban Tributary (TRIB)**, a small tributary that drains a residential and light commercial area before it crosses the golf course and joins the main stem of the Río Mameyes. Site characteristics are summarized in table 4.

Table 4—Characteristics of sites for sampling periphytic diatoms in the Río Mameyes drainage

Site	Elevation (drainage area)	Riparian vegetation and cover	Channel features	Land use
Bisley Quebrada3	~200 m (35 ha)	Native forest, closed canopy	Boulder-lined, steep gradient tributary channel	Mature tabonuco forest
Puente Roto	~85 m (1758 ha)	Open canopy of native and nonnative forest	Steep gradient, boulder and bedrock-lined main channel	Forested, but used for swimming and picnicking
Intake	~15 m (3460 ha)	Open canopy of tall grass, native and non-native forest	Low-gradient alluvial channel with sand and cobble bed	Forested with mixed suburban land use
Golf course channel	~1 m (3483 ha)	Open canopy with golf course grass, bamboo, some wetland vegetation	Low-gradient alluvial channel with sand and cobble bed, last submerged aquatic vegetation, nontidal freshwater reach	Residential, light commercial, and golf course
Urban tributary	~1 m (419 ha)	Open canopy that drains partially open woody vegetation and golf course grass	Open-canopy channel with sand and pebble bed with some submerged aquatic vegetation	Residential, light commercial, and golf course

Methods

Nine samples were collected from each of the three main channel sites, and three samples were taken from each of the small tributaries sites (B3 and TRIB) on a monthly basis. Extra samples were collected weekly for 3 months after Hurricane Georges. To date, 795 samples have been collected on a total of 42 dates. Each sample consists of the material scraped from a 16-cm^2 area on the upper surface of a randomly collected rock. Samples have been or will be analyzed for density, ash-free dry weight, area of coverage, and diversity.

The density of diatoms is based on the number of diatom cells per square millimeter of rock, and is reported as cells per square millimeter. This is determined with a formula that includes the area scraped, the volume of suspension, and the volume of the aliquot examined (Greenberg et al. 1981). Samples were examined with a magnification of 200X, and the number of cells that were alive and dead upon collection was recorded. Thus far, 567 samples have been examined for density.

Preparation of permanent slides containing cleaned diatoms is necessary for identification of individual diatoms. To accomplish this, a subsample of each sample was cleaned with nitric acid and mounted on a microscope slide in Cargill

Figure 7—Diatom research sites: (a) B3—Bisley Quebrada 3, (b) PR—Puente Roto, (c) and (d) INT—Intake, (e) TRIB—urban tributary, (f) TC—the main channel in the golf course.

Meltmount, a permanent mounting medium with a high refractive index. These were examined at a magnification of 1,000X to determine the number of species, the number of cells for each species, and the area of each cell in square millimeters. Figure 8 shows some examples of cleaned diatoms. This information is used to determine diversity and an estimate of the area of substratum covered by diatoms. In all, 305 samples have been examined for diversity and area.

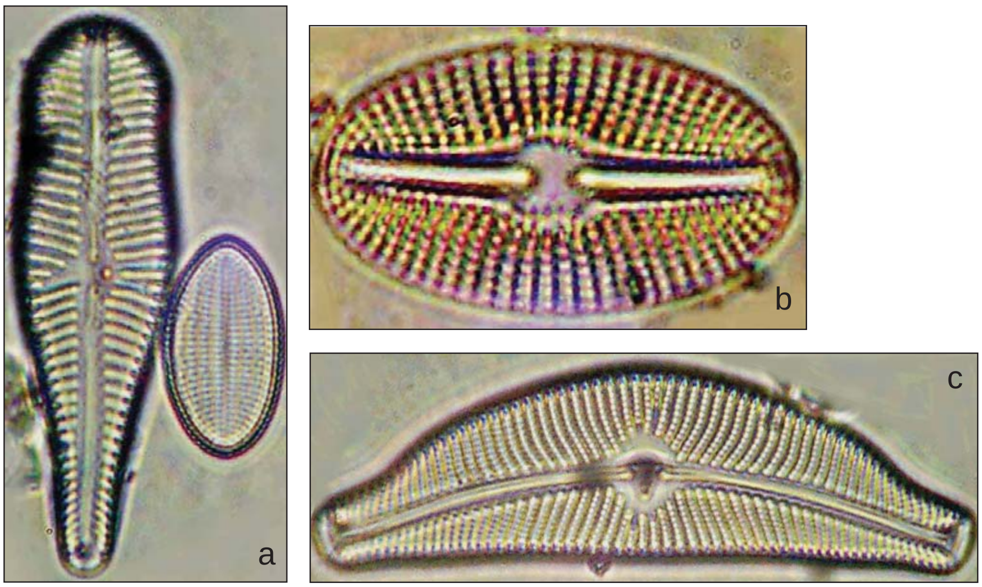

Figure 8—Examples of diatoms that have been cleaned with nitric acid: (a) *Gomphonema truncatum* and *Cocconeis placentula*, (b) *Diploneis smithii*, and (c) *Cymbella tumida*.

Results

The samples have so far yielded 379 species, of which 154 were unique to a particular sampling site. Some of these unique species were abundant at their respective sites, either once or on all dates. A few species were abundant at least occasionally at all sites. Details about preliminary findings can be found by following the link to **Report** in the Web site mentioned above.

English Equivalents

When you know:	Multiply by:	To get:
Meters (m)	3.28	Feet
Hectares (ha)	2.47	Acres
Square centimeters (cm^2)	.155	Square inches

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Soil Biology/Ecology Studies

Grizelle González
Research Ecologist

A new project has been initiated that studies the effects of soil organisms on soil ecosystem processes at sites with large differences in climate as measured by rainfall and temperature, along an elevational gradient on the eastern side of Puerto Rico. The climatic gradient in this study encompasses eight forest types that occur on similar geological features (table 5; figs. 9 and 10). The overall goal is to develop a model of tropical soil biology that estimates soil organismal contributions to the functioning of the different ecosystem types within the tropical island of Puerto Rico. Quantification of soil biological parameters includes the relative abundance and functionality of soil faunal groups, the measure of biomass of soil microorganisms (fungi and bacteria), and the metabolic and respiratory capabilities of the micro-organisms. Soil physical and chemical properties will be used to characterize the conditions under which soil organisms function in each forest type within the elevation/climatic gradient. It is expected that soil physical and chemical properties will differ as a function of the patterns of precipitation and temperature

Table 5—Average elevation (n = 3), annual precipitation, and temperature within each forest type[a]

Forest type	Elevation	Precipitation	Temperature
	m	*mm/yr*	*°C*
Mangrove	0	1565	25.7
Dry	6	1451	26.4
Pterocarpus	12	1811	25.2
Moist lowland	36	1825	25.3
Tabonuco[b]	291	3537	24.5
Colorado[b]	769	4191	22.2
Sierra palm[b]	856	4167	20.7
Elfin[b]	957	4849	20.5

[a] Precipitation and temperature data represent the mean value of 1963-93 as recorded by the National Oceanographic and Atmospheric Administration unless otherwise indicated.
[b] Precipitation data obtained from Garcia-Martinó et al. (1996); temperature data is for 1997 and was obtained from the Luquillo Long-Term Ecological Research Web site: http://luq.lternet.edu/.

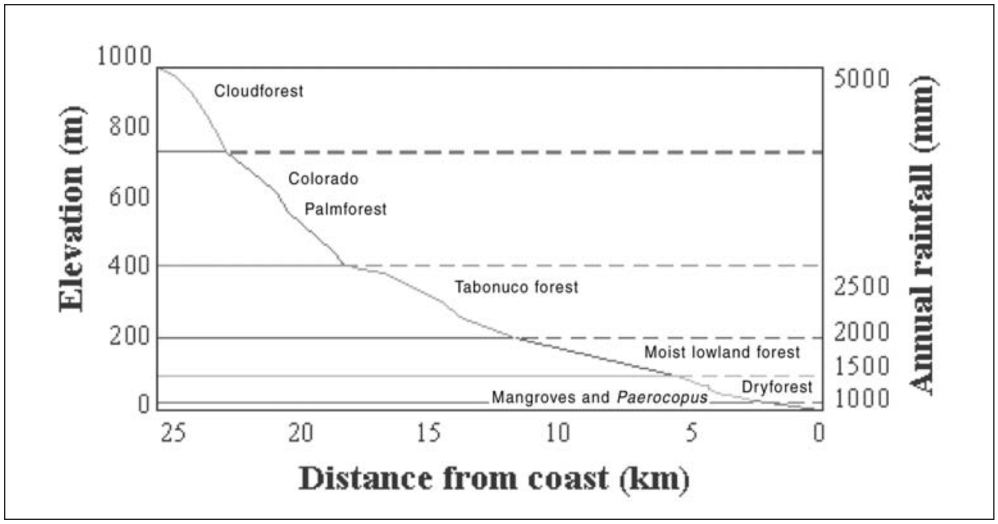

Figure 9—Location of study sites within eight forest types along an elevation gradient.

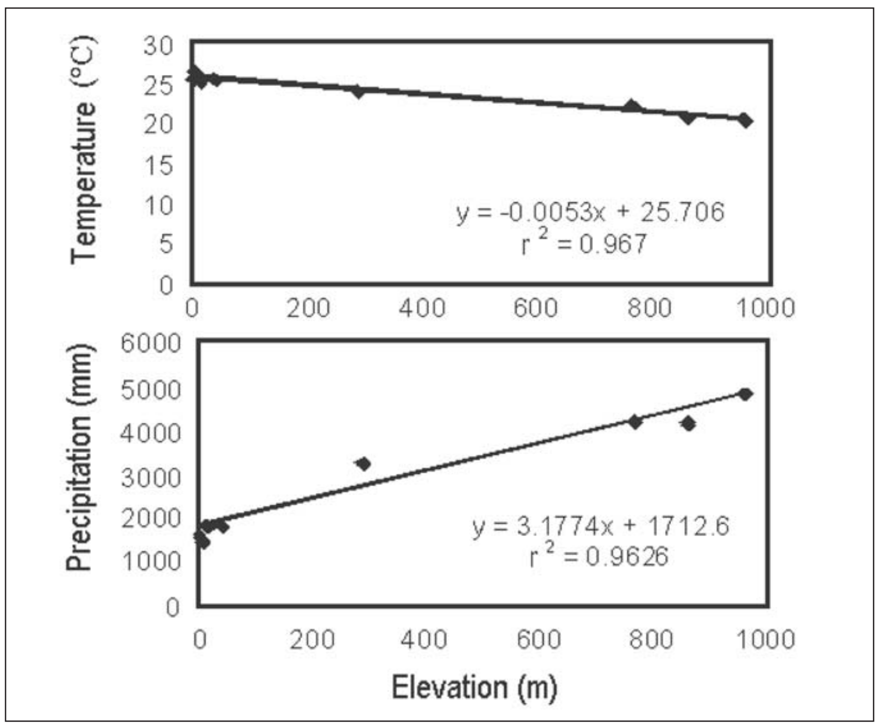

Figure 10—Temperature and precipitation as related to the elevation gradient ($P < 0.05$).

among the ecosystem forest along the elevation gradient. This situation might present an ideal field setting to determine soil organismal contribution to the fragmentation and mineralization of substrates of varying quality.

Three plots (10 by 10 m) were randomly established within each of the eight forest types (fig. 9). They will be sampled for (1) plant species composition; (2) soil nutrients; (3) litter quality and quantity; (4) relative abundance of soil micro-, meso-, and macrofauna; (5) relative abundance of the dominant microbial groups (bacteria and fungi); (6) nitrogen mineralization/nitrification potentials; (7) carbon dioxide and methane emissions; (8) soil temperature, pH, moisture content, water-holding capacity, and bulk density, and (9) climate (precipitation and temperature).

Preliminary Data on Soil Characteristics

Six soil cores (5.1 cm long and 4.3 cm in diameter) were collected at random within each of the mature forest stands (n = 3 for each of the eight forest types) to obtain baseline data on soil characteristics and microarthropod density along the gradient. In total, 144 samples were used to measure soil pH, and carbon (C) and nitrogen (N) concentrations. Mean differences in soil pH, percentage of C and N, and C:N ratio (dependent variables) among the forest types were analyzed by a one-way ANOVA by using a general linear model (GLM) procedure and the Student-Newman-Keuls (SNK) as a post hoc test ($\alpha = 0.05$). Linear regressions were performed between each dependent variable and temperature, precipitation, and elevation. All statistics were performed with SPSS 9.0 Win.

Soils from the mangrove and dry forests had the highest pH values. *Pterocarpus* and other lowland forests had intermediate values of soil pH, whereas soils within the Luquillo Mountains (tabonuco, colorado, palm, and elfin forests) were acidic with soil pH values of less than 5. Soil pH was significantly related to mean air temperature, annual precipitation, and elevation (fig. 11). Soil C and N percentages were highest in the mangrove and *Pterocarpus* forests (fig. 12 and 13). Soil C was lowest in the lowland moist forests at 36 m elevation, and increased along with elevation up to 1000 m (fig. 12). Soil C, N, and C:N were significantly related to mean air temperature, annual precipitation, and elevation (figs. 11-14).

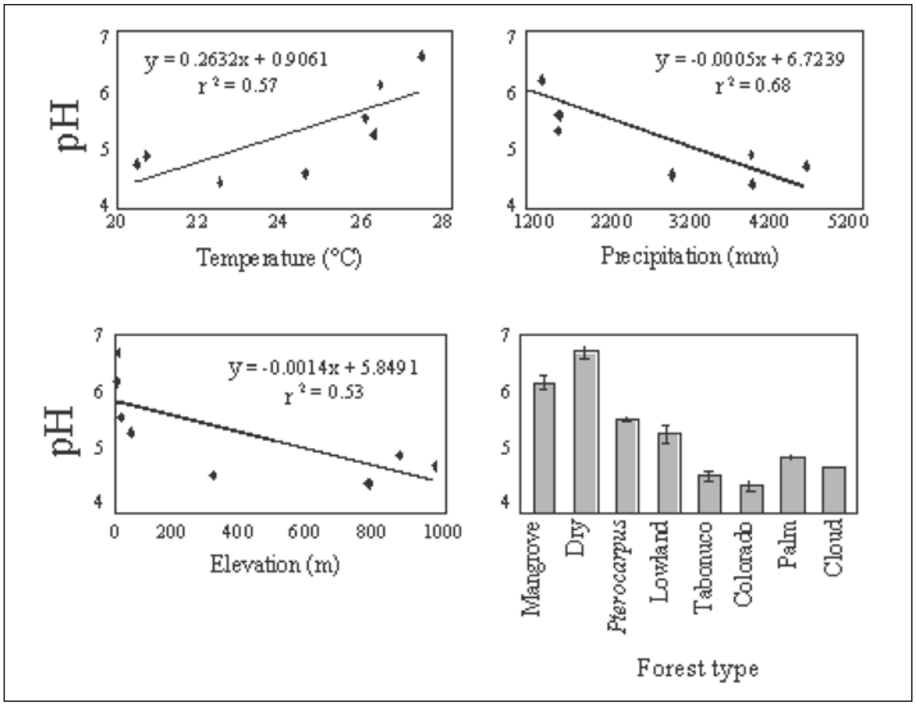

Figure 11—Soil pH as related to temperature, precipitation, elevation, and forest type.

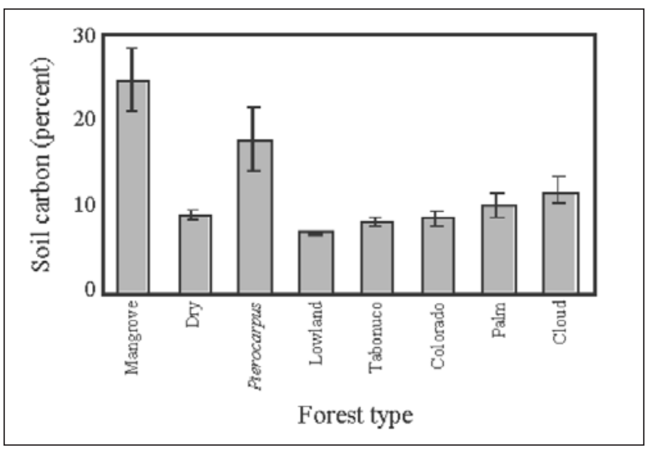

Figure 12—Soil carbon percentage (± standard error) within eight forest types along the elevation and climatic gradient.

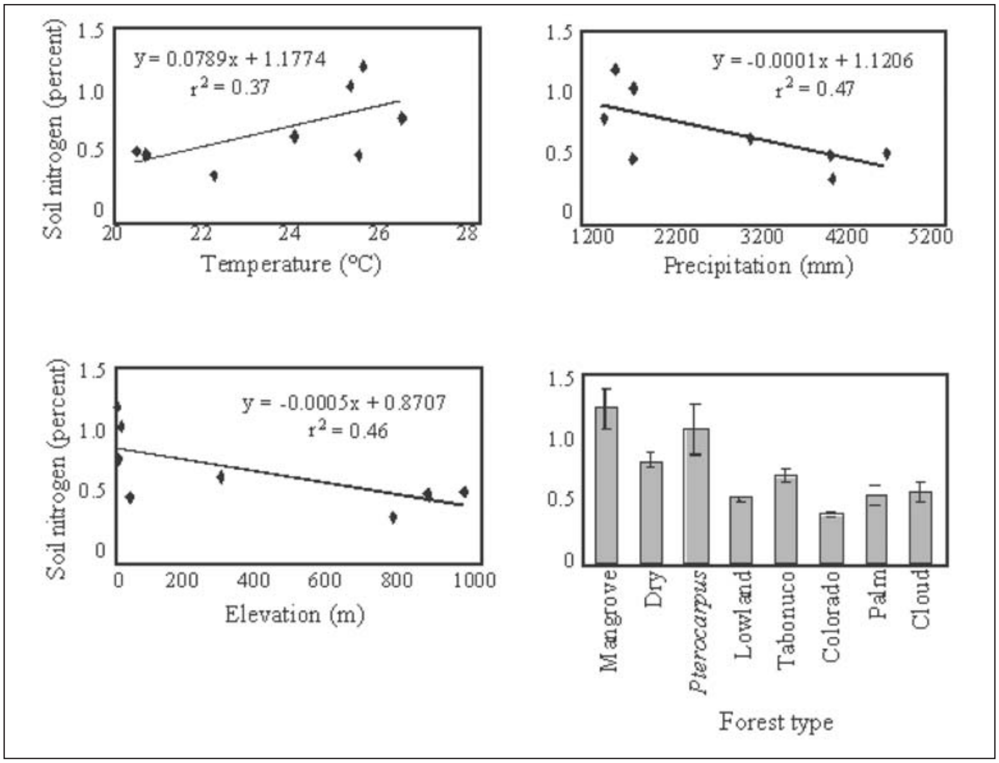

Figure 13—Soil nitrogen percentage (± standard error) as related to temperature, precipitation, elevation, and forest type.

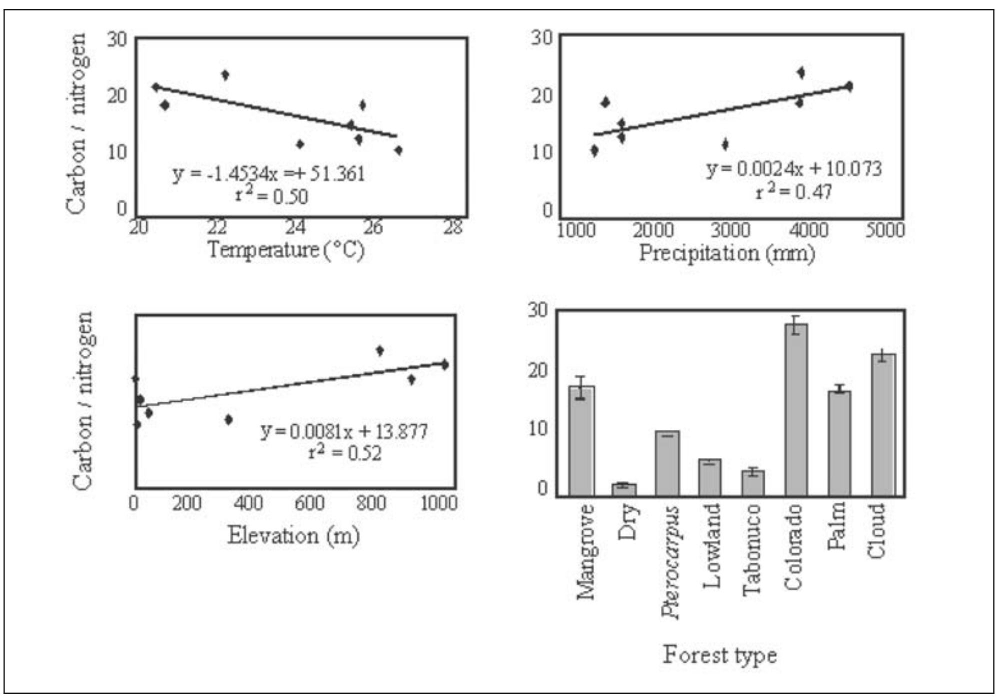

Figure 14—Soil C:N ratio (± standard error) as related to temperature, precipitation, elevation, and forest type.

English Equivalents

When you know:	Multiply by:	To get:
Centimeters (cm)	0.394	Inches
Millimeters (mm)	.03937	Inches
Meters (m)	3.28	Feet
Kilometers (km)	.6215	Miles
Degrees celsius (°C)	1.8 C+32	Fahrenheit

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Landscape Ecology Studies

William Gould
Research Ecologist

Two new projects are underway that link field studies of vegetation and ecosystem characteristics with landscape characteristics visible in satellite imagery. They have the promise of linking the International Institute of Tropical Forestry's (IITF) long history of excellent field studies with emerging technologies in the fields of geographical information system (GIS) and remote sensing. Additionally, some of these projects expand the IITF study boundaries to temperate regions of the United States and the Alaskan and Canadian Arctic.

The first study, funded through the Joint Fire Science Program, is a collaboration among three IITF scientists, Bill Gould, Grizelle González, and Fred Scatena, and Forest Service researchers Andy Hudak in Moscow, Idaho, and Marilyn Walker in Fairbanks, Alaska. The project is titled Landscape Fragmentation and Forest Fuel Accumulation: Effects of Fragment Size, Age, and Climate and will address the effect of forest fragmentation on fuel loads along gradients of climate, stand age, and fragment size. We will use a combination of remote sensing, field sampling and experimentation, GIS, multivariate analyses, and empirical modeling to quantify and compare fuel loads in fragments of different sizes (e.g., ha to km^2), ages (e.g., remnant young to old secondary), and in different climates (e.g., tropical, temperate, and boreal).

Our goal is to develop methods to better predict and map fuel loads in fragmented forests and to aid management decisions on public forested lands. The research will be coordinated from USDA Forest Service Research Stations in Puerto Rico and the Rocky Mountain Region. We will conduct field work at sites in Puerto Rico, Idaho, and Alaska to investigate a climatic gradient defining a wide range of high-biomass evergreen forest types found in the United States. Field studies, remote sensing analyses, and mapping of fuel loads will focus on state and federal forests, experimental forest sites, and National Science Foundation Long-Term Ecological Research sites in all three states.

The second study is the Puerto Rico Gap Analysis Project (PR-GAP). It will be a 4- to 5-year project and is a collaboration with Jaime Collazo at North Carolina State University and the Department of Natural Resources and Environment in Puerto Rico. The PR-GAP is the state-level representative of the National Gap Analysis Program sponsored by the Biological Resources Division of the U.S.

Geological Survey (USGS-BRD). The project goal is to map terrestrial vertebrate distribution and diversity patterns for Puerto Rico.

The project has two phases: The goals for years 1 and 2 will be to produce a habitat/vegetation map for Puerto Rico with map units correlated with terrestrial vertebrate distributions and compatible with GAP species-habitat modeling methods. This will be based on the vegetation map of Eileen Helmer. The goals for years 3 and 4 will be to catalog terrestrial vertebrate species occurring in Puerto Rico, to link the habitat/vegetation map to vertebrate distributions and map distributions and vertebrate diversity patterns. Year 5 will involve determining current land management strategies related to conservation, biodiversity, and critical species ranges and identifying gaps in conservation efforts.

A third study is being proposed along the same lines of linking field studies, remote sensing, and GIS databases. The 5-year project will involve assessing and predicting patterns of fire severity and ecosystem consequences of fire and fuels management in the Caribbean Basin. Funding is being sought by the National Fire Plan research and development program.

One of the goals of the National Fire Plan is to develop tools and approaches to better understand the complexity of interactions among fire, climate, landscapes, atmosphere, and people. This understanding will allow us to better predict fire potential and severity, manage landscapes and fuel treatment, and predict ecosystem response to fire and fuels management. Data from remote sensing and ground-based field measures integrated into a GIS database are a good approach to understanding this complexity. The problem we will address is developing landscape analyses that link field and satellite measures with both regional and local fire-related ecosystem consequences and management solutions. We are proposing to develop capabilities within the IITF to serve as the GIS and remote sensing analysis center for fire analysis in the Caribbean region. This will be a collaborative effort among IITF scientists Bill Gould, Grizelle González, Fred Scatena, and Eileen Helmer.

Optical Remote Sensing to Monitor Selective Logging Activity in the Amazon Region of Brazil

Michael Keller
Research Physical Scientist

The Amazon basin contains the world's largest contiguous area of tropical forest. This area has been subject to continual deforestation and land use expansion that is typical of tropical forests worldwide. Recently, Nepstad et al. (1999) pointed out that selective logging has become a dominant land use in the Brazilian Amazon. According to this study, the total logged area in 1996-97 (10 000 to 15 000 km^2) was nearly equal to the area of forest converted to pasture or agriculture. These rates of selective logging could have major implications for biogeochemical processes —including carbon sequestration—and for the long-term sustainability of forest productivity in the region.

Selective logging practices in the Brazilian Amazon result in high levels of collateral forest damage. Canopy opening on three logging plots in the Paragominas area of the eastern Amazon ranged from 25 to 45 percent of the total logged area (Verissimo et al. 1992). On average, 27 trees were damaged for each tree harvested. Logging can result in substantial carbon losses from tropical forests. Canopy opening and the concentration of logging debris may lead to greater flammability. In addition, timber harvesting leads to a variety of short- and long-lived effects including changes in the forest microclimate, erosion, soil compaction, and disruption of nutrient cycling. These changes can affect the recruitment of forest plant species and may lead to long-term changes in tree species composition and in the diversity and abundance of forest fauna.

Although the potential impacts of selective logging on ecological and biogeochemical processes in the Amazon are recognized, these impacts have not been well quantified at the regional level. Barriers to regional studies include natural spatial variability in forest structure and socially and economically driven variations in logging intensity and methods. It is difficult to track the diverse range of structural and functional effects of logging activities in the Amazon region without the use of remotely sensed data.

Using remote sensing for the detection and quantification of selective logging in the Amazon region is difficult because tree species diversity in the Brazilian Amazon is very high, and most species are locally rare. Logging is selective because markets accept only a few species for timber use. In areas far from markets, sometimes only a single species (e.g., mahogany, *Swietenia macrophylla*) will be cut. In contrast, over 80 species are acceptable in other areas supplying lumber to the national Brazilian markets. These dramatic differences in logging intensity result in concomitant variation of forest canopy disturbance and collateral damage caused by harvesting activities. Forest disturbance also differs even under the same market conditions for a given locale because of logging practices. The very best harvesting practices (often referred to as reduced-impact logging) being adopted by a few large-scale commercial operations can diminish canopy damage by nearly half compared to conventional practices (Pereira et al. 2001).

To date, remote sensing has not provided clear estimates of the extent or intensity of selective logging operations in the Amazon basin, where intensity refers to the level of ground and canopy structural damage and subsequent biomass losses. Few studies have quantified the accuracy of remote sensing for tracking changes in canopy structure and gap fraction during regrowth following selective logging (Asner et al., in press). One of the primary factors slowing the use of quantitative remote sensing approaches is the lack of detailed and systematic multitemporal observations of selectively logged sites with quantification of conditions on the ground.

Recently, we combined a spatially explicit field study of forest canopy gap fraction with spectral mixture analyses of Landsat 7 ETM+ satellite imagery to assess landscape and regional dynamics of canopy damage following selective logging in the Paragominas municipality in eastern Para, Brazil. Our field studies in collaboration with our cooperators at the Tropical Forest Foundation encompassed measurements of ground damage and canopy gap fractions along multitemporal sequences of postharvest regrowth of 0.5 to 3.5 years. We focused on the measurement of canopy gap fraction because of its functional link to important ecological processes such as energy balance and gas exchange and because of the obvious linkage of canopy cover to optical remote sensing analysis. We used a new probabilistic spectral mixture model (AutoMCU = Automated Monte Carlo Unmixing; Asner and Heidebrecht 2002) that provides estimates of forest canopy cover fraction within Landsat image pixels, a scale commensurate with logging activities on the ground and with field measurement capabilities (fig. 15). The model not only identified logging sites across a multitemporal sequence of selectively logged sites spanning a range of harvest intensities, it also allowed us to

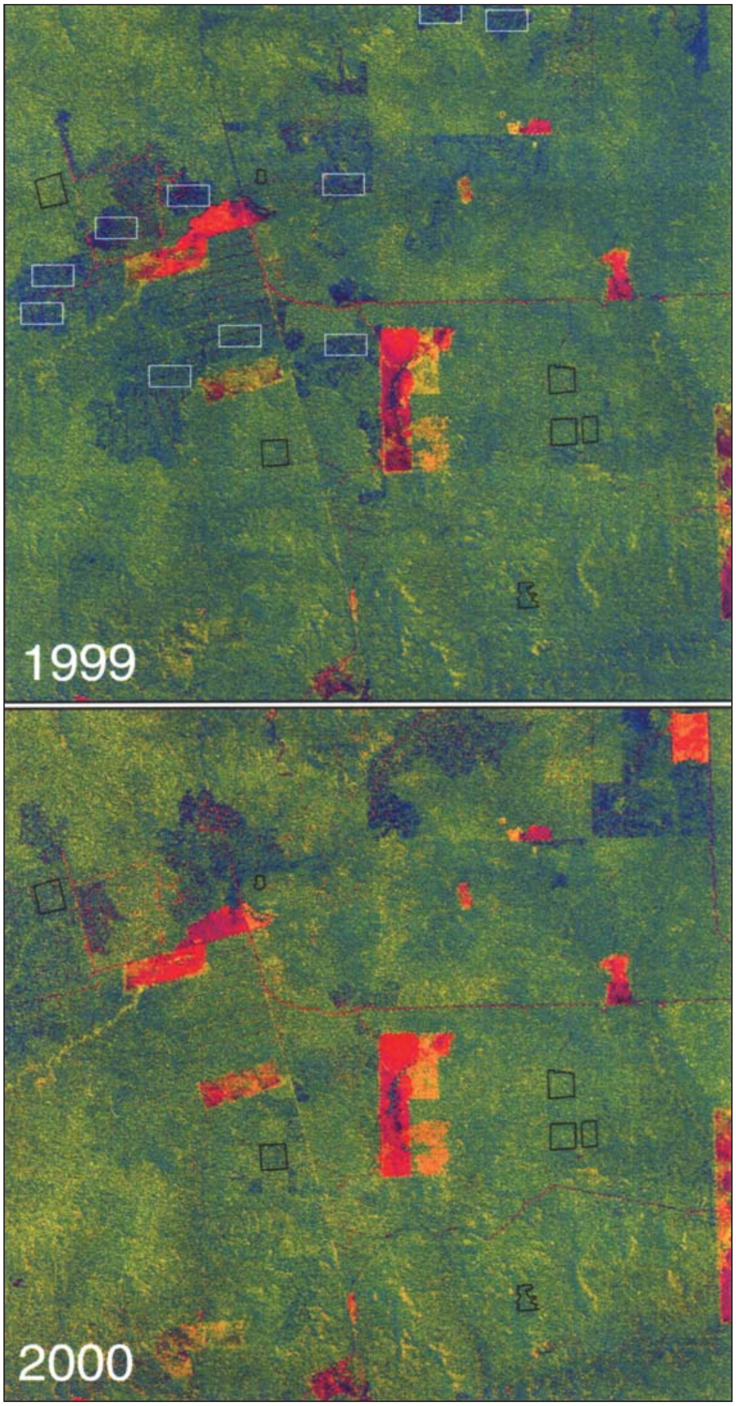

Figure 15—Color composite images of AutoMCU output for 1999 and 2000 Landsat ETM+ images of the Cauaxi area in eastern Para, Brazil. Red colors show bare soil, green shows forest canopy with shading, and blue shows exposed nonphotosynthetic vegetation (slash in logged areas). Logging research areas used for bottom-up calibrations are delineated in black. Larger areas of 1999 heavy logging used for top-down analyses are shown in white boxes. Note the canopy recovery in the white boxes from the 1999 to 2000 images.

estimate with precision the degree of canopy damage caused by logging and ameliorated by canopy recovery after logging. The study is under review for publication. Please contact michael.keller@unh.edu for further information.

English Equivalent

1 square kilometer = 0.3861 square mile

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Ecological Research

Ariel E. Lugo
Director

Effects and Outcomes of Caribbean Hurricanes in a Climate-Change Scenario

Hurricanes are complex disturbance systems with significant effects on vegetation and built-up land (table 6). I summarized research on the effects and outcomes of hurricanes on Caribbean forests (Lugo 2000). Twelve effects and outcome topics were presented: (1) sudden and massive tree mortality, (2) delayed patterns of tree mortality, (3) alternative methods of forest regeneration, (4) opportunities for a change in successional direction, (5) high species turnover and opportunities for species change in forests, (6) diversity of age classes, (7) faster biomass and nutrient turnover, (8) species substitutions and changes in turnover time of biomass and nutrients, (9) lower aboveground biomass in mature vegetation, (10) carbon sinks, (11) selective pressure on organisms, and (12) convergence of community structure and organization. Effects of hurricanes on urban systems also were discussed. Although there is scientific uncertainty as to whether hurricane frequencies and intensity will change as a result of global climate change, available understanding on the effects and outcomes of hurricanes can be used to anticipate possible effects of either increasing hurricane frequency or intensity.

Table 6—Criteria by which hurricane intensity is defined according to the Saffir/Simpson (SS) scale (Gray et al. 1997)

SS scale	Central pressure	Maximum sustained windspeed	Storm surge	Relative potential destruction
	mbar	*m/s*	*m*	
1	980	33-42	1.0-1.7	1
2	965-979	43-49	1.8-2.6	10
3	945-964	50-58	2.7-3.8	50
4	920-944	59-69	3.9-5.6	100
5	<920	>69	≥5.6	250

Should hurricanes increase in frequency and intensity, the following consequences are likely to occur:

- A larger percentage of the natural landscape will be set back in successional stage, i.e., there will be more secondary forests. A modeling study of different hurricane intensities and frequencies showed that a range of forest types are possible ranging from mature forests with large trees in areas of low hurricane frequency to an area in which forest trees are not allowed to mature when hurricane frequencies are high (O'Brien et al. 1992).
- Forest aboveground biomass and height will decrease because vegetation growth will be interrupted more frequently or with greater intensity.
- Familiar species combinations will change as species capable of thriving under disturbance conditions will increase in frequency at the expense of species that require long periods of disturbance-free conditions to mature.
- Human settlements in coastal locations, flood-prone areas, and on slopes prone to mass wasting will become increasingly expensive to sustain.
- Flimsy constructions, such as trailer parks and poorly constructed structures will be affected adversely.
- People's mental states will be impacted by the anxiety caused by the increased threat of hurricanes.

Should hurricanes decrease in frequency and intensity, the following consequences will likely occur:

- A larger percentage of the natural landscape will advance in successional stage, i.e., there will be more mature forests and fewer secondary forests.
- Forest aboveground biomass and height will increase because the longer disturbance-free periods allow greater biomass accumulation and tree height.
- Species combinations will change as species capable of thriving under disturbance conditions will decrease in frequency, and species typical of disturbance-free conditions will increase.
- Human settlements in coastal locations, flood-prone areas, and on slopes prone to mass wasting will be less impacted.
- Flimsy constructions will thrive.
- Stress associated with fear of hurricanes will decrease in the population.

Proposed mitigation actions and research priorities can be effective and desirable even if the frequency and intensity of hurricanes remains unchanged. With increased levels of disturbance, the well-being of people can be optimized by a number of strategies that build resistance to, and survivability after, hurricanes. Some of these include:

- Sound land uses so that people know and understand the degree of safety of their dwellings relative to the particular hazards of specific disturbances.
- An increased use of wind- and flood-resistant designs for construction purposes.
- Rapid access to reliable forecasts of atmospheric conditions to allow for timely preparations for disturbance events.
- Clear understanding among the population of available escape routes and refuges.
- Adequate road and refuge capacity for people to use during periods of catastrophe.
- A well-designed and maintained green infrastructure to assure some level of mitigation of the excessive winds, water, and mass wasting associated with the hurricanes.

To accomplish these mitigation strategies, investments are needed for:

- Hurricane-proofing of infrastructure by use of underground electric and telephone lines, provision for adequate drainage and increased resistance to winds, and more effective escape routes from coastal and lowland to upland areas.
- Improving construction techniques, quality of constructions materials, building codes, and enforcement of building codes such that dwellings can survive high-velocity winds.
- Improved land use planning, including zoning to avoid locating dwellings in areas prone to floods and mass wasting.
- Greater and more effective use of green infrastructure.
- A diverse set of connected natural areas to minimize effects on biodiversity.

Secondary Forest Ecology

Approximately half of the tropical biome is in some stage of recovery from past human disturbance, most of which is in secondary forests growing on abandoned agricultural lands and pastures. Reforestation of these abandoned lands, both natural and managed, has been proposed as a means to help offset increasing carbon emissions to the atmosphere. Silver et al. (2000) discuss the potential of these forests to serve as sinks for atmospheric carbon dioxide (CO_2) in aboveground biomass and soils. Data show that aboveground biomass increases at a rate of 6.2 $Mg•ha^{-1}•yr^{-1}$ over the first 80 years of regrowth. During the first 20 years of regrowth, forests in wet life zones have the fastest rate of aboveground carbon accumulation with reforestation, followed by dry and moist forests (fig. 16). Soil carbon accumulated at a rate of 0.41 $Mg•ha^{-1}•yr^{-1}$ over a 100-year period, and at faster rates during the first 20 years (1.30 Mg carbon $ha^{-1}•yr^{-1}$) (fig. 17). Past land use affects the rate of both above- and belowground carbon sequestration. Biomass accumulates faster on forests growing on abandoned agricultural land than on other past land uses (fig. 18), whereas soil carbon accumulates faster on sites that were cleared but not developed, and on pasture sites. Our results indicate that tropical reforestation has the potential to

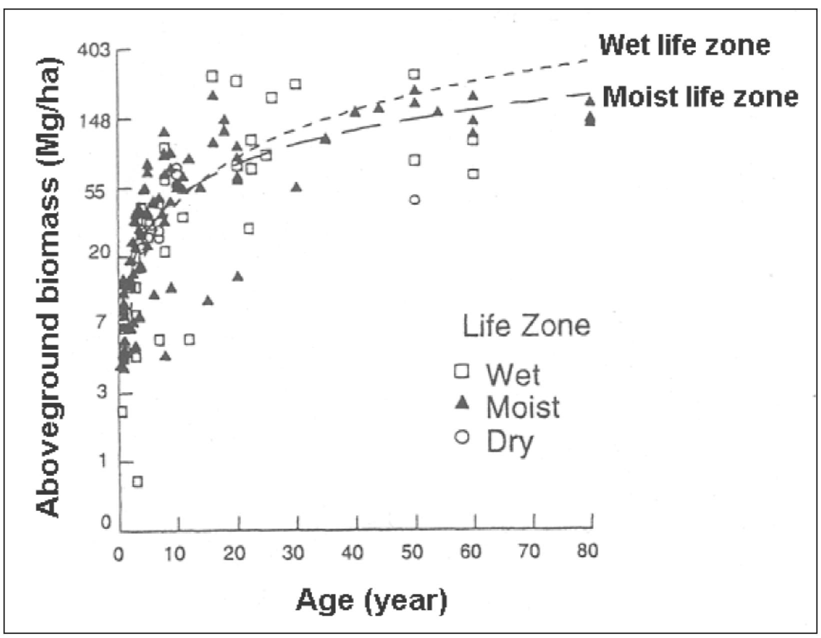

Figure 16—Aboveground biomass (Mg/ha) by age (years) and life zone in reforested tropical ecosystems. Data and regression equations are listed in Silver et al. (2000). Life zone categorizations were determined by the authors, or were estimated from total annual rainfall reported in the studies according to the following classifications: dry (>1000 mm/yr), moist (1000-2500 mm/yr), and wet (>2500 mm/yr). Data for dry forests did not differ significantly with age. Note that the y-axis is a log scale.

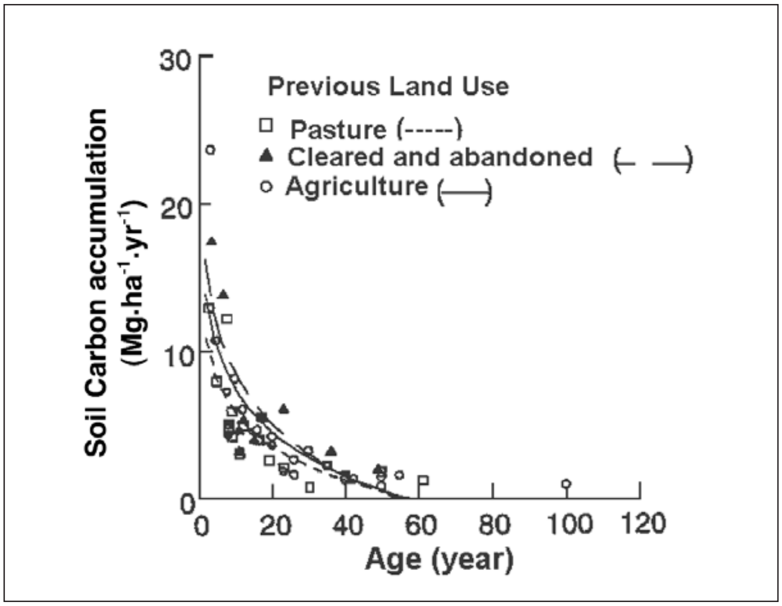

Figure 17—The rate of exchange in soil carbon accumulation over time and by previous land use. Data and regression equations are given in Silver et al. (2000).

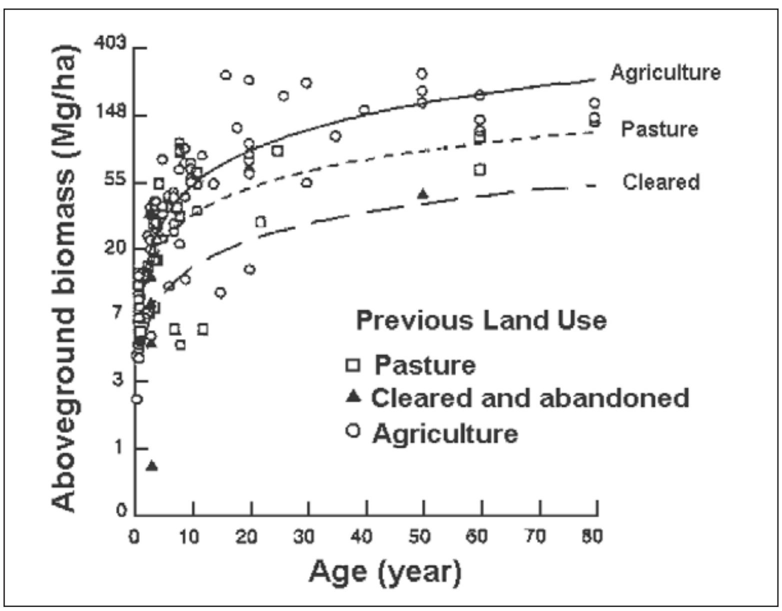

Figure 18—Aboveground biomass (Mg/ha) with age and previous land use in reforested tropical ecosystems. Data and regression equations are listed in Silver et al. (2000). Note that the y-axis is a log scale.

serve as a carbon offset mechanism both above- and belowground for at least 40 to 80 years, and possibly much longer. More research is needed to determine the potential for longer term carbon sequestration for mitigation of atmospheric CO_2 emissions.

Popper et al. (1999) compared species composition, vegetation structure (table 7), litter accumulation, and soil chemistry of three secondary forest stands on sites previously used as coffee plantations in the central mountains of Puerto Rico. All sites were on the subtropical moist forest life zone. The stand at Utuado was the youngest and had slightly higher stem density (1,680 stems/ha) and lower basal area (17.6 m^2/ha) than stands at Barranquitas (936 and 1,312 stems/ha and 40.9 and 38.7 m^2/ha for Barranquitas 1 and 2, respectively). They found a total of 41

Table 7—Structural parameters of vegetation in two secondary forests in the central mountains of Puerto Rico[a]

Variable	Barranquitas 1	Barranquitas 2	Utuado overstory	Utuado understory
Tree density (stems per ha)	936 (65)	1,312 (51)	1,680	2,670
Basal area (m^2 per ha)	40.9 (5.1)	38.7 (3.4)	17.6	1.7
Stems <10 cm (percent)	16	25	71	
Tree height (m)	11.5 (0.5)	10.9 (0.2)	9.4 (0.4)[b]	5.1 (0.1)[c]
Bole height (m)	5.3 (0.3)	4.9 (0.2)	—	—
Crown diameter (m)	5.2 (0.3)	6.2 (0.2)	—	—
Tree species per plot	20	28	17	21
Mean number of tree species per 100 m^2	4.0 (0.3)	5.7 (0.3)	—	—

— = data not available or not applicable.

[a] Plot areas were 0.25 ha for Barranquitas 1 and 2, and 0.10 ha for Utuado. Standard error is in parentheses for Barranquitas where n = 25 suplots. Diameter classes were ≥4 cm for overstory and <4 cm for understory.

[b] n = 168 trees.

[c] n = 267 trees.

overstory tree species on all stands combined, most of which were native (table 8). The understory at Utuado had six species not found in the overstory of the study stands. Barranquitas 1 and 2 had 20 and 28 tree species per 0.25 ha, whereas the Utuado stand had 17 tree species per 0.10 ha. The Barranquitas stands had greater species dominance and higher soil organic matter than the stand at Utuado. All stands had a high accumulation of litter on the forest floor (range of 10.7 to 16.5 Mg/ha), and all but Barranquitas 1 exhibited temporal fluctuation in the amount of litter on the ground. The presence of *Prestoea montana* in Barranquitas and its absence in Utuado suggests the Barranquitas sites are wetland sites. Soil chemistry

Table 8—Species importance values (in percentage) based on density and basal area

Status[a]	Species[b]	Barranquitas 1	Barranquitas 2	Utuado	Understory
n	*Prestoea montana*	43.11	48.06		
n	*Cecropia schreberiana*	12.68	7.77	8.70	
n	*Alchornea latifolia*	11.55	.36	5.93	6.26
n	*Cordia alliodora*	7.00	2.02		
n	*Inga laurina*	5.46		9.67	.29
n	*Ocotea sintenisii*	2.96	2.71		
n	*Inga vera*	2.56	1.06	2.75	.78
na	*Dendropanax arboreus*	2.34	.78		
n	*Citrus aurantium*	2.07			
en	*Sapium laurocerasus*	1.90	.16		
n	*Casearia sylvestris*	1.38	.64		
n	*Pisonia subcordata*	1.20			
n	*Myrcia deflexa*	.82	1.93		
n	*Guarea glabra*	.54	.47		
en	*Tetrazygia biflora*	.35	3.12		
na	*Citrus paradisi*	.27	.89		
n	*Cyathea arborea*	.22	6.33		
n	*Myrcia splendens*	.21	3.68	4.08	4.37
n	*Ilex nitida*	.21			
na	*Citrus aurantifolia*		3.98		
n	*Cordia sulcata*		3.80	2.83	.40
n	*Miconia laevigata*		3.35		
n	*Cedrela odorata*		1.14		
en	*Cyathea portoricensis*		1.09		
na	*Coffea arabica*		1.08	9.88	
en	*Tetrazygia urbanii*		.99		
na	*Senna siamea*		.89		
na	*Eugenia jambos*		.83	11.62	45.56
i	*Spathodea campanulata*		.70		
n	*Turpinia occidentalis*		.16		
en	*Tabebuia haemantha*		.15		
n	*Miconia prasina*			23.75	12.31
en	*Schefflera morototoni*			10.59	2.96
n	*Casearia arborea*			7.56	1.34
n	*Ocotea leucoxylon*			4.16	7.00
n	*Byrsonima coriacea*			4.78	.33
n	*Clusia rosea*			1.70	
n	*Andira inermis*			.86	1.59
n	*Miconia grandis*			.34	
n	*Meliosma herbertii*			.34	.61
en	*Eugenia stahlii*			.34	2.56
n	*Casearia guianensis*				1.07
n	*Palicourea barbinervia*				.88
n	*Miconia serrulata*				.76

Table 8—Species importance values (in percentage) based on density and basal area (continued)

Status[a]	Species[b]	Barranquitas 1	Barranquitas 2	Utuado	Understory
n	*Guarea trichilioides*				.41
n	*Solanum rugosum*				.34
n	*Palicourea riparia*				.32

[a] Species status codes are n = native, en = endemic, i = introduced, and na = naturalized.

[b] Species order is according to frequency importance values for Barranquitas 1, 2, and Utuado (U). Empty cells mean the species is not found on the site.

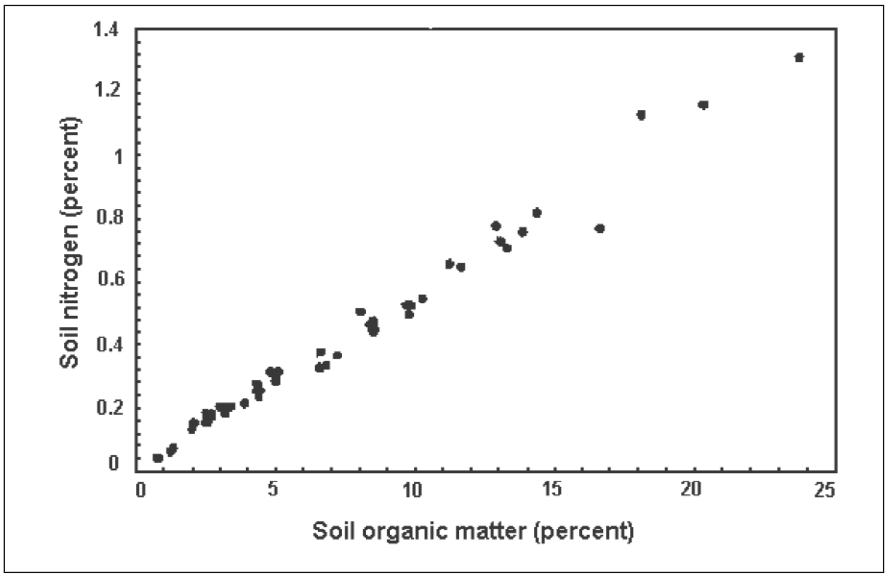

Figure 19—Relation between soil organic matter and soil nitrogen in a secondary forest at Barranquitas, Puerto Rico.

at all sites reflect nitrogen and organic matter-rich soils (fig. 19) in comparison with global averages for tropical forests. Stand structure and composition reflected past land use at both sites.

Lugo et al. (1999a) studied nutrient and organic matter dynamics associated with litter in a secondary forest that had developed some 60 years after the abandonment of coffee production at La Torrecilla sector of Barranquitas, Puerto Rico. The site was located at about 670-m elevation in the subtropical moist forest life zone. They measured the rate of litterfall and the return of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), aluminum (Al), iron (Fe), manganese (Mn), and ash by various litterfall components (leaves, wood, flowers and fruits, and miscellaneous) over a period of 994 days between December 1990 and June 1993. They also measured the accumulation of loose litter on the forest floor and the nutrient content of loose litter and topsoil (0 to 35 cm). The site had an annual rate of litterfall of 5.3 to 7.5 Mg/ha; an average annual nutrient return to the forest floor of 108, 4, 41, 90, 20, 1, 12, 7, and 546 kg/ha for N, P, K, Ca, Mg, Al, Fe, Mn, and ash, respectively; a standing stock of loose litter of 11 to 16 Mg/ha; an accumulation of nutrients in loose litter of 227, 7.7, 33, 166, 41, 73, 62, 3.5, and 1520 kg/ha for N, P, K, Ca, Mg, Al, Fe, Mn, and ash, respectively; an accumulation of 118 Mg/ha of soil organic matter; and 6701, 18, 152, 8320, 1396, 266, 319, and 345 kg/ha of N, P, K, Ca, Mg, Al, Fe, and Mn, respectively, in topsoil. Nutrient-use efficiency in litterfall tended to be low in secondary forests compared to plantations (table 9). Mast-year production of fruits had significant impact in nutrient return to the forest floor. Litterfall rates were lower than those of mature forests, but loose litter and nutrient return and accumulation values were all higher than observed for mature, secondary, and plantation forests in Puerto Rico. In the Luquillo Mountains, secondary forests have higher litterfall than mature forests (fig. 20). The forest at Barranquitas appears to be a nutrient and organic matter sink, and functions at low nutrient-use efficiency. This can result in the accumulation of nutrients and biomass on the forest floor of degraded sites.

Table 9—Nutrient-use efficiency in litterfall of various secondary forests and plantations in Puerto Rico

	N		P		K	
Site	**Leaf fall**	**Total**	**Leaf fall**	**Total**	**Leaf fall**	**Total**
			Secondary forests			
Guzmán	132	—	2,652	2,747	584	—
Cubuy	117	123	2,366	2,382	447	477
Sabana	66	69	1,329	1,310	434	490
El Verde	91	92	3,222	2,999	527	565
Guánica	—	—	—	—	—	—
Barranquitas	56	57	1,553	1,544	164	159
			Plantations			
Pine	198	134	4,997	4,153	974	992
Mahogany	82	92	140	163	537	611
Eucalyptus	165	—	—	5,100		

— = data not available.

Source: Lugo et al. 1999a.

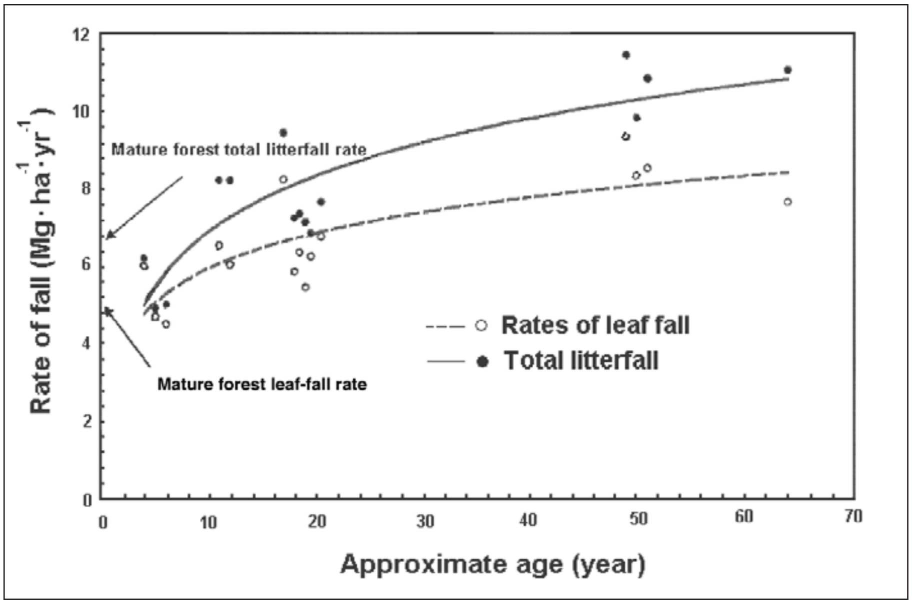

Figure 20—Rates of leaf fall (open circles) and total litterfall (solid circles) in secondary forests in the Luquillo Mountains of Puerto Rico. Data sources are given in Lugo et al. (1999b).

Tree Plantation Understories

It is commonly thought that alien species prevent the establishment of native species in plantations. Studies conducted in Puerto Rico and other parts of the world, however, have demonstrated the opposite (Lugo et al. 1999b). They studied the structure and species composition of the understory in nine plantations of alien species and in one of native species (*Hernandia sonora*) established adjacent to one another. The understories were studied in 1987 and 1998. Twenty of the eighty-three species observed were considerably abundant. The most abundant were *Palicourea riparia*, *Prestoea montana*, *Syzgium jambos*, *Schefflera morototoni*, *Maesopsis eminii*, and *Thespesia grandiflora*. Species planted in these plots grew very little in their own shade, with the exception of the native plantations. Understories were characterized by high dominance and great richness of native species with seven species endemic to Puerto Rico and three alien species. After cutting the understory and following the passage of two hurricanes, they observed changes in the parameters studied. Decreases in number of species and in stem density were found. The rate of species exchange increased dramatically, surpassing 100 percent in some plantations (table 10). The structure and composition of plantation understories are variable in time

Table 10—Change in the number of species in the understory of 10 tree plantations in the Luquillo Experimental Forest[a]

	Species in the understory[b]			
	1987	1999		
Plantation	Total	Total	New	Not found
Pinus caribaea	18	21[c]	14	11
Hibiscus elatus	18	31[d]	19	6
Pinus elliottii	23	15	8	15
Eucalyptus robusta	21	24	10	7
Khaya nyasica	19	19	8	8
Hernandia sonora	24	14	5	15
Anthocephalus chinensis	24	18	11	17
Swietenia macrophylla	22	10	5	16
Terminalia ivorensis	25	20	7	13
All plots	56	59	27	23

[a] The area sampled was 0.1 ha per plot except where otherwise indicated.
[b] Numbers may not add up because unknown species were not counted.
[c] Area sampled was 0.04 ha per plot.
[d] Area sampled was 0.02 ha per plot.

and space, but because of the limited scope of the sampling, it is difficult to generalize behavior as it responds to many environmental and biotic factors.

Mangrove Ecology

In 1988, Ruiz and Lugo (1999) remeasured 10 mangrove plots that had been established in 1984 in the Jobos Bay National Estuarine Research Reserve (table 11). They found three mangrove species in the overstory and two in the understory. *Rhizophora mangle* had the highest total tree density (live and dead trees) and total basal area. *Laguncularia racemosa* had the highest live basal area represented in a live tree density about one-third that of *Rhizophora*. We found no *Laguncularia* in the understory, which also was dominated by *Rhizophora*. *Laguncularia* was the most dominant species in terms of basal area and exhibited positive changes in basal area, tree density, and ingrowth. *Avicennia germinans* had a few trees in the overstory, a few seedlings in the understory, and no dead trees. Ingrowth trees were growing in diameter 2 to 14 times faster than trees tagged in 1984. We found more dead trees than live ones—owing mostly to *Rhizophora*, which had 1.6 times as many dead as live trees. *Laguncularia* had 2.4 times as many live as dead ones. *Rhizophora* had 1,029 live trees per/ha from the 1984 cohort and 1,429 ingrowth trees per/ha. Annual mortality rate ranged from 8.7 to 15.9 percent equivalent to a massive tree mortality. High salinity, normal stand thinning, and hurricane disturbance are the likely causes of the observed stand changes.

Table 11—Summary of tree data (number of trees) by plot, origin, and status of trees in the Jobos Bay National Estuarine Research Reserve

	1984 data			1998 data												
				Ingrowth in 1998			Trees tagged in 1984					Ingrowth + tagged				
Plot	Live	Dead	Total	Live	Dead	Total	Live	Dead	Total	Not found	HE[a] dead	Live	HE[a] dead	Dead[b]	HE[a] total	Total
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
1	38	3	41	0	17	17	0	5	5	33	38	0	55	22	55	22
2	21	1	22	0	7	7	0	9	9	12	21	0	28	16	28	16
3	27	2	29	1	2	3	10	11	21	6	17	11	19	13	30	24
4	24	0	24	2	2	3	24	2	26	0	2	26	4	4	29	30
5	25	1	26	3	2	5	11	6	17	8	14	14	16	8	30	22
6	13	0	13	13	3	16	6	2	8	5	7	19	10	5	29	24
7	12	3	15	3	10	13	0	8	8	4	12	3	22	18	25	21
8	26	3	29	0	7	7	0	3	3	23	26	0	33	10	33	10
9	20	0	20	0	6	6	3	9	12	8	17	3	23	15	26	18
10	42	0	42	9	3	13	20	15	35	7	22	29	25	18	55	47
Total	248	13	261	31	59	90	74	70	144	106	176	105	235	129	340	234

Note: The number in parentheses identifies columns. Trees tagged in 1984 and not found in 1998 were assumed dead. Plots 1 through 9 had an area of 50 m^2, and plot 10 had an area of 75 m^2. Estimates in columns 11 to 16 were as follows: 11 = 8 + 10; 12 = 4 + 7; 13 = 5 + 11; 14 = 5 + 8; 15 = 6 + 9 + 10; and 16 = 12 + 14.

[a] HE = high estimate.
[b] Confirmed dead.

Land Use Planning

Lugo et al. (2000) presented a zoning map of the lands surrounding the periphery of the Caribbean National Forest, also known as the Luquillo Experimental Forest, and locally known as El Yunque (fig. 21). The zoning displayed has been in force in accordance with the Special Zoning Rule for nonurban zones of the municipalities surrounding El Yunque. This rule went into effect on March 31, 1983, and was subsequently amended in 1991. The map covers approximately 76 000 ha and includes 21 zoning districts. The largest districts are agricultural (three districts), forest (two

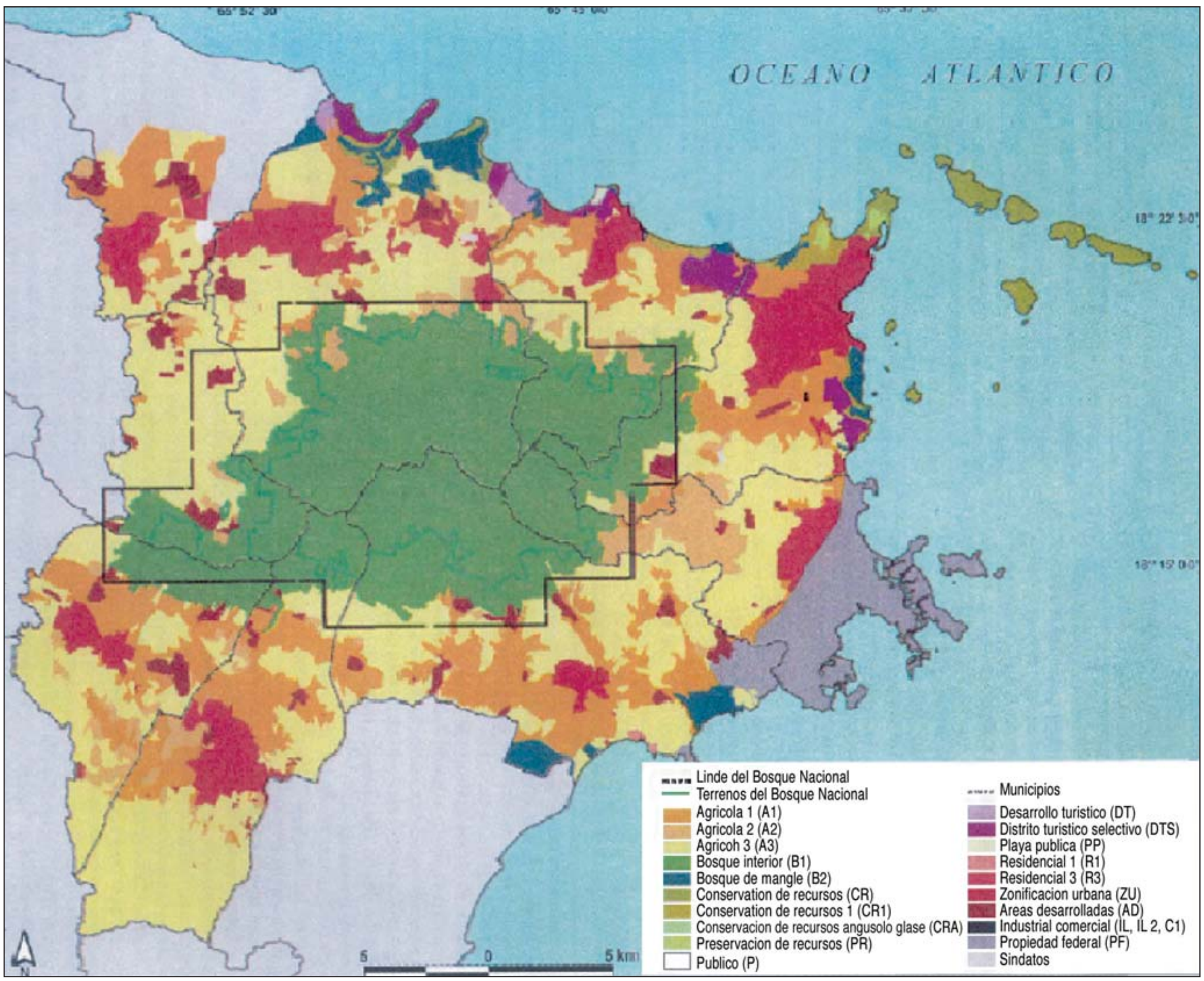

Figure 21—Special zoning map for nonurban zones for the municipalities surrounding the Caribbean National Forest. The national forest occupies the same area as the Luquillo Experimental Forest, locally known as El Yunque.

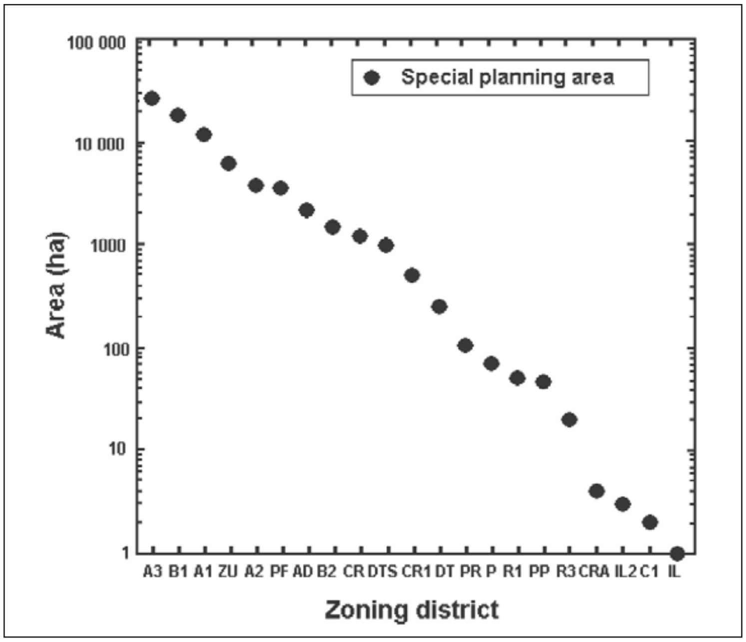

Figure 22—Area for 21 zoning districts in the El Yunque special planning region. The definitions for the codes can be found in Lugo et al. (2000).

districts), and those pertaining to urban zoning (fig. 22). Additionally, 7 percent of the region is zoned under conservation districts. This is a useful map for the municipalities surrounding the national forest in the development of their territorial ordinance plans and is also of great value for the conservation and protection of El Yunque. At the same time, it is an instrument by which the effectiveness of the Special Zoning Rule as a conservation mechanism in Puerto Rico can be monitored.

English Equivalents

When you know:	Multiply by:	To get:
Centimeter (cm)	0.394	Inches
Meters (m)	3.28	Feet
Kilograms per ha	0.893	Pounds per acre
Millibars (mbar)	0.0145	Pounds per square inch
Meters per second (m/s)	2.36	Miles per seconds
Square meters (m^2)	10.76	Square feet
Megagrams per hectare (Mg/ha)	.446	Tons per acre
Millimeters	.0394	Inches
Square meters per hectare (M^2/ha)	4.37	Square feet per acre
Trees (or stems) per hectare	.405	Trees per acre

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Watershed Research

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Research Hydrologist

Institute Facilities

The past year will be remembered as a year dedicated to construction and reorganization for the International Institute of Tropical Forestry (IITF) future. In Rio Piedras, construction crews worked daily to build the new laboratory annex at the site previously occupied by nursery planting boxes. In Sabana, high-speed computer lines, a local area computer network, and new air conditioning units, were installed. The year also marked the completion of building plans for the Sabana bunkhouse and woodshop and IITF conference center. A new Research Work Unit Description also was developed, and a Blue Ribbon Technical Advisory meeting was held to review the research program in late October. Finally, a complete reorganization of the IITF administrative unit was developed and is expected to be completed by the end of the calendar year.

Several new Ph.D. research projects also were initiated during the past year. Kerry Brown of SUNY-Stoney Brook initiated studies of the nonnative tree *Syzygium jambos* in the lower Luquillo Experimental Forest (LEF). This species grows frequently along streambanks in the Luquillo Mountains but, for the first time, seedlings and small saplings have been found in the Bisley vegetation plots within the watersheds. Along with nonnative bamboo, this species is clearly expanding its range into the watersheds and the Tabonuco forest.

During the year, Frisco Holwerda, a Ph.D. student at the Vriji University of Amsterdam, lived in the Sabana field station while he completed his first-year field campaign on the hydrology of the Luquillo Mountains. During this period, he installed a small gauging station on the headwaters of the Fajardo, and we hope to get the first complete water budget of the Luquillo cloud forests. Juan Felipe Blanco of the University of Puerto Rico also began his Ph.D. research on the migration of freshwater snails in Luquillo rivers. Initial estimates suggests that these snails may take from 4 to 6 years to migrate from the coast to Puente Roto. Jordan Macy and Bill McDowell of the University of New Hampshire also were able to complete the installation of their long-term nitrogen dynamics study in Bisley.

The year also will be remembered as the year that the magic of cinema came to the field station. Documentaries focusing on Luquillo research were produced by several well-known companies. Moreover, the British Broadcasting Company produced a new film on the nocturnal activities in the forest and aired their film on hurricane damage. The Weather Channel also produced and aired a film on the Luquillo cloud forests as part of their weekly series “Atmospheres.” Finally the weekly environmental program of the local educational channel, Canal 6, did a documentary on Rio Mameyes.

Research Progress

Understanding the ecological rhythms and patterns continues to be a unifying theme in our research. A common premise in modern forest management is that land management should operate over large enough spatial and temporal scales that common natural disturbances are present and implicitly considered. Less emphasis has been focused on adjusting the management of humid tropical forest ecosystems with the periodic ecological processes that occur between disturbances. The central premise of this approach is that timing management activities to the periodic ecological cycles or rhythms that occur between disturbances is an additional prerequisite for the effective management of humid tropical forests (Scatena 2001). Ecological rhythms are defined here as biological or biogeochemical processes that have definable periodicities and can operate at the level of individuals, populations, or communities. They are commonly related to climate (i.e., phenological patterns), daily processes (i.e., diel or circadian cycles), life histories (i.e., reproduction, feeding behavior, etc.) or physical and biogeochemical processes (i.e., tidal cycles).

Examples of managing with ecological rhythms is tabulated in tables 12 and 13. Although this type of dynamic management has proven benefits, managers and regulatory agencies have been hesitant to use complex, ecologically based dynamic management schedules because they can be difficult to monitor and regulate. Fortunately, recent technological advantages greatly increase the ability to conduct complex real-time, spatially explicit management. Continued effort will be placed on developing the understanding of these ecological rhythms to take advantage of these technological advances. For example, recent research on the life histories of freshwater shrimp in the area suggest that understanding their life histories is essential to managing to ensure their survival (Scatena and Johnson 2001). This study develops two habitat-based approaches for evaluating instream-flow requirements (ISF) within the LEF in northeastern Puerto Rico. The analysis is restricted to ISF requirements in upland streams dominated by the common communities of freshwater decapods.

Table 12—Examples of ecological rhythms used in natural resource management in the Luquillo Mountains of Puerto Rico

Ecological cycle or life history trait	Management objective	Management guidelines	Source
Annual reproductive cycle and daily foraging behavior	Protect endangered Puerto Rican Parrot	Limit management activity by season and time of day	Caribbean National Forest 1997, Snyder et al. 1987
Diurnal habitat preference	Define instream flow requirements for resident biota	Develop nighttime and daytime instream flow requirements	Johnson and Covich 1999
Diurnal and seasonal larval release	Maintain migratory aquatic biota	Restrict water withdrawals by night and season	Benstead et al. 2000
Weekly and seasonal recreational use patterns	Maintain aquatic recreation downstream of water intakes	Restrict water withdrawals during summer weekends	This paper
Diurnal and seasonal dissolved oxygen cycles	Minimize eutrophication by sewage plant effluent	Reduce releases during nighttime and low flow periods	This paper
Annual growth rates and light response	Improve timber yields	Selective thinning by density and species	Wadsworth 1997
Regeneration in natural tree fall gaps	Sustained timber resources	Harvesting that mimics natural gaps	Odum 1996
Annual phenology and response to canopy opening	Sustainable Mahogany plantations	Limit harvesting during seed set, thinning after canopy disturbances	Wang and Scatena 2003

Source: Scatena 2001.

Table 13—Examples of ecological rhythms and life history traits that can potentially be used in tropical forest management

Ecological rhythm or life history trait	Source	Ecosystem process or service	Management implications
Decadal mode in North Atlantic climate	Black et al. 1999	Climate, net productivity, disturbance regime	Disaster preparation, plantations, restoration efforts
Annual and decadal hurricane frequency	Gray et al. 1997	Climate, net productivity, disturbance regime	Disaster preparation, plantations, restoration efforts
Lunar cycles	Vogt et al. 2002	Plant growth, insect dynamics	Planting and harvesting
Coastal larval drift patterns	Schmidt 1997	Sustainable oceanic fisheries	Designing fisheries reserves to maintain supply of regional larval
Seasonal algal blooms in tropical lakes	James et al. 1996	Recreation and water supply	Reservoir and water supply operation
Riverine food web and population response to disturbances	Wootton et al. 1996, Johnson et al. 1998, Pringle et al. 1997	Sustainable fisheries	Fishing permits and limits
El Niño-La Niña cycles	Neeling et al. 1998, Curran et al. 1999, Woods 1989	Phenology, growth, fires, rains, droughts, etc.	Disaster preparation, harvesting, restoration efforts
Rift Valley Fever Epidemics	Linthicum et al. 1999	Sea-surface temperatures, rainfall and vegetation cover used to predict outbreaks	Health management
Malaria and dengue epidemics	Epstein 1999	Hurricane-related defoliation	Health management

Source: Scatena 2001.

In headwater streams, pool volume was the most consistent factor in predicting the abundance of freshwater shrimp; in second- and third-order tributaries, both water depth and velocity can be used to define the habitats. The most common species of shrimp are reclusive during the day, and at night they prefer areas of low velocity (< 0.09 m/s) and areas with water depths shallower than 0.4 m. In headwater streams, total usable shrimp habitat declines rapidly when water depth in the deepest pool is less than 0.5 m and or when discharges fall below 0.06 to 0.02 m/s. In second- and third-order tributaries, the amount of habitat declines rapidly when discharge is within one standard deviation of the average annual 7-day minimum flow. These discharges are typically exceeded between 95 and 99 percent of the time, that is Q95-Q99.

Analysis of habitat loss associated with different ISF constraints showed that habitat loss increases greatly when water extraction is equal to or greater than Q98. Among-reach differences in the amount of usable habitat resulting from differences in channel morphology can be 35 percent or more. Therefore, reach surveys should be site-specific when habitat preference relationships are used to define ISF levels for a particular area. The publication provides criteria for designing ISF requirements, and extraction schedules are provided.

English Equivalents

When you know:	Multiply by:	To get:
Meter (m)	3.28	Feet
Meter per second (m/s)	3.28	Feet per second

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Long-Term Avian Research

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Research Wildlife Biologist

Puerto Rican Parrot Restoration and Related Research

Cooperative research on thrashers (bird species) continues with Steven Beissinger and Mark Cook, professor and post doctoral candidate, respectively, of the University of California at Berkeley. In the intervening months between the 2000 and 2001 thrasher breeding seasons, the number of available nest boxes was almost doubled to increase potential sample sizes for the egg experiments. Curiously, given the increased number of available nest sites, the 2001 thrasher productivity was well below that of the 2000 season.

Reproductive Summary

In total, 226 eggs were laid in 74 nests during the 2001 breeding season: a decrease in egg production of 34 eggs (n = 260 in 2000) and an increase of only 2 nests in 2001 (n = 72 in 2000) although the number of available boxes was almost doubled. Although 83 eggs (37 percent) produced nestlings, hatching success also was lower for 2001, as 114 eggs (44 percent) hatched last season. Moreover, after excluding the number of new recruits into the breeding population, the next-most important reproductive parameter, percentage of nestlings fledged, dropped from about 30 percent to 15 percent. In short, the thrasher's overall 2001 reproductive success dropped by 50 percent from that of last year.

Although the experimental manipulations are unquestionably the major causative factor behind the observed diminution in hatching success and, albeit more indirect, in fledging success, the fact that there were only two additional nesting attempts even after the number of available nest sites was doubled suggests that the thrasher population has reached the carrying capacity of the colorado forest. As evidenced by constant saturation dispersal and ever-present "floaters" (unpaired individuals attempting to take over nest boxes) in the Icacos study area, insufficient food resources are limiting the number of new nesters. A 13-year analysis (fig. 23) of the number of pearly-eyes (*Margarops fuscatus*) in primary habitat (colorado forest, Icacos Valley) and in contemporary parrot (*Amazona vittata*) areas (tabonuco forest, El Verde) suggests that, after returning to prehurricane levels, the rain-forest thrasher population remains steady in both forest types, also

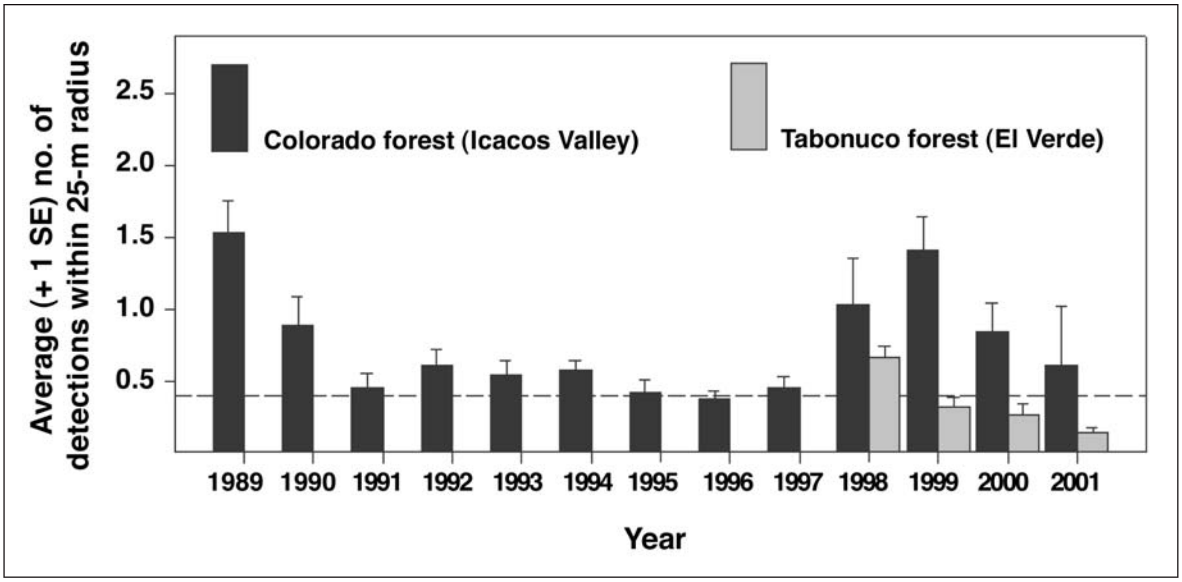

Figure 23—Thirteen-year analysis of the number of pearly-eyed thrashers (*Margarops fuscatus*) in primary habitat (colorado forest, Icacos Valley) and in contemporary parrot (*Amazona vittata*) areas (tabonuco forest, El Verde).

attesting to the fact that the thrasher population has not yet reached equilibrium in the rain forest.

Long-Term Studies in the Guánica Dry Forest

The annual mist netting and banding of Guánica's forest birds took place in January 2001, marking the 29th year of this long-term study of forest-bird populations. The 2001 data support the notion that populations of Nearctic-Neotropical migrants that winter in the forest continue to decline (Dugger et al. 2001). A 25-year analysis of the effect of rainfall on population levels and survival rates of resident and migratory birds resulted in strong correlations between population levels and total annual rainfall in addition to parameters associated with rainfall during the first 6 months of each year. The time-dependent survival model, constrained by deviations from normal in total annual rainfall and constant capture probability, was the best survival model for the frugivore data (Dugger et al. 2001).

From an historical perspective (Faaborg et al. 2001), the Guánica dry forest avian research has evolved from an early focus on patterns of abundance and community comparisons in both resident and winter resident species, to population trends (including notable declines), survival, longevity, and the invasion of two new species. Most recently, as a result of extensive damage to the forest by Hurricane Georges in 1998, we have begun analyzing the hurricane's effects on bird populations and survival.

English Equivalents

1 meter (m) = 3.28 feet

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Wildlife Research

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Wildlife

During fiscal year 2001, we continued four studies and supported various cooperative studies. The following are current ongoing major projects.

Effects of Low-Impact Logging on Birds and Bats

We continued our studies on birds and bats in the Tapajós National Forest, near Santarém in the Brazilian Amazon. These studies are designed to both inventory the diversity of birds and bats in the national forest and to determine the effects of low-impact selective logging on these two important taxa. The work is being conducted in cooperation with Michael Willig of Texas Tech University and researchers from the Emilio Goeldi Museum in Belém, Brazil. Field work was completed in July 2001, and data entry is still continuing.

Our current selective logging study is designed to compare bird and bat distribution in natural treefall gaps as well as gaps created by timber harvest. In addition, we are monitoring these taxa in the remaining forest understory to see how the forest understory fauna changes with selective logging. So far we have documented over 340 bird species and 55 bat species in the national forest. The bat survey work has resulted in one M.S. thesis summarizing the bat taxa of the forest, which was completed this fiscal year (Saldanha 2000). In the course of this work, Saldanha captured a fruit bat (*Artibeus* sp.), which had been previously banded at a site over 100 km away. This is a record movement for a tropical bat and indicates that some fruit bats may be moving greater distances in the Amazon basin than previously thought. Whether bats are actually transporting seeds this distance is unknown.

Saldanha's work was based on mist net captures and demonstrated that bat species richness was highest in the understory of mature undisturbed forest and lowest in secondary forest. Bat densities and species richness were lowest in forest openings, whether natural treefall gaps or gaps created by logging. It is apparent that most bats tended to avoid the forest openings, in contrast to birds that were abundant in small forest gaps. Such studies are beneficial for devising tropical logging and silvicultural methods that minimize biodiversity loss and ensure that animal seed dispersers remain on timber harvest sites to provide adequate seed dispersal.

Movements, Home Range, and Habitat Use by the Endangered Puerto Rican Boa (*Epicrates inornatus*) in the Luquillo Experimental Forest (LEF)

This study is based on surgically implanted radio transmitters that enable us to use radiotelemetry to locate and follow snakes in the LEF. The locations where the radio-tagged snakes are found by telemetry are mapped by the use of a global positioning system, which allows us to quantify distances moved and determine the size of a boa's home range. Field work was completed in June 2001 when the batteries expired in the transmitters of the last two snakes in the wild. Data accuracy is currently being checked, and analysis will begin in the next fiscal year.

Phenology of Some Common Tree and Vine Species That Produce Fruits Consumed by the Puerto Rican Parrot

We have now completed the 5th year of this phenology study designed to monitor fruit production of some of the common tree and vine species with fruits and seeds important to the endangered Puerto Rican parrot (*Amazona vittata*). The study involves monthly sampling along two trails in the palo colorado forest of the LEF and has characterized phenologies for 2 years prior to Hurricane Georges and 3 years of recovery in the storm's aftermath. This work is not only valuable for characterizing variation in the food supply for the parrot but will allow us to better understand the timing of breeding in the parrot and pearly-eyed thrasher (*Margarops fuscatus*), both species with breeding seasons that may be synchronized with fruiting phenologies.

A Review of the Puerto Rican Parrot and Its Recovery, 1973-2000

I am currently working with participants from the Puerto Rican parrot workshop, which we sponsored in 1995, and others involved in the recovery effort to summarize and evaluate the parrot's population biology and the overall success of the recovery effort. The goal of the project is to identify critical research needs and areas in which increased management intervention could increase population growth rate.

A major concern facing the Puerto Rican parrot recovery effort is the risk of genetic difficulties resulting from the random loss of genetic diversity, genetic drift, and increased homozygous expression of lethal and deleterious genes. Given that the wild Puerto Rican parrot population has remained less than 50 birds for over 30 years and only 6 or fewer pairs actually breed, it is reasonable to expect genetic problems. One of the first places to expect the appearance of such genetic difficulties in the parrot is in the hatchability of eggs. Hatchability of eggs is defined as the percentage of eggs that successfully produce chicks and excludes eggs lost to predation, accident, abandonment, or nest damage.

My analysis of the eggs of 32 wild Puerto Rican parrot pairs indicates that egg hatchability averages 72.6 percent ± 5.4 SE of the eggs per pair over the course of the recovery effort (1973-2000). This value falls below the mean of 90.6 percent hatchability found in 155 populations of a variety of bird species, and the slightly lower mean (88.7 percent) for cavity nesters (Koenig 1982). The Puerto Rican parrot rate also contrasts with the high hatchability (100 percent) of wild Hispaniolan parrot (*Amazona ventralis*) eggs reported by Snyder et al. (1987). It is unknown how much of the relatively low hatchability of wild Puerto Rican parrot eggs is attributable to genetic factors or environmental factors in the colorado forest, such as high-humidity nest sites. However, it should be noted that pearly-eyed thrashers using nest boxes in the colorado forest had an egg hatchability of 83 percent (Arendt 2000).

Puerto Rican parrot egg hatchability per pair has been highly variable over the course of the recovery effort partly reflecting egg hatchability differences among pairs. Mean egg hatchability per pair fell to its lowest level in 1984, when both the West Fork and East Fork pairs produced eggs that failed to hatch and the other pairs produced eggs with low hatchability (20 to 67 percent). Despite this decline in egg hatchability per pair, overall egg hatchability per pair has not changed significantly ($P > 0.50$) from the early years of the recovery effort (1973–1985, median = 80.0 percent) to the more recent period (1990-2000, median = 84.6 percent). Although the relatively low hatchability of wild Puerto Rican parrot eggs is of concern as a potential indication of genetic problems, there appears to be little evidence as yet for widespread genetic difficulties in the wild. Nor is there evidence over the 1973 to 2000 period for declining trends in reproductive measures that could indicate potential genetic problems, such as egg hatchablity, egg fertility, embryonic mortality, or chick developmental problems.

Publications During Fiscal Year 2001

Three publications by cooperators appeared in this period. As previously mentioned, Saldanha (2000) completed his Masters thesis summarizing the bat diversity and distribution in the Tapajós National Forest, Brazil. Modeling simulations by Thompson (2000) indicated that nesting areas for the Puerto Rican parrot are in decline in the colorado forest and that the tabonuco forests of the lowlands will be most suitable for nesting trees. In addition, Thompson's modeling simulations based on fruit abundance and phenology indicate that the LEF can support 8,608 parrots and 1,076 breeding pairs. Finally, Lee and Walsh-McGehee (2000) reviewed the population estimates for white-tailed and red-billed tropicbirds (*Phaethon lepturus* and *P. aethereus*, respectively) of the western Atlantic and made conservation recommendations in light of evidence for substantial population declines in the region, especially in white-tailed tropicbirds.

English Equivalents

1 kilometer (km) = .6215 miles

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International Cooperation and Research Activities

Peter L. Weaver
Research Forester

International Cooperation

The International Cooperation (IC) staff was involved in numerous activities during the year. A slide program entitled "The San Lorenzo Protected Area: Panama's Caribbean Treasure" was completed and is currently being reviewed by the Panamanian government. San Lorenzo lies within the Fort Sherman complex that reverted to Panama along with other Canal Zone properties during 1999. Also, the June 4-7, 2001, PROARCA Round-up of the United States Agency for International Development (USAID) activities in Central America was attended with special interest in establishing contact with individuals and groups involved in conservation projects.

The Dominican Republic was visited in July to review the newly adopted forestry regulations and the proposed Sabana Clara forest management plan developed for the upper reaches of the Artibonito River. Several suggestions were made to broaden the plan in accordance with the new norms. Moreover, two studies conducted in the forests of the Dominican Republic were completed and reviewed. The first dealt with the ecological aspects and distribution of *Juglans jamaicensis* C.DC., and the second concerned natural regeneration in dry community forests. Both will be edited and published in the future.

The IC was represented at the FAO's (Food and Agriculture Organization of the United Nations) "expert consultation on private forestry programs" organized by Claus Martin-Ecklemann and held in Trinidad during August. The IC talk concerned Puerto Rico's secondary forests that require either forest management or enrichment (line planting) to improve the their long-term productive potential. The institute's experience in line planting mahogany on the degraded lower slopes of the Luquillo Mountains was reviewed. Many Antillean islands can expect a situation similar to that of Puerto Rico when farming and grazing activities are abandoned.

Other IC activities included a talk on line planting to Earthwatch participants during their visit to Puerto Rico. They were measuring mahogany trees planted nearly 15 years ago near the Guavate Forest. The IC also hosted Mário Jorge da Silva Fadell, the Coordinator of Extractive Activities in Acre, Brazil.

Research

No papers were published this fiscal year. As with previous annual letters, a brief discussion of research results will be delayed until the papers are published. In the interim, a brief outline of major research activities during fiscal 2001 follows:

- 5th urban forestry conference: Two papers were presented and submitted as part of the St. Croix proceedings, yet to be published.
- Colorado forest monitoring. The results of a thinning conducted in the mid-1940s were analyzed and accepted for publication.
- Tinaja ordination. Data from 109 plots in the Tinaja section of Sierra Bermeja were organized in matrices for analysis.
- Tabonuco forest monitoring. A 55-year summary of growth and change in species composition on tabonuco ridge plot TR-1 is currently being peer reviewed.
- Dwarf forest monitoring. A 10-year recovery of dwarf forest after Hurricanes Hugo and Georges is being analyzed.
- Mombacho Volcano, Nicaragua: A paper describing the volcano's environmental conditions and current research and management activities was submitted for journal review.
- Sixth urban forestry conference: A poster entitled "Hurricanes: Puerto Rico and Continental Areas" was presented at the 6th urban forestry conference held in San Juan.
- Luquillo Forest ordination: From mid-January to mid-April, 30 new plots were located in the dwarf, palm, and tabonuco forest types in the Luquillo Experimental Forest. Additional plots are required. Once plot data collection is completed, information will be analyzed for trends as part of several species-site ordinations.

State and Private Forestry Accomplishments

Terry W. Hoffman
Forester

State and Private Forestry in the U.S. Virgin Islands

The cooperative programs are administered and implemented through a partnership between the government of the U.S. Virgin Islands (USVI), the USDA Forest Service, and many other private and government entities. These programs promote the health and productivity of the USVI's forest lands and rural economies (table 14). Emphasis is on timber and other forest products, wildlife, water resources, rural economies, and conservation practices. The goal is to maintain and improve the health of urban and rural forests and related economies. These programs:

- Reduce costs through the use of partnerships.
- Increase values through sustained productivity of forests.
- Facilitate synergism between traditional and nontraditional partners.
- Are voluntary and nonregulatory in their delivery.

Table 14—Investment in the U.S. Virgin Islands Cooperative Programs

Program	Federal funds	Match funds	Total funds
		Dollars	
State Fire Assistance	60,000	0	60,000
Coop. Lands Forest Health	0	0	0
Economic Action Programs	0	0	0
Title VIII Forest Legacy	0	0	0
Forest Legacy	40,000	13,420	53,420
Forest Stewardship	40,000	40,000	80,000
Title VIII State Fire Assist.	40,000	0	0
Title VIII Vol. Fire Assist.	30,000	0	30,000
Title IV Surveys	0	0	0
Title VIII Urban and Community Forestry	20,000	20,000	40,000
Urban and Community Forestry	203,024	203,024	406,048
Volunteer Fire Assistance	8,000	0	8,000
Total	441,024	276,444	717,468

Key issues that the territory addressed in implementing the 2001 budget were:

- Urbanization and sprawl into natural areas.
- Ecological restoration of natural and built-up areas.
- Soil protection and watershed management.
- Sustainable urban forestry program.
- Creation of jobs and income from natural resource-based opportunities.

The USVI has 5594.3 ha of privately owned forest land and 56.7 ha of experimental forest (table 15). Of the estimated 1,000 individuals owning forest lands, most have parcels of less than 8.1 ha. Almost all of these landowners report that agriculture and aesthetics are primary reasons for owning forest land. The territory's 150,000 people include 44 communities with populations over 100; 41 percent of these have initiated some level of community forestry program.

Table 15—Forest facts and accomplishments for the U.S. Virgin Islands

Selected facts		Selected results	
Population	60,702.86	Stewardship plans prepared (current year)	7
Hectares of forest land	8629.5	Hectares under stewardship plans (current year)	219.7
Hectares of nonindustrial private forest land	5594.4	Hectares under stewardship plans (all years)	465.0
Hectares of private land under state fire protection	5594.4	Rural hectares planted	68.0
Number of rural fire departments	0	Technical assists to private landowners	186
Number of cities and towns	44	Cities and urban areas assisted	25
Forest-based employment	None	Firefighters trained	0
Forest-based earnings	Minimal	Hectares surveyed for forest health	5594.4

Program Highlights

Urban and Community Forestry

The Virgin Islands Urban and Community Forestry Council was reorganized during the year with new members from all three of the major islands. The Virgin Islands Department of Agriculture was active in soliciting challenge cost-share proposals for urban and community forestry projects and awarded grants to 17 project proponents totaling $139,730. The council also adopted a 5-Year Comprehensive

Strategic Plan for Urban Forestry in the Virgin Islands. The program is gaining momentum, and financed projects inspire hope in the community for an improved urban forestry environment.

Cooperative Fire Protection

The entire territory can be classified as an urban/wildland interface. In this island environment, there are very few rivers, no lakes, limited human-made ponds, and a limited number of fire hydrants. Variable trade winds, fuel buildup associated with dry tropical forests, narrow and steep roads, and difficult building entrances all combine to create a wildfire challenge. During the year, the Fire Service contracted for basic wildland fire training for all of its employees. The emphasis on the program is to have trained firefighters with proper safety equipment and clothing. Consideration is also being given to the potential for developing dry hydrant installations in freshwater ponds for additional water sources. National Fire Program funds are available in both State Fire Assistance and Volunteer Fire Assistance to improve firefighting capability, along with implementing stronger fire prevention and Fire Wise home protection programs.

Forest Stewardship

Matching natural resource professionals with farmers and other landowners is expanding the vision for forest stewardship opportunities in the territory. Recognizing the importance of protecting habitat for wildlife, soil for water quality, and aesthetics for tourism and economic development changes the way people view the opportunities and their responsibility for a healthier island. The accomplishments in the program are growing slowly as landowners begin to realize the need to actively manage their lands for the overall health of the island environment. Seven new plans were prepared during the year, with all of these being done for St. Croix. There is a recognized need to expand the program to St. Thomas and St. John as well. A highlight of the Stewardship Program has been the completion of the Southgate Pond Watershed Assessment and Draft Management Plan. The St. Croix Environmental Association took the lead in working with the many landowners within the watershed to develop a management plan to improve water quantity and quality within this basin. Once this prototype plan is completed, emphasis will be on implementation of the recommendations, and then expanding the planning process to other watersheds in the Virgin Islands.

Forest Health Protection

The pink hibiscus mealybug, *Maconellicoccus hirsutus* (Green), has infested all of the islands of St. Croix, St. Thomas, and St. John. Additional damage to the tree resource is occurring from bark beetles, aphids, white flies, caterpillars, wilt, shoot borers, hurricanes, and construction stress. Lack of an organized governmental tree care policy or land use planning allows tree removal without replacement, and improper or neglected care of trees on public lands.

Economic Action

The Virgin Islands Resource Conservation and Development Council is an active partner in delivering the economic action program. Supporting the existing resources for helping established and newly developed business, the Council strives to increase job and income opportunities that utilize the islands" natural resources. The Council did award a grant to the Virgin Islands Department of Justice, Bureau of Corrections called the Golden Grove Wood Craft Project. The goal of the project is to teach inmates at the Golden Grove Adult Correctional Facility how to create products made of wood and to hand paint these products. The intent is to teach skills that will allow the inmates to become self-sufficient upon release through the practice of creating and selling woodcrafts. During detention, the crafts will serve as a therapeutic hobby and help improve their self-esteem.

Natural Resource Conservation Education

The Virgin Islands ReLeaf Program addresses the territory's need for new tree planting, tree care information, and education. The Virgin Islands ReLeaf provides trees for schools, benefiting 2,000 students annually. The Trees for Schools program teaches students the benefits of trees and their proper care, thus encouraging greater pride in the schools and the islands. The Forest Service Conservation Education Program is being refocused to coordinate through the St. Croix Environmental Association Conservation Education Coordinator for the distribution of materials and curriculum guides, such as the "Natural Inquirer."

Forest Legacy

The goal of the Forest Legacy Program (FLP) is to effectively protect and conserve environmentally important forest areas that are threatened by conversion to nonforest uses. This is a voluntary land conservation program between the USDA Forest Service, state or territorial governments, land trusts, and private landowners. The program uses fee acquisition or conservation easements to protect these lands forever. The U.S. Virgin Islands will consider joining this program in 2002. The first step in making this decision is to prepare an assessment of need. This study and resulting document, evaluates the present forest resources, the values of these forests, and the threat to this resource from conversion to other land uses. Based on this analysis and the resulting public involvement, the Governor of the Virgin Islands will make a decision on participation and will designate forest legacy areas if this tool is accepted for use. A grant has been given to The Nature Conservancy to conduct this assessment for the Commissioner of the Virgin Islands Department of Agriculture.

State and Private Forestry in Puerto Rico

The cooperative programs are administered and implemented through a partnership between the government of Puerto Rico, the USDA Forest Service, and many other private and government entities. These programs promote the health and productivity of Puerto Rico's forest lands and rural economies (table 16). Emphasis focuses on timber and other forest products, wildlife, water resources, rural economies, and conservation practices. The goal is to maintain and improve the health of urban and rural forests and related economies. These programs:

- Reduce costs through the use of partnerships.
- Increase values through sustained productivity of forests.
- Are voluntary and nonregulatory in their delivery.

Key issues that Puerto Rico addressed in implementing the 2001 program were:

- Rapid urbanization and sprawl into natural areas.

Table 16—Investment in Puerto Rico's cooperative programs

Program	Federal funds	Match funds	Total funds
		Dollars	
State Fire Assistance	80,000	80,000	160,000
Coop. Lands Forest Health	29,000	29,000	58,000
Economic Action Programs	34,000	14,000	48,000
Title VIII Forest Legacy	399,120	133,040	532,160
Forest Legacy	992,830	330,943	1,323,773
Forest Stewardship	292,430	292,430	584,860
Title VIII State Fire Assistance	37,000	37,000	74,000
Title IV Surveys	40,000	30,000	70,000
Title VIII Urban and Community Forestry	39,856	39,856	79,712
Urban and Community Forestry	270,000	240,000	510,000
Volunteer Fire Assistance	25,000	25,000	50,000
Totals	2,239,236	1,251,269	3,490,505

- Water quality, including storm-water runoff, and restoration of natural areas.
- Soil protection and watershed management.
- Sustainable urban forestry programs at the local level.
- Creation of jobs and income from using natural-resource-based opportunities.

Puerto Rico has 287 394 ha of forest land, of which 43 599 ha is in public ownership, including the 11 331 ha in the Caribbean National Forest. Of the 368,000 individuals owning forest lands, most have parcels of less than 8.1 ha. Almost all of these landowners report that conservation, aesthetic enjoyment, and recreation are primary reasons for owning forest land. The Commonwealth's 3.8 million people include 78 municipalities. All have initiated some level of community forestry program (table 17).

Table 17—Forest facts and 2001 accomplishments for Puerto Rico

Selected facts		Selected results	
Population	3.8 million	Stewardship plans prepared (current year)	31
Population density, people per square mile	1,000	Hectares under stewardship plans (current year)	413
Percentage of protected lands	5%	Stewardship plans prepared (all years)	69
Hectares of forest land	287,394	Hectares under stewardship plans (all years)	780
Hectares of nonindustrial private forest land (NIPF)	240,795	Technical assists to private landowners	455
Number of NIPF landowners	368,668	Firefighters trained	105
Number of tracts in Forest Legacy Program	9	Number of Forest Legacy tracts acquired (current year)	3
Total hectares of Forest Legacy tracts	578	Hectares of Forest Legacy tracts acquired (current year)	112
Hectares of federal land under state fire protection	0	Hectares surveyed for forest health	4047
Hectares of private land under state fire protection	889,661	Forest health assistance visits	43
Number of rural fire departments	0	Cities and towns assisted	78
Number of municipalities	78	Economic Action Grants to rural areas	0

Program Highlights

Urban and Community Forestry

The 6th Urban and Community Forestry conference was held in San Juan in June. One hundred attended the 2-day conference titled “Trees and Hurricanes.” The International Society of Arboriculture (ISA) gave an additional day of urban forestry training to another 25 attendees. The Sustainable Forestry Initiative Challenge Grant Program continues to provide grants to local communities and organizations for community forestry projects. A total of $125,000 was added to the program for new projects. Five new projects were evaluated and are being funded. A major project has been the initiation of an urban forest resource inventory of the urban forest in the municipalities of the San Juan Basin. These data will be used with a computer model to evaluate the effects of the vegetation to the urban environment. Communities being inventoried are San Juan, Carolina, Cataño, and Loiza.

Cooperative Fire Protection

An analysis was completed for the 1999 fire season to help guide fire program investments to areas with the highest fire risk and hazard. The report will be the basis for allocations to implement the National Fire Plan strategies. A second analysis is being done to look at the organization of wildland firefighting resources and to determine areas needing improved interagency cooperation to develop an efficient incident command system. Funding is available to the “Bomberos” to implement organizational efficiencies, to outfit and train crews in wildland firefighting, and for the purchase of supporting equipment. National Fire Program funds are available in both State Fire Assistance and Volunteer Fire Assistance to improve firefighting capability, along with implementing stronger fire prevention and Fire Wise home protection programs.

Forest Stewardship

The program has continued to grow with an increase in the number of stewardship plans prepared for individual forest landowners. In total, 31 plans were prepared, and 12 of these were contiguous to each other along the Rio La Plata. By focusing on a contiguous area within one watershed, the cumulative impacts of improvements in management are more significant. To this date, 69 plans totaling 779.8 ha have been prepared. Three watershed projects were funded through the Sustainable Forestry Initiative. The U.S. Department Agriculture Forest Service National Nursery Team conducted a review of Commonwealth, Department of Transportation, and private nurseries. An action plan was then prepared to address the findings from this review. This plan addresses the needed changes to improve the quality of planting stock on the island. An emphasis has been placed on inventorying and protecting the karst region of northern Puerto Rico. Numerous agreements have been made among federal and commonwealth agencies and nonprofit organizations that have resulted in ongoing survey and mapping work, along with land protection through FLP. The USDA Forest Service General Technical Report WO-65, *Puerto Rican Karst—A Vital Resource*, was published in both English and Spanish. This publication is a complete treatise of the karst region. Work is being done to develop digital versions of historical land use/land cover maps of Puerto Rico, with an emphasis on the karst region. The original maps were produced from 1951 aerial photos. Digitizing these maps into a geographic information system will permit their integration with more recent data to help identify old forest patches that may have higher ecological integrity, and to map forest age classes.

Forest Health Protection

During the year, technical assistance was provided to 43 individuals or nurseries, and 4046.9 ha were surveyed for forest health. The University of Puerto Rico-Mayaguez Cooperative Extension Service staff maintains the database listing pesticides available for the control of pests common to forests, shrubs, palms, urban trees, and ornamental woody plants. The Plant Disease Diagnostic Clinic is updating the index record of common pests of all woody species as well. The publication *Enfermedad del Anillo Rojo de las Palmas* (red ring disease) was completed and mailed to agricultural agents and Department of Natural Resources nurseries. Twenty-five samples of shrubs and trees were processed in the Diagnostic Plant Clinic for pest identification with an impact of approximately $5,000 saved on the use of pesticides. Integrated pest management recommendations were made for each of the 25 samples processed.

Economic Action

Three subgrants have been approved as a part of the Sustainable Forestry Initiative. These will address the development of cultivation and trading of aromatic and medicinal trees; the use of small-diameter wood and waste wood products; and the development of a Recreation Opportunity Spectrum poster and field guide for Puerto Rico. Agriculture Handbook No. 205, *Puerto Rican Woods, Their Machining, Seasoning and Related Characteristics* by Franklin Longwood has been reprinted in both English and Spanish and is now available through the IITF Library, or electronically on the IITF Web page.

Natural Resource Conservation Education

A new memorandum of understanding was signed by the University of Puerto Rico, the Puerto Rico Department of Education, and IITF to facilitate continued cooperation in the conservation education to support the Long-Term Ecological Research (LTER) being done by six high schools. Scientific equipment worth $17,000 was distributed to the six schools in recognition of the expanded program they are providing. This was done in partnership with the University of Puerto Rico and the National Science Foundation. The results of previous LTER projects by the students were published in *Acta Cientíica*.

Forest Legacy

The goal of the Forest Legacy Program is to effectively protect and conserve environmentally important forest areas that are threatened by conversion to non-forest uses. This is a voluntary land conservation program between the USDA Forest Service, Puerto Rico Department of Natural and Environmental Resources (DNER), land trusts, and private landowners. The program uses fee acquisition or conservation easements to protect these lands forever. This year, the DNER closed on three cases totaling 112.1 ha in the Guanica Forest Legacy Area. These acquisitions are now part of the Guanica State Forest and Biosphere Reserve. These lands are important for the protection of habitat for six endangered species, scenic quality, and recreation use. The total protected area under the FLP now includes nine tracts totaling 578.3 ha. In fiscal year 2001, the commonwealth received $1.3 million for 445.2 ha of new acquisitions within the karst area of the Caonillas-Dos Bocas Forest Legacy Area. Work is continuing on these projects, which will be completed in 2002.

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Appendix 1: Recent Publications of the IITF, 2000-2001

Beldini, T.P. 2000. An analysis of internode variation in Sierra palm (*Prestoea montana*) of the Luquillo Mountains of Puerto Rico. Syracuse, NY: State University of New York, College of Environmental Science and Forestry. 104 p. M.S. thesis.

01 **Benstead, J.P.; March, J.G.; Pringle, C.M. 2000.** Estuarine larval development and upstream post-larval migration of freshwater shrimps in two tropical rivers of Puerto Rico. Biotropica. 32(3): 545-548.

Buzby, K.M. 1998. The effect of disturbance on the ecological efficiency of a small tropical stream. Syracuse, NY: State University of New York, College of Environmental Science and Forestry. 166 p. Ph.D. thesis.

Clark, J.J.; Wilcock, P.R. 2000. Effects of land-use change on channel morphology in northeastern Puerto Rico. GSA Bulletin. 112(12): 1763-1777.

Conway Oren, D.; Pinto Henriques, L.M. 2000. Distribucao de aves em areas de retirada seletiva de madeira na floresta nacional do Tapajos. Relatorio final. Belem, Para, Brazil: Museu Paraense Emilio Goeldi, Departamento de Zoologia. 78 p.

02 **Covich, A.P.; Crowl, T.A.; Scatena, F.N. 2000.** Linking habitat stability to floods and droughts: effects on shrimp in montane streams, Puerto Rico. Verh. Internat. Verein. Limnol. 27: 1-5.

Crill, P.M.; Keller, M.; Weitz, A.; Grauel, B.; Veldkamp, E. 2000. Intensive field measurements of nitrous oxide emissions from a tropical agricultural soil. Global Biogeochemical Cycles. 14(1): 85-95.

Davidson, E.A.; Keller, M.; Erickson, H.E.; Verchot, L.V.; Veldkamp, E. 2000. Testing a conceptual model of soil emissions of nitrous and nitric oxides. BioScience. 50(8): 667-680.

Epting, J. 2001. Hydrological processes in a humid tropical rainforest—through-fall: quantity and required instrumentation. Freiburg, Germany: Institute of Hydrology. 26 p.

03 **Erickson, H.E.; Keller, M.; Davidson, E.A. 2001.** Nitrogen oxide fluxes and nitrogen cycling during postagricultural succession and forest fertilization in the humid tropics. Ecosystems. 4: 67-84.

04 **Francis, J.K. 2000.** Estimating biomass and carbon content of saplings in Puerto Rican secondary forests. Caribbean Journal of Science. 36(3-4): 346-350.

05 **Francis, J.K.; Lowe, C.A. 2000.** Bioecologia de arboles nativos y exoticos de Puerto Rico y las Indias Occidentales [Silvics of native and exotic trees of Puerto Rico and the Caribbean Islands], Salvador Trabanino, translator. Gen. Tech. Rep. IITF-15. Rio Piedras, PR: International Institute of Tropical Forestry. 582 p.

06 **Gonzalez, G.; Ley, R.E.; Schmidt, S.K.; Zou, X.; Seastedt, T.R. 2001.** Soil ecological interactions: comparisons between tropical and subalpine forests. Oecologia. 128: 549-556.

07 **Gonzalez, G.; Seastedt, T.R. 2001.** Soil fauna and plant litter decomposition in tropical and subalpine forests. Ecology. 82(4): 955-964.

08 **Guariguata, M.R.; Ostertag, R. 2001.** Neotropical secondary forest succession: changes in structural and functional characteristics. Forest Ecology and Management. 148(1-3): 185-206.

Heyne, C.M. 1999. Soil and vegetation recovery on abandoned paved roads in a humid tropical rain forest, Puerto Rico. Las Vegas, NV: University of Nevada, Las Vegas. 151 p. M.S. thesis.

Keller, M.; Lerdau, M. 1999. Isoprene emission from tropical forest canopy leaves. Global Biogeochemical Cycles. 13(1): 19-29.

Keller, M.; Rocha, H.; Trumbore, S.; Kruijt, B. 2001. Investigating the carbon cycle of the Amazon forests. Global Change Newsletter. 45(March): 15-18.

Kent, R.; Odum, H.T.; Scatena, F.N. 2000. Eutrophic overgrowth in the self-organization of tropical wetlands illustrated with a study of swine wastes in rainforest plots. Ecological Engineering. 16(2): 255-269.

Lee, D.S.; Walsh-McGehee, M. 2000. Population estimates, conservation concerns, and management of tropicbirds in the Western Atlantic. Caribbean Journal of Science. 36(3-4): 267-279.

Linde, te, A.H.; Bruijnzeel, L.A.; Groen, J.; Scatena, F.N.; Meijer, H.A.J. 2001. Stable isotopes in rainfall and fog in the Luquillo Mountains, eastern Puerto Rico: a preliminary study. In: Schemenauer, R.S.; Puxbaum, H., eds. Proceedings of the second international conference on fog and fog collection. Ottawa, Canada: International Development Research Centre: 181-184.

09 **Little, E.L., Jr.; Feheley, J.B. 2001.** New world trees (excluding Canada and the United States): a selected bibliography for identification. Gen. Tech. Rep. IITF-GTR-19. Rio Piedras, PR: U.S. Department of Agriculture, Forest Service, International Institute of Tropical Forestry. 59 p.

Liu, S.; Reiners, W.A.; Keller, M.; Schimel, D.S. 1999. Model simulation of changes in N_2O and NO emissions with conversion of tropical rain forests to pastures in the Costa Rican Atlantic Zone. Global Biogeochemical Cycles. 13(2): 663-677.

Liu, S.; Reiners, W.A.; Keller, M.; Schimel, D.S. 2000. Simulation of nitrous oxide and nitric oxide emissions from tropical primary forests in the Costa Rican Atlantic Zone. Environmental Modelling and Software. 15: 727-743.

Lopez, T.M.; Aide, T.M.; Thomlinson, J.R. 2001. Urban expansion and the loss of prime agricultural lands in Puerto Rico. Ambio. 30(1): 49-54.

10 **Lugo, A.E.; Miranda Castro, L.; Vale, A.; Lopez, T.M.; Hernandez Prieto, E.; Garcia Martino, A.; Puente Rolon, A.R.; Tossas, A.G.; McFarlane, D.A.; Miller, T.; Rodriguez, A.; Lundberg, J.; Thomlinson, J.; Colon, J.; Schellekens, J.H.; Ramos, O.; Helmer, E. 2000.** Puerto Rican karst–a vital resource. Gen. Tech. Rep. WO-65. Washington, DC: U.S. Department of Agriculture, Forest Service. 99 p.

11 **Lugo, A.E.; Lopez, T.M.; Ramos, O.M. 2000.** Zonificación de terrenos en la periferia de El Yunque. Gen. Tech. Rep. IITF-16. Rio Piedras, PR: U.S. Department of Agriculture, Forest Service, International Institute of Tropical Forestry. 12 p.

Lugo, A.E. 2000. Effects and outcomes of Caribbean hurricanes in a climate change scenario. The Science of the Total Environment. 262: 243-251.

12 **Lugo, A.E. 1999.** Metodología para estimar el almacenaje y flujo de nutrients de hojarasca y suelo de bosques secundarios. Acta Científica. 13(1-3): 11-26.

Lugo, A.E., ed. 1999. Acta Científica 13(1-3): 109 p. San Juan, PR: Asociación de Maestros de Ciencia de Puerto Rico.

13 **Lugo, A.E.; Domínguez Cristóbal, C.; Méndez Irizarry, N. 1999.** Biomasa y nutrients en raíces y brinzales de un bosque secundario en la zona cafetalera de Utuado. Acta Científica. 13(1-3): 75-87.

14 **Lugo, A.E.; Domínguez Cristóbal, C.; Santos, A.; Torres Morales, E. 1999.** Nutrient return and accumulation in litter of a secondary forest in the coffee region of Puerto Rico. Acta Científica. 13(1-3): 43-74.

15 **Lugo, A.E.; Salgado Herrera, M.; Ramírez, J.; Pérez Castro, I.E. 1999.** Estructura y composición del sotobosque de plantaciones en el arboreto del Bosque Experimental de Luquillo. Acta Científica. 13(1-3): 89-105.

16 **Lugo, A.E.; Silver, W.L.; Brown, S.; Scatena, F.N.; Ewel, J.J. 2001.** Managed ecosystems deserve greater attention. Bulletin of the Ecological Society of America. 82(1): 91-93.

March, J.G. 2000. The role of freshwater shrimps: patterns and processes along a tropical island stream continuum, Puerto Rico. Athens, GA: University of Georgia. 207 p. Ph.D. thesis.

March, J.G.; Benstead, J.P.; Pringle, C.M.; Ruebel, M.W. 2001. Linking shrimp assemblages with rates of detrital processing along an elevational gradient in a tropical stream. Canadian Journal of Fisheries and Aquatic Sciences. 58: 470-478.

17 **McGroddy, M.; Silver, W.L. 2000.** Variations in belowground carbon storage and soil CO_2 flux rates along a wet tropical climate gradient. Biotropica. 32(4a): 614-624.

18 **Mosier, A.R.; Delgado, J.A.; Keller, M. 1998.** Methane and nitrous oxide fluxes in an acid oxisol in western Puerto Rico: effects of tillage, liming and fertilization. Soil Biology and Biochemistry. 30(14): 2087-2098.

19 **Myster, R.W. 2001.** What is ecosystem structure? Caribbean Journal of Science. 37(1-2): 132-134.

20 **Myster, R.W.; Everham, E.M., III. 1999.** Germination cues across the disturbance regime in the Puerto Rican rainforest. Tropical Ecology. 40(1): 89-98.

21 **Odum, H.T.; Doherty, S.J.; Scatena, F.N.; Kharecha, P.A. 2000.** Emergy evaluation of reforestation alternatives in Puerto Rico. Forest Science. 46(4): 521-530.

22 **Perez, T.; Trumbore, S.E.; Tyler, S.C.; Davidson, E.A.; Keller, M.; Camargo, P.B. 2000.** Isotopic variability of N_2O emissions from tropical forest soils. Global Biogeochemical Cycles. 14(2): 525-535.

23 **Popper, N.; Domínguez Cristóbal, C.; Santos, A.; Mendez Irizarry, N.; Torres Morales, E.; Lugo, A.E.; Rivera Lugo, Z.Z.; Toledo, B.; Santiago Irizarry, M.; Rivera, L.I.; Zayas, L.A.; Colon, C. 1999.** A comparison of two secondary forests in the coffee zone of central Puerto Rico. Acta Científica. 13(1-3): 27-41.

Pringle, C.M. 2000. Managing riverine connectivity in complex landscapes to protect "remnant natural areas." Verh. Internat. Verein. Limnol. 27: 1-16.

Pringle, C.M. 2000. Threats to U.S. public lands from cumulative hydrologic alterations outside of their boundaries. Ecological Applications. 10(4): 971-989.

Pringle, C.M.; Scatena, F.N.; Paaby-Hansen, P.; Nunez-Ferrera, M. 2000. River conservation in Latin America and the Caribbean. In: Boon, P.J.; Davies, B.R.; Petts, G.E., eds. Global perspectives on river conservation: science, policy and practice. Chichester, New York: John Wiley and Sons: 41-77.

24 **Ramos-Gonzalez, O.M. 2001.** Assessing vegetation and land cover changes in northeastern Puerto Rico 1978-1995. Caribbean Journal of Science. 37(1-2): 95-106.

Reiners, W.A.; Keller, M.; Gerow, K.G. 1998. Estimating rainy season nitrous oxide and methane fluxes across forest and pasture landscapes in Costa Rica. Water, Air, and Soil Pollution. 105: 117-130.

Richardson, B.A.; Hull, G.A. 2000. Insect colonization sequences in bracts of *Heliconia caribaea* in Puerto Rico. Ecological Entomology. 25: 460-466.

25 **Ruíz Bernard, I.; Lugo, A.E. 1999.** Stand dynamics of a south coast mangrove forest in Puerto Rico. Acta Científica. 13(1-3): 107-119.

Saldanha, N. 2000. Caracterizacao da comunidade de quiropteros (Mammalia) em areas naturais e manejadas da floresta nacional do Tapajos, PA-Brasil. Belem, Para, Brazil: Museu Paraense Emilio Goeldi, Departamento de Zoologia. 98 p. M.S. thesis.

26 **Santos, A.; Torres Morales, E. 1999.** Enfoque de investigación en el curso de biología: estudio ecológico de un bosque secundario en Barranquitas. Acta Científica. 13(1-3): 5-9.

Scalley, T.H. 2000. Multi-scale assessment of riparian systems: land cover, riparian vegetation and stream characteristics in three tropical montane watersheds. Rio Piedras, PR: Faculty of Natural Sciences, University of Puerto Rico. 53 p. M.S. thesis.

27 **Scatena, F.N. 2000.** Drinking water quality. In: Dissmeyer, G.E., ed. Drinking water from forests and grasslands: a synthesis of the scientific literature. Gen. Tech. Rep. SRS-39. Asheville, NC: U.S. Department of Agiculture, Forest Service, Southern Research Station: 7-25. Chapter 2.

28 **Scatena, F.N. 2000.** Future trends and research needs in managing forests and grasslands as drinking water sources. In: Dissmeyer, G.E., ed. Drinking water from forests and grasslands: a synthesis of the scientific literature. Gen. Tech. Rep. SRS-39. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 197-201. Chapter 21.

29 **Scatena, F.N.; Johnson, S.L. 2001.** Instream-flow analysis for the Luquillo Experimental Forest, Puerto Rico: methods and analysis. Gen. Tech. Rep. IITF-GTR-11. Rio Piedras, PR: U.S. Department of Agriculture, Forest Service, International Institute of Tropical Forestry. 30 p.

30 **Sharpe, J.M. 1997.** Leaf growth and demography of the rheophytic fern *Thelypteris angustifolia* (Willdenow) Proctor in a Puerto Rican rainforest. Plant Ecology. 130: 203-212.

31 **Silver, W.L.; Ostertag, R.; Lugo, A.E. 2000.** The potential for carbon sequestration through reforestation of abandoned tropical agricultural and pasture lands. Restoration Ecology. 8(4): 394-407.

32 **Swanson, F.J.; Scatena, F.N.; Dissmeyer, G.E.; Fenn, M.E.; Verry, E.S.; Lynch, J.A. 2000.** Watershed processes—fluxes of water, dissolved constituents, and sediment. In: Dissmeyer, G.E., ed. Drinking water from forests and grasslands: a synthesis of the scientific literature. Gen. Tech. Rep. SRS-39. Asheville, NC: U.S. Department of j, Forest Service, Southern Research Station: 26-41. Chapter 3.

Thompson Baranello, J.J. 2000. Resource and population modeling of the Puerto Rican parrot (*Amazona vittata*). Rio Piedras, PR: University of Puerto Rico, Faculty of Natural Sciences, Rio Piedras Campus. 208 p. M.S. thesis.

33 **Torres, J.A.; Snelling, R.R.; Canals, M. 2000.** New records of parasitoids of aculeate Hymenoptera in Puerto Rico. Journal of Agriculture of the University of Puerto Rico. 84(1-2): 99-100.

34 **Torres, J.A.; Snelling, R.R.; Canals, M. 2001.** Seasonal and nocturnal periodicities in ant nuptial flights in the tropics (Hymenoptera: Formicidae). Sociobiology. 37(3B): 601-626.

35 **Torres, J.A.; Snelling, R.R.; Jones, T.H. 2000.** Distribution, ecology and behavior of *Anochetus kempfi* (Hymenoptera: Formicidae) and description of the sexual forms. Sociobiology. 36(3): 505-516.

36 **Torres, J.A.; Zottig, V.E.; Co, J.E.; Jones, T.H.; Snelling, R.R. 2001.** Caste specific alkaloid chemistry of *Solenopsis maboya* and *S. torresi* (Hymenoptera: Formicidae). Sociobiology. 37(3B): 579-583.

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37 **Wadsworth, F.H. 2001.** Not just reduced but productive logging impacts. International Forestry Review. 3(1): 51-53.

38 **Wadsworth, F.H. 2000.** Producción forestal para America Tropical. Manual de Agricultura 710-S. Washington, DC: U.S. Department of Agriculture, Forest Service. 603 p.

Weitz, A.M.; Linder, E.; Frolking, S.; Crill, P.M.; Keller, M. 2001. N_2O emissions from humid tropical agricultural soils: effects of soil moisture, texture and nitrogen availability. Soil Biology and Biogeochemistry. 33: 1077-1093.

Weitz, A.M.; Veldkamp, E.; Keller, M.; Neff, J.; Crill, P.M. 1998. Nitrous oxide, nitric oxide, and methane fluxes from soils following clearing and burning of tropical secondary forest. Journal of Geophysical Research. 103(D21): 28,047-28,058.

Werf, van der, G. 2001. The use of chemical and isotopic tracers in identifying stormflow generating processes in a small humid tropical catchment. Amsterdam: Vrije Universiteit. 30 p.

Appendix 2: Other Publications Available for Distribution

39 **Various authors. 1985–1999.** IITF Silvics Manual. SO-ITF-SM 1–88. Rio Piedras, Puerto Rico: USDA Forest Service, International Institute of Tropical Forestry: sectionally numbered. [complete silvics manual available in English, has detailed silvicultural descriptions for 88 species of trees, e.g., *Swietenia macrophylla*, *Khaya senegalensis*, *Pterocarpus macrocarpus*, others]. [**Note:** this was translated into one volume in Spanish and is available as "Bioecología de árboles nativos y exóticos de Puerto Rico e Indias Occidentales," traducido al espanol y disponible bajo este otro titulo, Gen. Tech. Rep. IITF-15].

40 **Anderson, R.L.; Birdsey, R.A.; Barry, P.J. 1982.** Incidence of damage and cull in Puerto Rico's timber resource, 1980. Resour. Bull. SO-88. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, Institute of Tropical Forestry. 13 p.

41 **Arendt, W.J. 1988.** Range expansion of the cattle egret (*Bubulcus ibis*) in the greater Caribbean Basin. Colonial Waterbirds. 11(2): 252-262.

42 **Arendt, W.J.; Arendt, A.I. 1988.** Aspects of the breeding of the cattle egret (*Bubulcus ibis*) in Monserrat, West Indies, and its impact on nest vegetation. Colonial Waterbirds. 11(1): 72-84.

43 **Barres, H. 1964.** Rooting media for growing pine seedlings in hydroponic culture. Res. Note 2. Rio Piedras, PR: U.S. Department of Agriculture, Forest Service, Institute of Tropical Forestry. 4 p.

44 **Bauer, G.P.; Gillespie, A.J.R. 1990.** Volume tables for young plantation-grown hybrid mahogany (*Swietenia macrophylla* x *S. mahagoni*) in the Luquillo Experimental Forest of Puerto Rico. Res. Pap. SO-257. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, Institute of Tropical Forestry. 8 p.

45 **Benstead, J.P.; March, J.G.; Pringle, C.M.; Scatena, F.N. 1999.** Effects of a low-head dam and water abstraction on migratory tropical stream biota. Ecological Applications. 9(2): 656-668.

46 **Birdsey, R.A.; Weaver, P.L. 1987.** Forest area trends in Puerto Rico. Res. Note SO-331. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, Institute of Tropical Forestry. 5 p.

47 **Birdsey, R.A.; Weaver, P.L.; Nicholls, C.F. 1986.** The forest resources of St. Vincent, West Indies. Res. Pap. SO-229. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, Institute of Tropical Forestry. 25 p.

48 **Briscoe, C.B. 1962.** Crecimiento en diámetro de los árboles en los cerros de la región caliza seca. Apuntes Forestales Tropicales ITF-12. Rio Piedras, PR: U.S. Department of Agriculture, Forest Service, Tropical Forest Research Center. 2 p.

49 **Briscoe, C.B. 1962.** Tree diameter growth in the dry limestone hills. Tropical Forest Note ITF-12. Rio Piedras, PR: U.S. Department of Agriculture, Forest Service, Tropical Forest Research Center. 2 p.

50 **Briscoe, C.B.; Nobles, R.W. 1962.** Height and growth of mahogany seedlings. Tropical Forest Note ITF-13. Rio Piedras, PR: U.S. Department of Agriculture, Forest Service, Tropical Forest Research Center. 2 p.

51 **Chinea, J.D. 1999.** Changes in the herbaceous and vine communities at the Bisley Experimental Watersheds, Puerto Rico, following Hurricane Hugo. Canadian Journal of Forestry Research. 29(9): 1433-1437.

52 **Chinea, J.D.; Beymer, R.J.; Rivera, C.; Sastre de Jesus, I.; Scatena, F.N. 1993.** An annotated list of the flora of Bisley area, Luquillo Experimental Forest, Puerto Rico, 1987 to 1992. Gen. Tech. Rep. SO-94. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, International Institute of Tropical Forestry. 12 p.

53 **Chudnoff, M.; Goytía, E. 1967.** The effect of incising on drying, treatability, and bending strength of fence posts. Res. Pap. ITF-5. Rio Piedras, PR: U.S. Department of Agriculture, Forest Service, Institute of Tropical Forestry. 20 p.

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