El Toro Wilderness, Luquillo Experimental Forest, Puerto Rico

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Abstract—The El Toro Wilderness, designated by Congress in 2005, occupies about 36 percent of the 11,300 ha Luquillo Experimental Forest (LEF) in northeastern Puerto Rico. It is the only tropical forest in the wilderness system managed by the U.S. Department of Agriculture. El Toro extends from 370 to 1,074 m in elevation, and is occupied by four forest types found in the mountainous Caribbean: lower montane rain forest, montane rain forest, palm brake, and dwarf forest. The LEF, a Biosphere Reserve since 1976, contains 225 tree species, 45 of them endemic to Puerto Rico, and 23 to the LEF alone; 150 species of ferns; 79 species of orchids; 11 native bats; 101 birds, 12 of them endemic to the island; 19 native reptiles, 8 endemic; 14 native amphibians, 8 endemic; and 6 native fish species. Most of these species occupy the wilderness. The LEF's century of research has provided a wealth of useful information on local climate, geology, soils, water resources, flora, fauna, and ecology. Temporary and permanent plots established within the wilderness have provided information on forest structure and species composition along elevation and topographic gradients. El Toro, surrounded by a dense human population, is under multipurpose management. Future research should demarcate wilderness boundaries and wildlife habitat requirements, and monitor for environmental changes. El Toro must be managed for solitude, an uncommon resource on an island where stakeholder support for wilderness is lacking.

Keywords: Puerto Rico, El Toro Wilderness Area, research, fauna, flora, designated areas

Introduction

The Wilderness Act begins with "It is hereby declared to be the policy of Congress to secure for the American people of present and future generations the benefits of an enduring resource of wilderness," and later puts humans in their place with "A wilderness, in contrast with those areas where man and his own works dominate the landscape, is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain" (U.S. Department of Agriculture, Forest Service 1983, pages 177-178). Wilderness areas provide numerous advantages to society—ecological services such as clean air and water, natural habitat for flora and fauna, scenic beauty, and solitude—and direct economic benefits to surrounding communities through recreation and tourism (Dombeck 1999).

In 1999, a new wilderness agenda was proposed that specified six goals for the U.S. Forest Service (Dombeck 1999):

- Identify new wilderness areas that fill critical habitat gaps within the system.
- Coordinate activities with other entities that manage wilderness areas.
- Provide advice regarding wilderness needs in all regions.
- Monitor wilderness as a baseline to determine the nation's environmental health.
- Orient people to enjoy wilderness areas while protecting their intrinsic values.
- Demonstrate expertise regarding the wilderness areas.

The purposes of this report are to first briefly review the variety of ecological information available regarding the Luquillo Experimental Forest (LEF), including the El Toro Wilderness Area. Although the wilderness is only 3 years old, ecological research has been carried out within the LEF for about a century. The second purpose is to review permanent plot information and data collected along gradients within the wilderness area. The third purpose is to briefly relate the LEF's current management program to four program topics of importance to this wilderness conference, namely:

- Hydrologic and human connections with aquatic systems—conserving aquatic biodiversity and the ecological services of water and wilderness.
- Nature protection—humans and tourism.
- Global change and wilderness, especially with regard to monitoring and stewardship.
- The role of education in the stewardship of wilderness resources.

Luquillo Mountains: Setting

The Luquillo Mountains of northeastern Puerto Rico, which include 11,300 ha of the LEF and 4,050 ha of the El Toro Wilderness, are steep and wet. They rise abruptly from 150 m at the forest border (370 m at the lower wilderness border) to 1,074 m in elevation at El Toro Peak, the highest summit in both the wilderness and the LEF (fig. 1). Annual

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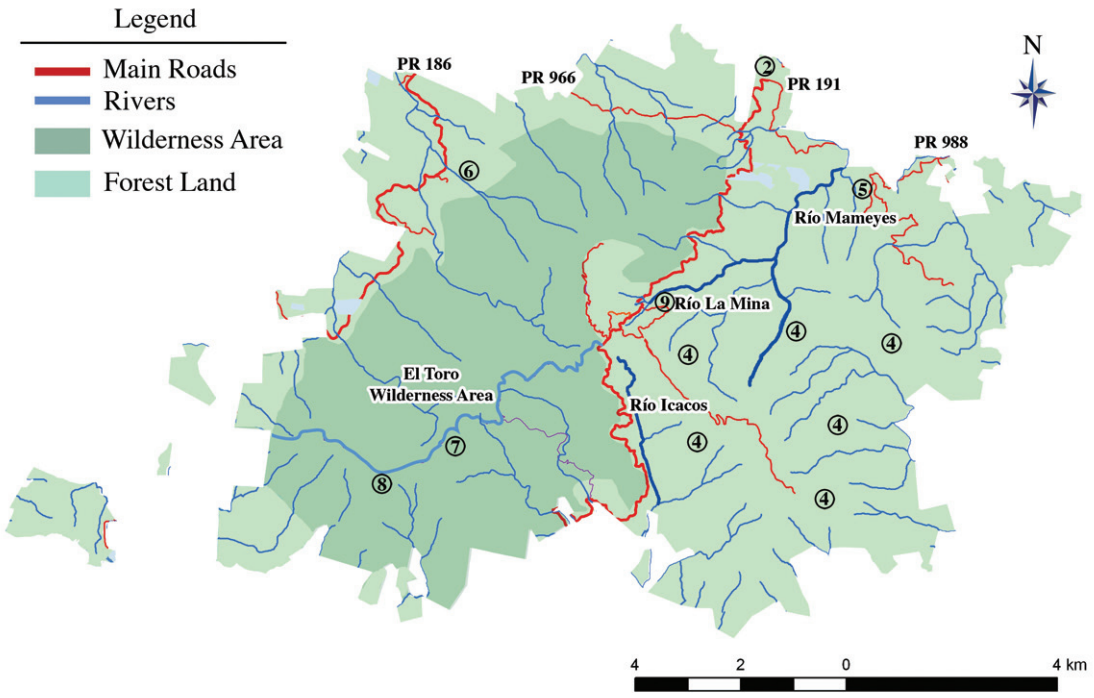

Figure 1—Map of the Luquillo Experimental Forest (LEF), showing the El Toro Wilderness and other areas mentioned in text: (1) Highways, including PR route 191; (2) El Portal Visitor Information Center; (3) Wild and Scenic Rivers: Río Icacos, Río de la Mina, and Río Mameyes; (4) Baño de Oro Research Natural Area; (5) Bisley Long-term Ecological Research Site; (6) Luquillo Forest Dynamics Plots at El Verde; (7) El Toro Trail; (8) El Toro Peak; and (9) recreation centers and picnic areas (Palo Colorado and Sierra Palm).

rainfall increases from 2,500 mm near the forest border to >4,500 mm at the summits (Briscoe 1966; Wadsworth 1948). Five ecological life zones are encountered along this gradient: subtropical moist forest, subtropical wet forest, subtropical rain forest, lower montane wet forest, and lower montane rain forest (Ewel and Whitmore 1973). Four major forest types are also recognized within the LEF and the El Toro Wilderness: lower montane rain forest between 150 and 600 m; montane rain forest between 600 and 900 m; and dwarf forest above 900 m (fig. 2). Palm brake occurs on steep slopes and in drainages above 450 m (Beard 1949; Wadsworth 1951).

Historical Perspective and El Toro Uniqueness

The following observations provide a brief orientation of the LEF's history, diversity, and challenges for management. The El Toro wilderness is unique, and its establishment has helped the agency to achieve its 1999 agenda of developing a more diverse wilderness system. First, the LEF is the only tropical forest within the National Forest system. It was set aside as a forest reserve in 1876 by the Spanish King Alfonso XII, whose declaration antedated the 1891 Land Revision Act that created the U.S. National Forest system (Domínguez Cristóbal 1997). Second, the number of distinct forest types, tree species, ferns, and orchids is impressive for such a small area (table 1). Tree species in the LEF exceed those in all other U.S. National

Figure 2—Dwarf forest, a short, dense, gnarled, and epiphyte-laden vegetation type occupies the summits of mountainous islands in the Caribbean, including the El Toro wilderness (photo by Peter L. Weaver).

Table 1—The El Toro Wilderness Area, Luquillo Experimental Forest (LEF), Puerto Rico. Summary of details regarding the wilderness and adjacent designated areas.

Factor	Explanation
El Toro Wilderness Area[a]	
Size	4,050 ha, established by the Caribbean National Forest Act of 2005.
Elevation (m)	Between 370 m at Quebrada Grande (north) to 1,074 m at El Toro Peak.
Forest types[b]	Lower montane rain forest (Tabonuco forest), montane rain forest (Colorado forest), palm brake, dwarf forest.
Permanent plots	Lower montane rain forest (TS-3); palm brake (PS-2), montane rain forest plots (CV-1, CV-3, CV-4, CS-3, CS-4) all established in 1946.
Gradient (temporary) plot study	18 groups of 3 (ridge, slope, and ravine) between 450 and 970 m elevation.
Major streams (clockwise)	North (Quebrada Grande, and Jiménez); east (Quebrada Linguete, Quebrada Coca, and Quebrada Juan Diego); south (Río Sabana, Río Cubuy, and Río Gurabo); southwest (Río Cubuy); northwest (Quebrada Grande, Río Espiritu Santo, and Quebrada Sonadora).
Plant species in LEF[c]	
Trees	225 species in 144 genera and 59 plant families; 45 endemic to Puerto Rico, and 23 to the LEF alone.
Ferns	150 species in the Luquillo Mountains.
Orchids	79 species in the Luquillo Mountains.
Classified plants	38 species, including 24 trees, 2 shrubs, and 12 herbs (1 liana, 1 grass, 1 fern, 2 Lycopodia, and 7 others). U.S. Forest Service lists 8 plant species as endangered and 30 as sensitive.
Wildlife vertebrates[d]	
Mammals	11 species of native bats.
Birds	101 species, including 12 island endemics.
Reptiles	19 species of native reptiles, including 8 island endemics.
Amphibians	14 natives, including 8 island endemics.
Fish	6 native species of fish.
Classified animals	13 species, including 1 bat, 1 snake, 5 frogs, and 6 birds. The U.S. Forest Service lists 5 animal species as endangered, 7 as sensitive, and 1 as threatened.
Trail	El Toro/Tradewinds Trail, situated between 650 and 1074 m elevation, and 11.4 km in length; points of interest—montane rain forest, dwarf forest, tree and bird species, El Toro peak and panorama; suggested as a challenging hiking experience.
Luquillo Experimental Forest (other designations)[e]	
Baño de Oro Research Natural Area in 1949	745 ha and contains lower montane rain forest, montane rain forest, palm brake, and dwarf forest.
Luquillo Forest Biosphere Reserve in 1976	11,300 ha, or the entire LEF.
Long Term Ecological Research Site (LTER) in 1985	About 363 ha of the Bisley watersheds.
Luquillo Forest Dynamics Plot (LFDP) in 1990	16 ha near the El Verde Field Station.
Wild and Scenic Rivers in 2002	2,812 ha, Río Icacos (329 ha), Río Mameyes (1,783 ha), Río de la Mina (700 ha).

[a]Source: United States 2005.
[b]Source: Wadsworth 1951.
[c]Sources: trees (Little 1970; Little and Wadsworth 1964; Little et al. 1974; Little and Woodbury 1976, 1980); ferns (Kepler 1975); orchids (Ackerman 1992, 1995; Kasomenakis 1988); classified plants (U.S. Department of Agriculture, Forest Service 1997a, 1997b).
[d]Sources: reptiles and amphibians (Joglar 1998, 2005); mammals, fish and classified species (U.S. Department of Agriculture, Forest Service 1997a, 1997b); birds (Wiley and Bauer 1985); for recent numbers of bird species (Wayne Arendt, see endnotes).
[e]Sources: Research Natural Area (Weaver 1994); Biosphere Reserve (Lugo 1987); LTER (Scatena 1989); LFDP (Thompson et al. 2004) ; wild and scenic rivers (U.S. Department of Agriculture, Forest Service 1997a, 1997b).

Forests combined (U.S. Department of Agriculture, Forest Service 1997b). In contrast, there are fewer bird species in the LEF's rain forests than in Puerto Rico's dry southwest (Kepler and Kepler 1970). This apparent anomaly may be due in part to the abundance of competing frogs and lizards within the forest. Also, during the Pleistocene, West Indian fauna was adapted to an island land mass that was larger and drier than today (Faaborg and Arendt 1990). Third, the Puerto Rican parrot (*Amazona vittata*) was probably among the first birds seen by Spanish explorers (fig. 3). At that time, the noisy parrot was widespread and flew in large flocks. By 1972, the parrot was rare and endangered—only 12 parrots remained—and they were confined to the LEF, including the wilderness area (Snyder and others 1987). Finally, in 1970, long after the island's native bird species had been identified, studied, and written about, the elfin woods warbler (*Dendroica angelae*) was discovered in the LEF (Kepler and Parks 1972; Raffaele 1983). The warbler lives at high elevations, including the wilderness area.

The 690 wilderness areas in the United States occupy a total of about 432,700 km^2 and range in size from 2.4 ha (Pelican Island, Florida) to 3,675,577 ha (Wrangell-Saint Elias, Alaska) (Wilderness.net 2007). The 4,050 ha El Toro Wilderness Area, with its high diversity of flora and fauna (table 1), is the only declared wilderness under U.S. Forest Service management. Moreover, the El Toro wilderness:

- Covers 36 percent of the LEF, making it proportionally large in comparison to the total area of the forest;
- Contains cloud covered peaks—El Cacique, La Mina, and El Toro—and lies near the renowned El Yunque peak;
- Encompasses the largest block of undisturbed vegetation on mainland Puerto Rico, is largely buffered by the LEF, and is traversed by one trail but no roads;
- Contains a great number of rare plants and animals, including several endemics;
- Lies within an area of tropical moist and wet forests, and contains the headwaters of 12 streams that provide pristine water supplies to surrounding communities; and
- Lies 40 km east of San Juan and is surrounded by a dense human population, providing one of the steepest gradients between a major metropolitan area and relative solitude within the wilderness system.

Research: LEF and Wilderness

A century of research within the LEF has provided a wealth of information on its flora, fauna, and ecology, much of it applicable to management of the El Toro Wilderness Area. Research methods for these studies varied considerably depending on research objectives. The earliest surveys at the beginning of the 20th century dealt with species identification, taxonomy, forest structure and composition, and were followed after 1960 by a variety of ecological studies.

Figure 3—*Amazona vittata*, Puerto Rico's only parrot, occupied most of the island at the time of discovery. Currently it is classified as rare and endangered (photo by Gerald P. Bauer).

Past Research Within the LEF

It would call for an effort well beyond the scope of this report to review all of the research carried out in the LEF, which is one of the best studied tropical forests in the world. However, several noteworthy publications provide an example of the type of information available for management of the wilderness area:

- The scientific survey of Porto Rico and the Virgin Islands (Britton and Wilson 1923-30; Gleason and Cook 1927), part of the New York Botanical Garden's expeditions to Puerto Rico, provides some of the earliest information on the LEF's flora and fauna.
- The Caribbean Forest atlas (Upson 1949) contains a chronology of legislation and events relating to the creation, enlargement, improvement, and management of the LEF from December 1898 to June 1949.
- Trees of Puerto Rico and the Virgin Islands, Volumes I and II (Little and Wadsworth 1964; Little and others 1974), consider all 547 native tree species and numerous introduced timber species.
- A tropical rain forest: a study of irradiation and ecology at El Verde (Odum and Pigeon 1970) is a 1600 page compendium of 9 chapters on the flora, fauna, and ecology of the LEF.
- The descriptive flora of Puerto Rico, Volumes I-V (Liogier 1985-97), contain a relatively recent taxonomic update of Puerto Rico's flora.
- History and conservation of the Puerto Rican Parrot (Snyder and others 1987) covers the history, ecology, and current efforts to save the rare and endangered Puerto Rican Parrot, a model for parrot conservation worldwide.
- Special hurricane issues of Biotropica: (1) Ecosystem, plant, and animal responses to hurricanes in the Caribbean; and (2) Long term responses of Caribbean ecosystems to disturbance (Walker and others 1991, 1996), contain post-hurricane observations on the LEF's flora and fauna.
- Tropical forests: management and ecology (Lugo and Lowe 1995), contains several chapters on the forests and ecology of the LEF.
- The food web of a tropical rain forest (Reagan and Waide 1996), with 14 chapters, summarizes studies of rain forest animals, including their abundance, food habits, and ecological roles in the ecosystem.
- The revised Land Management Plan for the Luquillo Forest (U.S. Department of Agriculture, Forest Service 1997a, 1997b) are two documents that contain an environmental impact statement and management plan for the entire LEF, including the 1997 proposal for wilderness.
- Forest biodiversity in North, Central and South America, and the Caribbean: research and monitoring (Dallmeier and Comiskey 1998) deals with the neo-tropics and includes five chapters on the LEF.
- Producción Forestal para América Tropical (Wadsworth 2000) describes forest management practices throughout the tropics, including some experiences from the LEF.
- Geology, geochemistry, geophysics, mineral occurrences and mineral resource assessment for the Commonwealth of Puerto Rico (Bawiec 2001) is a compendium that describes nine geologic formations found within the LEF.
- The soil survey of the Luquillo Experimental Forest (U.S. Department of Agriculture, Natural Resources Conservation Service 2002) summarizes five general and 20 detailed soil map units within the LEF, along with their classification, potential use, and management.
- The bio-ecology of native and exotic tree species in Puerto Rico (Francis and Lowe 2002) summarizes life history information for 88 tree species, including many native trees of the LEF.
- Innumerable journal articles and reports on the flora, fauna, geology, soils, water resources, and ecology of the LEF after the mid-1960s. Three of these papers consider forest structure, species composition, and post-hurricane changes within the Montane rain forest, and include plots sampled within the wilderness area (Weaver 1989b, 1991, 2000).

Studies Within the El Toro Wilderness Area

The wilderness is one of six designated areas within the LEF (table 1; fig. 1). Despite the abundance of research available within the LEF, only a few studies have actually been carried out within the wilderness boundaries.

Gradient study—The gradient study used 48 temporary plots to determine species composition and forest structure by elevation and topography between 460 and 970 m elevation. On each plot, all trees ≥4 cm in d.b.h. (diameter at 1.4 m above the ground) were identified and d.b.h. and height measured. Plot size varied by forest type: 42 plots of 0.05 ha were used within lower montane and montane rain forests, 6 plots of 0.025 ha in dwarf forest. Aboveground total woody biomass was determined by equations that were developed for different forest types within the LEF (Weaver and Gillespie 1992). The temporary plots showed (table 2; fig. 4):

- A total of 5,107 trees and 89 species on 2.25 ha;
- *Prestoea montana* (Sierra palm) and *Henriettea squamulosa* accounted for nearly one-third of the total stems, and the 10 most common species for nearly two-thirds; nine species were tallied only once and 29 species ≤5 times;
- Several tree species per plot, which decreased from low to high elevation;
- Relatively high stem density, which increased from low to high elevation;
- Moderate canopy height, which decreased from low to high elevation; and
- Estimates of biomass, which showed no trends with regard to elevation.

The temporary plots showed correlations of species richness and structural features with changes in elevation. The lack of correlation with biomass may be due to several factors, including the variety of habitats sampled, small plot size, and the sporadic occurrence of exceptionally large trees, which tend to inflate plot biomass estimates.

Table 2—Recorded tree species (126) within the El Toro Wilderness from the gradient study and permanent plots.[a]

Species name	Occurrences		Stems[b]			Percent
	Plots	Stems	R	S	V	of total
Species recorded (89) in gradient study						
Alchornea latifolia Sw.	14	40	14	12	14	0.78
Alchorneopsis floribunda (Benth.) Muell. Arg.	1	2	0	0	2	0.04
Antirhea obtusifolia Urban[c]	7	7	1	4	2	0.14
Ardisia luquillensis (Britton) Alain[c]	1	1	1	0	0	0.02
Buchenavia tetraphylla (Aublet) R. Howard	11	14	6	5	3	0.27
Byrsonima spicata (Cav.) HBK	2	2	1	1	0	0.04
Byrsonima wadsworthii Little[d]	15	35	24	7	4	0.68
Calyptranthes krugii Kiaersk.[d]	9	26	20	4	2	0.51
Casearia arborea (L.C. Rich) Urban	3	7	6	1	0	0.14
Casearia decandra Jacq.	3	3	0	1	2	0.06
Casearia sylvestris Sw.	2	2	0	0	2	0.04
Cassipourea guianensis Aubl.	4	9	7	2	0	0.18
Cecropia schreberiana Mig.	20	83	15	30	38	1.62
Cestrum macrophyllum Vent.	1	3	3	0	0	0.06
Citharexylum caudatum L.	7	18	2	0	16	0.35
Cleyera albo-punctata (Griseb.) Krug & Urban[e]	1	1	1	0	0	0.02
Clibadeum erosum (Sw.) DC.	3	9	5	2	2	0.18
Clusia clusoides (Griseb.) D'Arcy	13	97	52	42	3	1.90
Cordia borinquensis Urban[d]	34	251	89	78	84	4.91
Cordia sulcata DC.	1	2	0	0	2	0.04
Croton poecilanthus Urban[c]	25	173	6	33	134	3.39
Cyathea arborea (L.) J.E. Smith	7	34	3	27	4	0.66
Cyathea bryophila (R. Tryon) Proctor[d]	3	12	3	1	8	0.23
Cyathea portoricensis Spreng ex Kuhn[d]	1	1	0	0	1	0.02
Cyrilla racemiflora L.	19	117	75	36	6	2.29
Dacryodes excelsa Vahl	15	94	42	47	5	1.84
Daphnopsis philippiana Krug & Urban[d]	16	55	16	33	6	1.08
Dendropanax arboreus (L.) Decne & Planch.	1	2	0	0	2	0.04
Dendropanax laurifolius (E. March.) Decne & Planch.[d]	1	1	1	0	0	0.02
Ditta myricoides Griseb.[e]	13	30	2	9	19	0.59
Drypetes glauca Vahl	13	94	20	52	22	1.84
Eugenia borinquensis Britton[c]	18	151	55	64	32	2.96
Eugenia eggersii Kiaersk.[d]	1	3	0	0	3	0.06
Eugenia stahlii (Kiaersk.) Krug & Urban [d]	14	30	10	16	4	0.59
Ficus citrifolia P. Miller	3	3	0	2	1	0.06
Ficus crassinervia Desf.	3	3	1	2	0	0.06
Ficus sintenisii Warb.	2	2	1	1	0	0.04
Guarea glabra Vahl	6	10	0	6	4	0.19
Guarea guidonia (L.) Sleumer	4	6	1	2	3	0.12
Guatteria caribaea Urban	1	5	5	0	0	0.10
Guettarda valenzuelana A. Rich.	9	28	6	5	17	0.55
Haenianthus salicifolius Griseb.	21	109	57	30	22	2.13
Hedyosmum arborescens Sw.	4	7	5	1	1	0.13
Henriettea squamulosa (Cogn.) Judd.[d]	40	629	196	253	180	12.32
Hirtella rugusa Pers.[d]	18	119	78	40	1	2.33
Homalium racemosum Jacq.	4	11	5	6	0	0.22
Ilex nitida (Vahl) Maxim.	7	11	6	5	0	0.22
Ilex sideroxyloides (Sw.) Griseb.	1	1	1	0	0	0.02
Inga laurina (Sw.) Willd.	1	1	0	1	0	0.02
Inga vera Willd. Ex L.	5	6	1	2	3	0.12
Ixora ferrea (Jacq.) Benth.	8	23	15	8	0	0.45
Linociera domingensis Lam.	2	3	1	2	0	0.06
Magnolia splendens Urban[c]	15	29	7	17	5	0.57
Manilkara bidentata (A.DC.) Chev.	7	27	14	11	2	0.53
Matayba domingensis (DC.) Radlk.	21	112	59	47	6	2.19
Mecranium latifolium (Cogn.) Skean	4	4	0	1	3	0.08
Meliosma herbertii Rolfe	5	27	18	9	0	0.53
Menendezia urbanii Cogn.	3	8	7	1	0	0.16
Miconia laevigata (L.) DC.	10	32	10	21	1	0.63
Miconia pachyphylla Cogn.[d]	3	7	3	2	2	0.14
Miconia tetrandra D. Don	17	73	40	22	11	1.43

(continued)

Table 2 (Continued)

Species name	Occurrences		Stems[b]			Percent
	Plots	Stems	R	S	V	of total
Species recorded (89) in gradient study						
Micropholis garciniifolia Pierre[c]	30	389	160	212	17	7.61
Micropholis guyanensis (A. DC.) Pierre	27	289	147	109	33	5.65
Myrcia deflexa (Poir.) DC.	2	4	4	0	0	0.08
Myrcia fallax (A. Rich) DC.	18	54	38	14	2	1.06
Myrcia leptoclada DC.	4	18	7	10	1	0.35
Myrcia splendens (Sw.) DC.	1	1	0	0	1	0.02
Myrsine coriaceae (Sw.) R. Br. Ex Roem. & Schult.	1	1	0	0	1	0.02
Ocotea leucoxylon (Sw.) Mez	14	27	17	7	3	0.53
Ocotea moschata (Meisn.) Mez[d]	4	7	1	5	1	0.14
Ocotea portoricensis Mez[d]	4	5	4	0	1	0.10
Ocotea spathulata Mez	25	139	95	31	13	2.72
Ormosia krugii Urban	7	26	21	5	0	0.51
Palicourea croceoides W. Hamilton	2	4	3	0	1	0.08
Prestoea montana (R. Grah.) Nichols	38	1013	202	256	555	19.83
Psychotria berteroana DC.	12	33	12	7	14	0.64
Rheedia portoricensis (Urban) Alain[d]	4	31	23	8	0	0.61
Rondeletia portoricensis Krug & Urban[d]	3	8	2	0	6	0.16
Sapium laurocerasus Desf.[d]	13	31	4	5	22	0.61
Schefflera morototoni (Aubl.) Mcguire	9	23	11	11	1	0.45
Sloanea berteroana Choisy	17	43	20	10	13	0.84
Syzygium jambos (L.) Alston[f]	1	4	0	4	0	0.08
Tabebuia heterophylla (DC.) Britton	4	5	2	1	2	0.10
Tabebuia rigida Urban[c]	17	183	75	84	24	3.58
Tetragastris balsamifera (Sw.) Kuntze	6	37	27	8	2	0.72
Torralbasia cuneifolia (C. Wright) Krug & Urban	5	17	15	2	0	0.33
Trichilia pallida Sw.	1	3	0	0	3	0.06
Vitex divaricata Sw.	1	1	0	1	0	0.02
Xylosma schwaneckeanum Krug & Urban[c]	3	6	5	1	0	0.11
Totals	48	5107	1912	1795	1400	100.00

Species recorded (37) on permanent plots and not listed above

Andira inermis (W. Wr.) DC.
Ardisia glauciflora Urban[d]
Ardisia obovata Desv. ex Hamilton
Beilschmiedia pendula (Sw.) Hemsl.
Casearia guianensis (Aublet) Urban
Citharxylum caudatum L.
Clidemia cymosa (Wendl.) Alain
Clusia rosea Jacq.
Coccoloba swartzii Meissn. in DC.
Cupania americana L.
Daphnopsis americana (Mill.) J.R. Johnston
Faramea occidentalis (L.) A. Rich.
Ficus trigonata L.
Guetarda valenzuelana A. Rich.
Guettarda scabra (L.) Vent.
Haenianthus salifolius Griseb.
Hedyosmum arborescens Sw.
Hirtella triandra Sw.
Ilex nitida (Vahl) Maxim
Ilex sintenisii (Urban) Britton
Marliera sintenisii Kiaersk.[c]
Maytenus elongata (Urban) Britton[c]
Mecranium latifolium (Cogn.) Skean
Miconia mirabilis (Aublet) L.O. Williams
Miconia prasina (Swartz) DC.
Myrcia citrifolia (Aublet) Urban
Ocotea coriacea (Sw.) Britton
Ocotea coriacea (Sw.) Britton
Ocotea globosa (Aubl.) Schlecht & Cham.
Ocotea membranacea (Sw.) Howard
Ocotea sintenisii (Mez) Alain[c]
Ourata striata (v. Tiegh) Urban[e]
Piper aduncum L.
Quararibea turbinata (Sw.) Poiret in Lamarck
Symplocos micrantha Krug & Urban[d]
Ternstroemia heptasepala Krug & Urban[c]
Ternstroemia luquillensis Krug & Urban[c]

[a]Total area of gradient plots = 2.25 ha; total area of permanent plots = 2.8 ha.
Sources: USDA Forest Service 1997b; Little and Woodbury 1976, 1980; Woodbury et al. 1974.
[b]Stems: R = ridge, S = slope, and V = ravine topography.
[c]Endemic to Luquillo Mountains.
[d]Endemic to Puerto Rico.
[e]Rare in Puerto Rico but native elsewhere.
[f]Exotic (introduced).

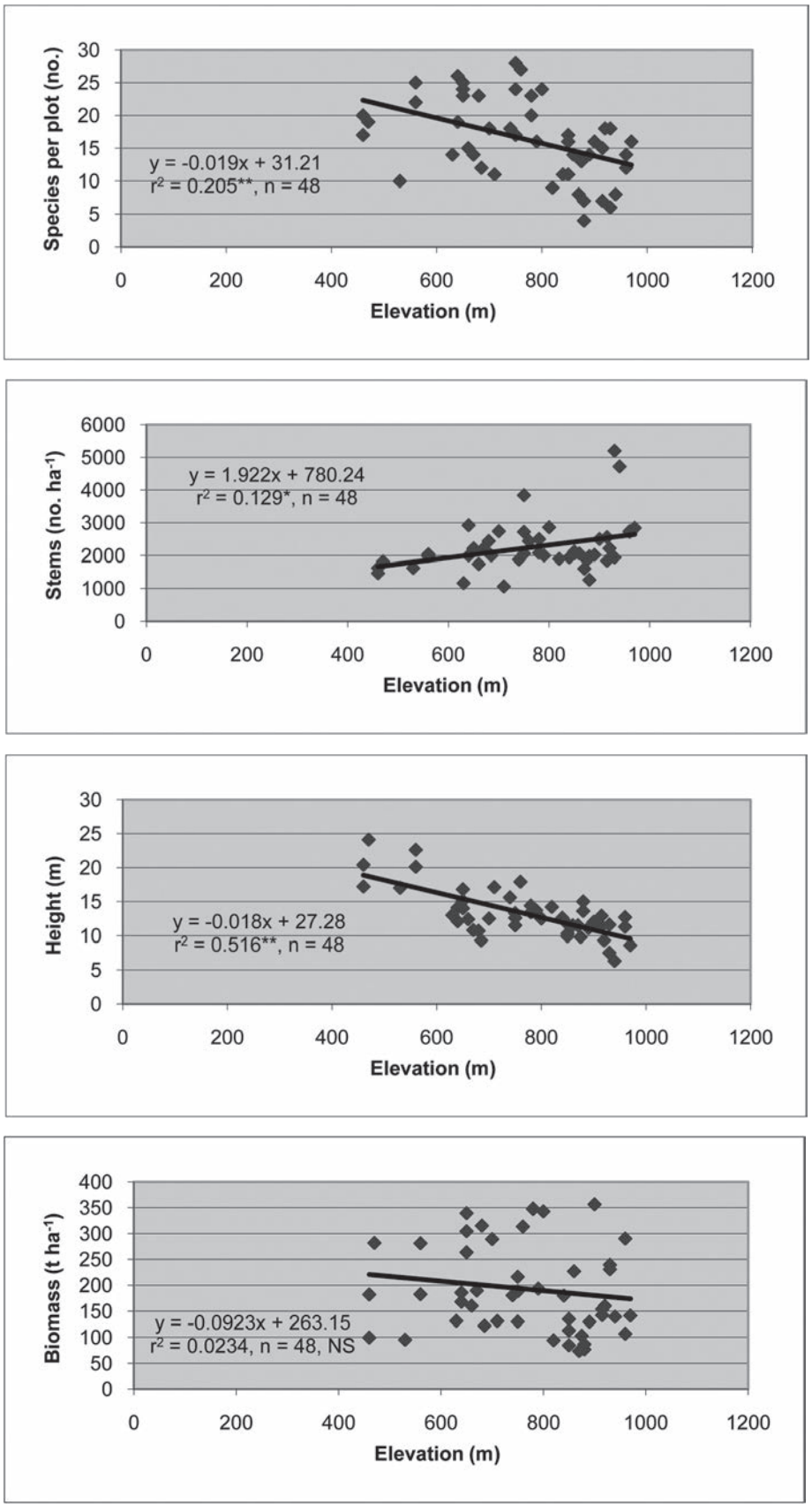

Figure 4—The gradient study showed increases in the number of stems with elevation, and decreases in mean canopy height and number of species per plot. Biomass showed no correlations

Permanent plot network—In 1946, seven permanent 0.40 ha plots were established: one in lower montane rain forest (TS-3), one in palm brake (PS-2), and five in montane rain forest, including valleys (CV-1, CV-3, CV-4) and slopes (CS-3, CS-4) (table 3). A total of 13,121 trees were originally sampled. The plots were re-measured in 1976 or 1981 to determine changes in species composition, basal area, and increment. Although palms were measured for determination of basal area, they were omitted from d.b.h. growth calculations. The permanent plots showed the following trends (table 3):

- Stem changes (per plot) ranged between a 17 percent loss and a 13 percent gain.
- Basal area changes (per plot) ranged between an 8 percent loss and a 19 percent gain.
- Long-term mean d.b.h. growth (per plot) for all tree species combined ranged between 0.09 and 0.21 cm yr-1.
- The logarithm of the d.b.h. distribution within the undisturbed, uneven-aged TS-3 plot was linear (Wadsworth 1977).

The measurement period on the permanent plots was characterized by forest recovery after hurricanes San Felipe and San Cipriano (1928 and 1932). The major negative changes in basal area during the measurement period were due to the loss of large *Cyrilla racemiflora* (Palo Colorado) trees; in contrast, major increases were caused by an influx of palms, mainly on valley plots. Both of these species are comparatively large in d.b.h. and influence basal area disproportionately within forest types dominated by small dimension trees. Broadleaf trees grew relatively rapid in palm brake where the abundance of narrow-crowned palms allows more light to filter through the canopy (table 3). D.b.h. growth rates were intermediate in lower montane rain forest, and declined from valley to slope plots within montane rain forest. Slow d.b.h. growth is typical for trees throughout the wilderness area where forest stands are characterized by many small tree species, high stem density, closed canopies, and competition for light.

A total of 126 tree species were tallied in the gradient and permanent plot studies on 5.05 ha, or only 0.125 percent of the El Toro Wilderness Area (table 2). The list includes 19 Puerto Rican endemics, 13 Luquillo Mountain endemics, and 3 species that are rare in Puerto Rico but native elsewhere. Based on this small sample, it would appear likely that all of the LEF's tree species are represented within the wilderness.

Riparian palm brake research—In 1980, research was initiated on a 0.25-ha palm plot located at 750 m in montane forest near permanent plot CV-1 (Frangi and Lugo 1985, 1991, 1998). The studies revealed:

- About 765 stems >1 cm in d.b.h. representing 27 tree species;.
- Abundant *Prestoea montana* accounting for 40 percent of the tallied stems; and
- Details regarding the carbon, phosphorus, and water cycles.

Periodic flooding, poor soil aeration, heavy annual rainfall, and low atmospheric saturation pressure deficits were suggested as the controlling factors in the abundant regeneration and growth of the palm. After Hurricane Hugo in 1989, the palm plot, protected by topography, showed only 1 percent tree mortality. About 30 percent of the trees, however, had suffered some damage, mainly in the canopy.

Conference Program Topics

The Wilderness Act serves to guide planning, implementation, and monitoring of the wilderness system. The El Toro Wilderness is relatively small and is surrounded by a dense human population. Under these conditions, wilderness protection calls for the management of the entire LEF to minimize further development, to set standards for forest use, to regularly monitor and patrol the entire forest, and to cooperate with local government officials to enforce buffer zone legislation, particularly near the wilderness boundary.

Table 3—Summary of stand data from permanent plots located within the El Toro Wilderness Area[a].

Forest type[b]	1946		1976/1981[c]		Ingrowth		Mortality	Increment		d.b.h. range	Species[e]	
	Stems	BA	Stems	BA	Stems	BA	Stems	MAI[d]	Stems	in 1946	first	last
	no.	*m^2*	*no.*	*m^2*	*no.*	*m^2*	*no.*	*cm yr^{-1}*	*no.*	*cm*	*no./plot*	
Lower montane rain	2359	41.6	2032	43.5	642	4.3	969	0.14	1099	4-106	51	45
Palm brake	1772	31.9	1470	31.8	338	3.3	640	0.21	383	4-49	37	33
Montane rain												
Colorado: CS-3	1677	45.2	1531	43.7	704	3.8	850	0.11	758	4-98	40	40
Colorado: CS-4	1810	51.7	1793	43.9	637	3.3	654	0.09	852	4-111	32	40
Colorado: CV-1	1650	36.0	1873	42.9	812	5.8	589	0.10	901	4-94	37	37
Colorado: CV-3	1949	42.5	2114	44.8	901	5.8	736	0.13	990	4-103	58	49
Colorado: CV-4	1904	33.7	2030	34.3	904	5.7	778	0.16	820	4-82	49	45

[a]Sources: Weaver 1983 and this paper. All data are in metric units and on a per hectare basis, as follows: stems (number ha^{-1}); basal area (m^2 ha^{-1}); MAI (mean annual d.b.h. increment) (cm yr^{-1}); and d.b.h. range (cm).
[b]Elevations: Lower montane rain forest (TS-3 at 570 m); Palm brake (PS-2 at 570 m); and Montane rain forest (Colorado slope, CS-3 and CS-4 at 690 m; and Colorado valley, CV-1 at 750 m, and CV-3 and CV-4 at 640 m).
[c]Measurement dates for Lower montane rain and palm brake forests, 1946 to1976; and for Montane rain forest, 1946 to1981.
[d]Surviving broadleaf stems per hectare used for d.b.h. calculations. On the palm brake plot, the palm was excluded from the MAI calculations.
[e]Number of species recorded at first (1946) and last (1976 or 1981) measurement.

Much of the proposed wilderness management program benefits from past research carried out in the LEF.

Hydrologic and Human Connections with Aquatic Systems

The Luquillo Mountains are in essence an island within an island. If sea level were to rise about 50 m, the valleys of the Río Grande de Loíza, Río Gurabo, and Río Antón would flood and the mountains would become an island comparable in size to many of the Lesser Antilles (Weaver 2002). Within that imaginary island, the water budget of the LEF may be summarized as follows: Rainfall averages 3,580 mm yr^{-1}, 64 percent of which is runoff and the remainder evapotranspiration (Crook and others 2007; García-Martinó and others 1996). The average volume of water extracted before leaving LEF boundaries is estimated at 250 mm yr^{-1}, which equals 7 percent of the annual rainfall and 11 percent of the annual runoff. Although little groundwater exists at high elevations, it may become important at lower levels (Larsen 1997). In summary, the LEF and its wilderness area are steep and wet; moreover, they provide streamflow to the surrounding lowlands throughout the year.

One of the major objectives of wilderness management is the maintenance of free flowing aquatic systems to provide ecological services and to conserve biodiversity. By 1990, more than 30 dams had been constructed for water supplies at some point on all the streams draining the LEF (i.e., within and below forest boundaries) except the Río Mameyes (Benstead and others 1999). By 1993, however, the Puerto Rico Water and Sewer Authority had plans to install a dam on that waterway as well (Nieves 1998). In addition, many LEF streams near bridges are used by visitors to the forest (Kartchner 2003). Surveys carried out at the Puente Roto bridge on the Río Mameyes and the Río Espiritú Santo bridge on PR route 186 showed that visitors enjoyed picnicking near the rivers, which were also used for bathing. In 1995, household and recreation surveys were carried out to estimate the willingness of islanders to pay for preserving in-stream flows on two forest rivers—the Río Mameyes and Río Fajardo (González-Caban and Loomis 1999). Protecting the environment for future generations was a common response for caring about the rivers. The annual "willingness-to-pay" to avoid placing dams on the rivers was $21.00 per household, which when extrapolated would yield $110 million yr^{-1}. Moreover, visitors to the Río Mameyes indicated that they would reduce their visits by >90 percent if heavy withdrawals were made from the river. Public opposition to the proposal for a dam resulted in a compromise involving the installation of an in-channel withdrawal system (March and others 2003). The new intake has minimal impact on the LEF's aquatic migratory fish and shrimp.

The Forest Service has a permit system for special uses to control and monitor all extractions from the LEF's streams. On a typical day, 70 percent of the water originating within the LEF is diverted before reaching the ocean (Crook 2005; Crook and others 2007). Unfortunately, water losses in the delivery system between island reservoirs and local users average 43 percent. Obviously, the water authority must take corrective measures to reduce water losses. The ecological integrity of LEF streams cannot be sacrificed because of inappropriate management and maintenance (Naumann 1994).

Nature Protection—Humans and Tourism

Naturalness, wildness, and protection from human influence are the wilderness values that society treasures. Management, therefore, is needed to keep human impacts on the environment to a minimum and to assure a wilderness experience for all visitors.

Some of the human influences within the LEF include: administration buildings and the El Portal Tropical Forest Center (a visitor information center); automobiles, roads, and trails; radar and communication towers; recreation, picnic, and bathing sites; independent hikers and guided tours; researchers and their project sites; and small dams for water supplies. Human presence, notably during vacation periods and local holidays, sometimes causes serious congestion along the roads and at favorite bathing areas like La Mina Falls and Puente Roto. The bathing sites are undoubtedly contaminated.

An estimated 650,000 recreation users visit El Yunque each year; moreover, during the past 17 years, rapid suburban development has occurred in areas adjacent to the LEF, including the wilderness area (Ramos Gonzalez 2001; U.S Department of Agriculture, Forest Service 1997b). In the past 8 years alone, counties surrounding the forest have increased in population from 268,900 to 288,600, or by 7.2 percent (U.S. Department of Agriculture, Forest Service 2009). In 1983, the area around the forest was zoned mainly for agriculture (amended in 1991) to promote its conservation, but recent suburban developments have been in violation of the suggested norms (Lugo and others 2000, 2004).

Current access to streams along the LEF's lower forest boundary and to recreation areas at higher elevation is unrestricted. In the future, however, vehicular traffic to the forest interior must be controlled to reduce noise and congestion, and to help protect wildlife, water supplies, and other forest resources. Safety precautions for visitors include first aid at the recreation centers and arrangements with emergency units surrounding the forest. Many of the current incidents involve hikers ill-prepared for a rigorous day in the field. Fortunately, the LEF has no dangerous animals or poisonous snakes.

The major LEF species calling for protection are sensitive, threatened, or endangered plants and wildlife (table 1). Efforts should be made to map their critical habitats and to protect them. Demands for new recreation opportunities by tour groups could present serious challenges regarding the nature of wilderness (untrammeled) and its use. Since Puerto Rico has no other wilderness areas at the moment, human use must be defined, controlled, and monitored.

A final consideration involves aircraft flying low over the LEF, including the wilderness area. Long considered a problem, the topic once again came to the attention of forest managers and the public on December 3, 2008, when

a Rockwell International 690B turbo commander crashed in the wilderness (Hernández Pérez 2008). Although such flights are prohibited to aid the recovery of the Puerto Rican Parrot, they apparently occur occasionally. In the case of wilderness, low flying aircraft may also be viewed from the standpoint of air quality issue and noise pollution.

Global Change and Wilderness—Monitoring and Stewardship

Monitoring is the basis for determining change. The now famous monitoring for global warming began in 1957 at the isolated Mauna Loa Observatory in Hawaii. In 1900, Christmas bird counts were initiated in the United States to protect bird species from traditional holiday hunts. That tradition was introduced to southwestern Puerto Rico in 1921 (McCandless 1962). Since 1994, bird counts have been underway in northeastern Puerto Rico, including sites within the LEF near the wilderness.

With continued urbanization around the LEF border and projections of increased global changes, the LEF may become warmer and consequently drier in the future (Scatena 1998). The LEF's hydrologic cycle could be altered affecting water availability for ecological processes and human activities. Some global models project that hurricanes may become more intense and frequent. Such changes could have an impact on the LEF's forests. Long-term changes in species' abundances and distributions might include more secondary species—those that complete their life cycles in shorter time spans—at the expense of primary species (Gomez-Pompa and Vazquez-Yanes 1974; Scatena 1998). Changes could also increase the rate of erosion, the number of landslides, the amount of debris accumulated in waterways, and alter wildlife populations.

During the mid-1940s, Forest Service researchers established several permanent forest plots within the LEF (Crow 1980; Weaver 1983), some of which are re-measured today. Monitoring revealed the impacts of past hurricanes, showing immediate damage and gradual recovery in forest structure, tree species composition, and species diversity (Crow 1980, Weaver 1989b). Some managers suggest that permanent plot monitoring could provide information on forest change caused by global warming and should continue. Hurricanes cause so many changes, however, that parts of the forest are always recovering from past events (Crow 1980; Weaver 1983, 2009). In summary, monitoring is expensive and should be statistically tailored to provide critical information for good management. Otherwise the cost of the program will collapse in future budgets

Regular monitoring of classified plant and animal species, or those cited as sensitive, threatened, or endangered (table 1), is called for in the management plan. Recurrent surveys by knowledgeable taxonomists might also provide information on plant and animal migrations within the LEF, or from the LEF to sites outside, or vice-versa. Recurrent surveys could provide information on the accidental introduction of exotic weeds by wilderness users, evidence of excessive human use such as trail erosion at particular locations, or possible violations like poaching of wildlife. Finally, surveys for cultural artifacts have been carried out within the LEF, including areas bordering the wilderness. Because of the tenuous nature of this information, reports have not been elaborated. All future research on the flora, fauna, insects, disease, and cultural sites should be formulated within management plan guidelines.

Role of Education in Stewardship of Wilderness Resources

In 1996, more than 50 years after the first recreation areas were constructed within the LEF, the El Portal opened to the public (fig. 5). Located along PR route 191 (National Forest, Route 191, Intersection 988, Km 4.4, Barrio Barceloneta, Río Grande, PR 00721) at the entrance to the LEF, El Portal has about 930 m^2 of exhibit space with four pavilions, a theater, a nature trail, and a gift shop (fig. 1). The pavilions orient visitors to the beauty, diversity, and complexity of tropical forests, and current activities aimed at their management. The information center's central theme is that tropical forests and people are linked together in a global community, and that people working together can help to conserve tropical forests. Interpretation is carried out in six areas: orientation; introduction to tropical forests; displays promoting an understanding of the forest; connections, or benefits and relationships that connect humans with forests; responsible forest management; and the future hope for forest conservation. The El Portal also has related interpretative facilities such as theater, a nature trail, and a nursery.

In addition, 15 hiking trails totaling >40 km offer visitors a close-up view the LEF's major plant and animal species (U.S. Department of Agriculture, Forest Service 1997b). The trails include Angelito and El Portal at low elevation, and 11 separate trails at intermediate to high elevations in the El Yunque and the La Mina groups. The longest is the El Toro/Tradewinds trail located in the wilderness area. It traverses Montane and Dwarf forests en route to El Toro Peak, the highest point in the LEF. Field tours are available within the LEF and guides provide details with regard to the flora and fauna. Free brochures are available for hikers. Signs for orientation and interpretation are strategically placed on well-marked trails.

The public has also been involved in planning the management of the LEF (U.S. Department of Agriculture, Forest Service 1997a, 1997b). The LEF's 1997 multi-purpose management plan, under current revision, considers primary forest, wildlife, water resources, wild and scenic rivers, wilderness, recreation, forest access (roads and trails), and research. Planning involves the presentation of management alternatives, the environmental impacts of proposed actions, and public input. A previous proposal for a demonstration of sustainable timber harvest was eliminated from the plan because of public concern about protection of the LEF. Current interest in expanding public use of the forest, especially tours and camping, must be carefully weighed against the obligation to protect forest resources, notably water and wildlife.

Figure 5—The El Portal Tropical Forest Center is the gateway to the Luquillo Experimental Forest. The center has numerous displays based on themes, a theater, a souvenir store, a snack bar, and ample parking (photo by Peter L. Weaver).

Conclusions and Recommendations

The El Toro Wilderness Area is new, small, diverse, and surrounded by a dense human population. Fortunately, the LEF's century of past research provides abundant information for multi-purpose forest management, public education, and interpretation. The updated multi-purpose management plan will consider forest resources and human impacts within the entire LEF. Recurrent surveys should determine habitat needs to protect the area's flora and fauna, and to monitor environmental change. The wilderness boundary must be determined; moreover, the area must be managed for solitude—an uncommon resource elsewhere on the island. Current stakeholder appreciation and support for wilderness is generally lacking, and the issue of protective rather than invasive public interest in the area may be a major challenge for LEF managers. Management uses a planning process to make decisions. Researchers should help managers to the extent possible with needed information. Managers, in turn, should make an effort to understand and correctly use the information. If not, "never the twain shall meet" (Kipling 1889).

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