Commonwealth of the Northern Mariana Islands' Forest Resources, 2004

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Abstract

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The Forest Inventory and Analysis program collected, analyzed, and summarized field data on 37 field plots on the islands of Rota, Tinian, and Saipan in the Commonwealth of the Northern Mariana Islands (CNMI). Estimates of forest area, tree stem volume and biomass, the numbers of trees, tree damages, and the distribution of tree sizes were summarized for this statistical sample. Detailed tables and graphical highlights provide a summary of the CNMI's forest resources and a comparison to prior vegetation mapping work.

Keywords: CNMI, biomass, damage, Forest Inventory and Analysis, forest inventory, volume, land cover.

Summary

The Forest Inventory and Analysis (FIA) program conducted a systematic inventory of the forests of Rota, Tinian, and Saipan in the Commonwealth of the Northern Mariana Islands (CNMI) in 2004 to estimate forest area, tree stem volume, biomass, carbon storage, tree damages, and the composition and percentage cover of understory vegetation species. Thirty-five permanent field plots were installed in a variety of forest types. By using recently acquired high-resolution satellite imagery, land cover was mapped into five broad classes: forest, nonforest vegetation, urban, barren, and inland water. Soil survey information was used to help refine the classification of forests. Our estimates for this inventory are derived from a sample based on 75,407 acres on the three main islands in the CNMI. About 12 percent of the landscape was classified as urban land, the largest percentage found on Saipan (21 percent). We estimated gross tree stem volume to be about 66.5 million cubic feet for all size classes including seedlings and saplings. Aboveground dry biomass for tree stems 5 inches and greater was estimated to be about 563,000 tons. About 32 percent of the trees sampled in the inventory had some form of damage. Vines in the crown were the most prevalent damage type, followed by lost apical dominance, and conks. The most frequently identified damaging agents were damage from other vegetation (e.g., strangling or smothering vines) and weather. The CNMI's forests are composed of small-diameter trees and have relatively low species diversity compared to other Pacific Islands. In total, 57 tree species and 107 understory species were measured on the FIA plots. The average number of tree species per one-sixth-acre plot was five. The CNMI foresters and ecologists were especially helpful with species identification in the field.

Introduction

This report on the forest resources of the three main islands of the Commonwealth of the Northern Mariana Islands (CNMI) (fig. 1) was based on a cooperative forest inventory conducted in 2004 by the USDA Forest Service, Pacific Northwest Forest Inventory and Analysis (FIA) program[1] and Pacific Island foresters. This work is an adaptation of the national FIA inventory system and was tailored to help answer local, national, and international questions about the status and trends in tropical forested ecosystems. Our partnership has concentrated on sharing technical forestry skills among cultures and agencies. The fieldwork for this inventory was conducted by a multinational crew including foresters from the CNMI, American Samoa, and mainland U.S. foresters and ecologists.

The FIA partnership yeilded a systematic, sample-based field inventory on the CNMI in conjunction with support for updating prior vegetation mapping work (Falanruw et al. 1989) to estimate land cover and forest-type area. We include new information on species composition, tree size distribution, stem volume, biomass, carbon mass, and damages for living and dead trees. The inventory was designed to provide resource managers with a broad overview of the current situation so they can better manage their forested and nonforested lands, and manage or mitigate any changes in the resource. The summarization of the field data is intended to help managers plan sustainable land use practices as well as plan sustainable supplies of wood, control invasive species and erosion, manage disturbances such as fire, and to track and mitigate damage from animals.

Objectives

The objectivs of this inventory are to:

- Estimate the current area of forest land by forest-type group and stand size class.
- Estimate the volume, biomass, and carbon storage for tree species by diameter class.
- Estimate the numbers of trees affected by damaging agents, such as insects and diseases, and estimate the numbers of dead trees.
- Share measurement and analysis techniques among groups involved in the inventory.

[1] The Forest Inventory and Analysis program is now part of the Resource Monitoring and Assessment program of the Pacific Northwest Research Station.

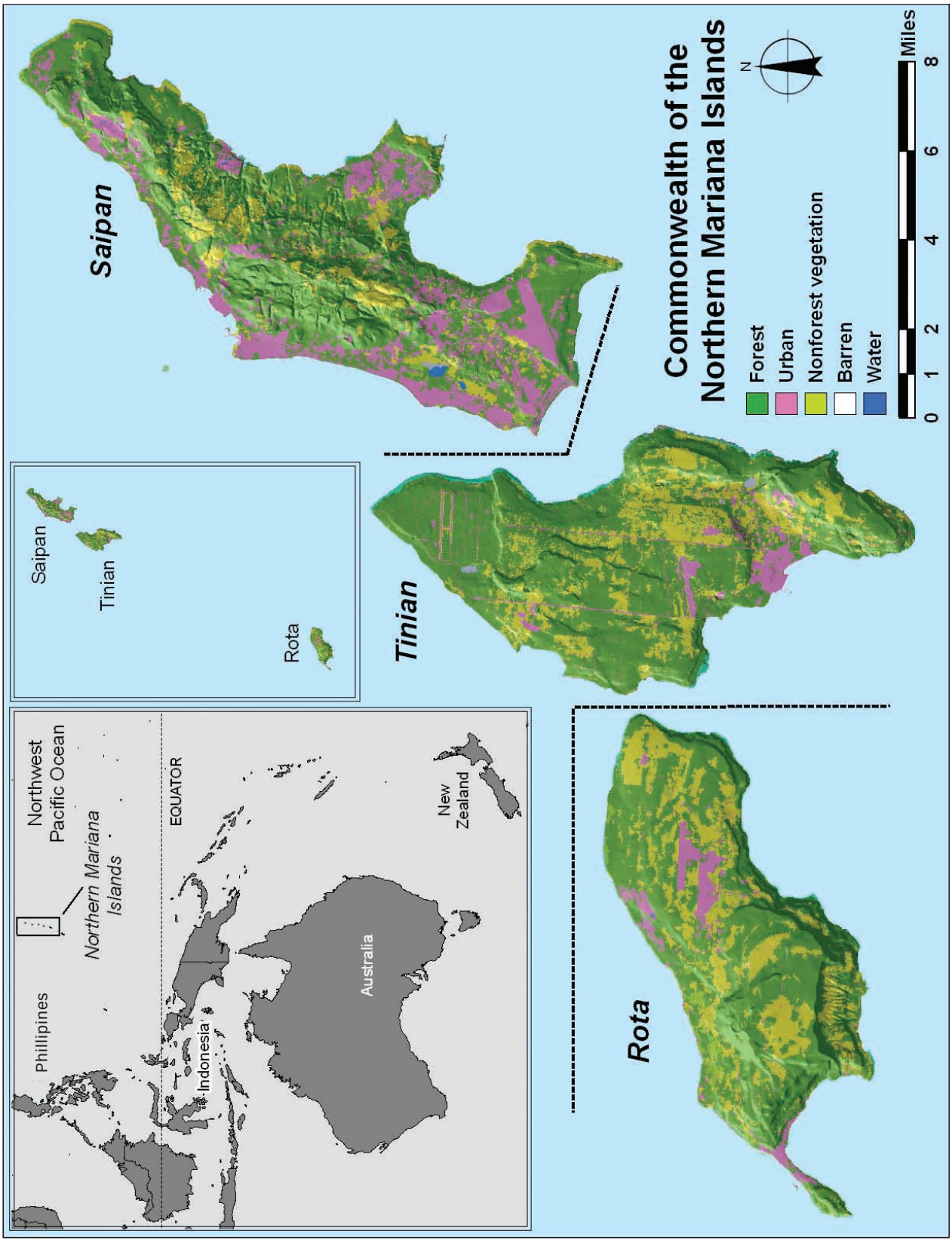

Figure 1—The Commonwealth of the Northern Mariana Islands is an archipelago in the northwestern Pacific Ocean about 470 miles east of the Phillipines. Land cover was mapped from 2005 QuickBird satellite data. The Forest Inventory and Analysis program collected data on the three larger and southernmost islands of Rota, Tinian, and Saipan.

Methods

Site Description

The archipelago of the Commonweatlh of the Northern Mariana Islands is a U.S.-associated political entity that parallels the Mariana Trench in the northwestern Pacific Ocean. Over an ocean distance of approximately 400 miles, the CNMI's 14 islands stretch from about 14 to 20 degrees north latitude: Rota, Aguijan, Tinian, Saipan, Farallon de Medinilla, Anatahan, Sarigan, Guguan, Alamagan, Pagan, Agrihan, Asuncion, Maug (three islets), and Farallon de Pajaros. The U.S. Territory of Guam, a separate political entity from the CNMI, lies to the south of Rota by less than 50 miles, and is the southernmost island in the Mariana Archipelago. Land area of the CNMI totals about 184 square miles. However, the forest inventory only covers the three largest, southern islands of Rota, Tinian, and Saipan, making up about 117 square miles (64 percent) of the land area.

The nine northern islands are geologically younger than the five southern islands (Fosberg 1960). The vegetation of the northern islands has been disturbed by volcanic activity, browsing by goats, and typhoon damage. A mixture of forest types and abundant sword grass (*Miscanthus floridulus* (Labill.) Warb. ex K. Schum. & Lauterb.) were described in a detailed survey by Ohba (1994). Currently the northern islands host little to no human settlement owing to relocation of locals, disturbance risk, isolation, and the harsh environment.

The three older, southern islands of Rota, Tinian, and Saipan have developed deep soils where the underlying volcanic parent materials have been exposed and weathered. Limestone areas tend to have shallow, highly weathered soils. Owing to relatively rapid water infiltration and consequently limited stream development, the limestone landscapes are characterized by plateaus and a series of steep escarpments (Young 1989) (fig. 2). Although deep, soil developed on volcanic parent materials have very low fertility, most of which resides in the topsoil. The abundance of calcium in the limestone and coral sand on these landscapes creates soils that are inherently more fertile than soils on volcanic landscapes.[2]

Rota, Tinian, and Saipan have a long history of human disturbance, with human settlement dating back as far as 4,300 years (Athens et al. 2004). The large population of Chamorro natives and Micronesian settlers likely was a significant impact on the vegetation of the CNMI even prior to European visit by Magellan in 1521 and subsequent Spanish occupation in the 1600s. The southern islands also were profoundly disturbed for agriculture by German and Japanese occupation in the

[2] Gavenda, R. 2010. Personal communication. Soil fertility in Pacific Island Landscapes, U.S. Department of Agriculture, Natural Resources Conservation Service, Pacific Basin Office, FHB Building, Suite 301, 400 Route 8, Maite, GU 96927-2003.

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Figure 2—The islands of Rota, Tinian, and Saipan are composed of volcanic cores capped by limestone, forming a series of plateaus and steep escarpments.

early 1900s and by heavy fighting during World War II (Young 1989). Coupled with regular natural disturbance from typhoons, the CNMI forests are in a continuous state of recovery.

The climate of the CNMI is warm and moderately humid (fig. 3). Mean annual temperature in Saipan is about 78.9 °F, with mean annual minimum and maximum about 74.5 °F and 83.3 °F, respectively. Total annual precipitation averages 82.3 inches with a pronounced wet season July to November (Western Regional Climate Center 2009).

The CNMI is located in a typhoon belt and often experiences major typhoons annually to semiannually. The typhoons are characterized by heavy rainfall, strong winds, and coastal surges that inundate low-lying areas. Changes in sea level and the frequency of coastal surges have become an immediate concern for Pacific Island inhabitants.

Vegetation Types

The native composition and structure of vegetation on Rota, Tinian, and Saipan mostly has been replaced over a long history of agroforestry, agricultural practices, and disturbances including typhoon, nonnative plants and animals, and World War II. What currently exists is a mixture of native and nonnative species, primarily of smaller tree size classes, with intact remnants of native limestone and ravine forest.

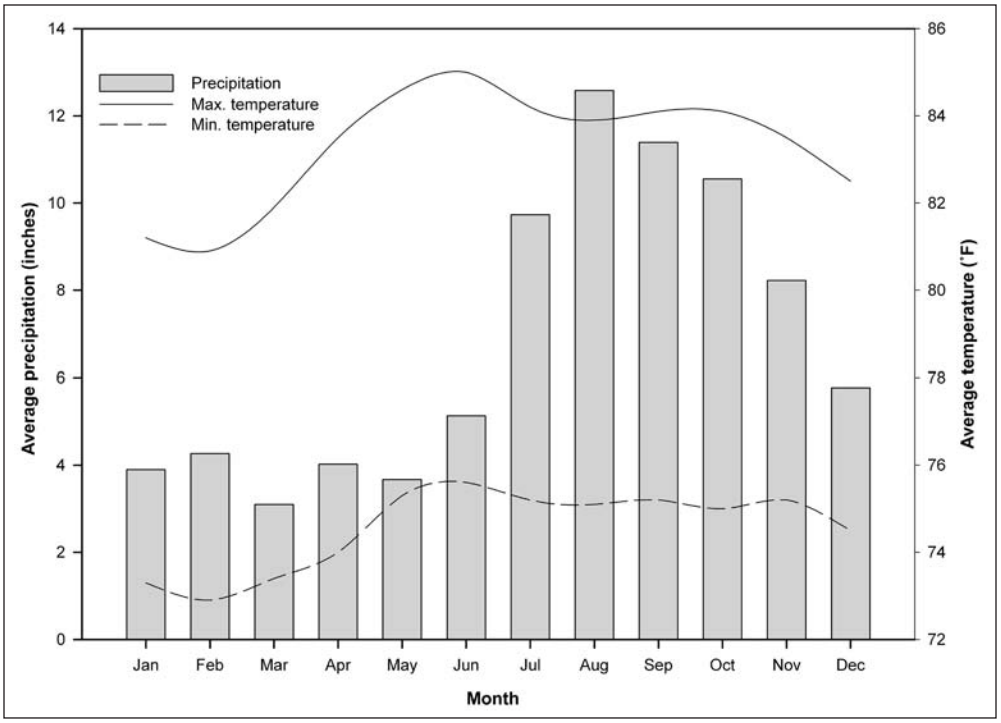

Figure 3—Both the annual maximum and minimum temperatures in the Commonwealth of the Northern Mariana Islands differ seasonally only by about 4 °F. However, average monthly precipitation totals vary from a low of about 3 inches in March, to over 12 inches in August with a distinct summer wet season and a dry winter/early spring (Western Regional Climate Center 2009).

The vegetation types described below use the mapping work of Liu and Fischer (2007) as the basis for classification with the species composition derived by overlaying the 2004 forest inventory plot data onto the mapped types. We purposely avoid the terms "primary" and "secondary" forest for this most recent mapping and summary; these terms suggest a dichotomy between disturbed and undisturbed forest when in reality, the majority of the forests on Rota, Tinian, and Saipan have been disturbed by humans continuously over several thousand years. Additionally, that terminology is somewhat arbitrary because of an unknown history of land use and the uncertainty surrounding the time required to recover from secondary back to an undocumented primary forest.

Native limestone forest—

Where limestone has not been cleared by humans recently, dense forest tends to develop. Owing to the widespread disturbance across the three southern islands, the label "native limestone forest" cannot be equated with intact, undisturbed forest. Instead, this type refers to forest occuring on limestone substrates where higher numbers of native species are found. Listed in descending abundance (as is the case for all forest types except ravine forest in this section) the following species

were found on forest inventory plots within native limestone forest: *Citrus hystrix, Pandanus tectorius, Guamia mariannae, Cynometra ramiflora, Ficus prolixa, Discocalyx ponapensis, Eugenia palumbis, Aglaia mariannensis, Hibiscus tiliaceus, Carica papaya, Drypetes* spp.*, Hernandia sonora, Premna obtusifolia, Psychotria mariana, Barringtonia racemosa, Allophylus timorensis, Claoxylon marianum, Pipturus argenteus, Cocos nucifera, Elaeocarpus joga, Intsia bijuga, Pandanus dubius, Guettarda speciosa, Artocarpus altilis, Barringtonia asiatica, Ficus* spp.*, Neisosperma oppositifolia, Mammea odorata, Morinda citrifolia, Ficus tinctoria,* and *Mangifera indica* (see table 1 for scientific names of tree species).

Ravine forest—

Only 204 acres of ravine forest were mapped for the CNMI (Liu and Fischer 2007); all of it occured on the southernmost part of Rota where the volcanic core has weathered into highly dissected ravines with relatively impermeable soils. No forest inventory plots fell inside of the ravine forest type. The vegetation in this area is primarily swordgrass (*Miscanthus floridulus* (Labill.) Warb. ex K. Schum. & Lauterb.) savanna mixed with shrubs. However, a variety of tree species occur in sheltered ravines. Dominant species (alphabetic listing) include *Areca catechu* L.*, Artocarpus altilis, Bambusa vulgaris* (Schrad. ex J.C. Wendl.)*, Barringtonia asiatica, Calophyllum inophyllum, Cananga odorata* (Lam.) Hook. f. & Thomson, *Cocos nucifera, Cynometra ramiflora, Hernandia labyrinthica* Tuyama*, Hibiscus tiliaceus, Intsia bijuga, Ixora triantha* Volkens*, Macaranga thompsonii, Mangifera indica, Melastoma malabathricum, Morinda citrifolia, Pandanus tectorius,* and *Scaevola sericea* Vahl.

As typified for the region, savanna areas are regularly ignited by arsonists, killing tree seedlings, burning into forested areas, and leaving soils barren for increased erosion and mass soil movement. Foresters on Rota currently are planting native species on the steep slopes with barren soils throughout the ravine badlands in an effort to reforest and stabilize these soils (fig. 4). The primary species planted recently include *Paspalum notatum* Flueggé*, Vetiveria zizanioides* (L.) Nash*, Acacia confusa, Calophyllum inophyllum* L.*, Morinda citrifolia, Barringtonia asiatica, Scaevola sericea, Hernandia labyrinthica,* and *Dodonaea viscosa* (L.) Jacq.

Mixed introduced forest—

This forest type is a mixture of native and nonnative species representing forests recovering from disturbance, native forests invaded by nonnatives, and forests that are establishing in disturbed areas from a mix of seed sources. Tree species include *Leucaena leucocephala, Cynometra ramiflora, Ficus prolixa, Melanolepis multiglandulosa, Pandanus tectorius, Albizia lebbeck, Ficus tinctoria, Guamia mariannae, Eugenia palumbis, Carica papaya, Premna obtusifolia, Hibiscus tiliaceus,*

Table 1—Scientific names, common names, estimated number and gross volume, and standard errors for estimated totals of species measured as trees in the Commonwealth of the Northern Mariana Islands

Scientific name	Common name	Number measured	Estimated Number (≥ 1 inch diam.)	Standard error for estimated number (±)	Gross volume (≥ 5 inches diam.)	Standard error for estimated volume (±)
Acacia confusa Merr.	formosa acacia	1	132,241	148,100		
Adenanthera pavonina L.	kulalis	3	34,199	36,870	1,108,736	1,195,315
Aglaia mariannensis Merr.	mapuñao	8	1,011,607	550,109	27,663	27,946
Aidia cochinchinensis Lour.	smak, sumac	1	142,004	153,093		
Albizia lebbeck (L.) Benth.	mamis	27	1,792,671	973,227	1,687,721	1,146,098
Allophylus timorensis (DC.) Bl.		1	132,241	148,100		
Annona spp.		1	142,004	153,093		
Artocarpus altilis (Park.) Fosb.	lemai, breadfruit	3	31,848	35,667	1,060,613	1,187,810
Barringtonia asiatica (L.) Kurz	puting	3	31,848	35,667	176,601	197,781
Barringtonia racemosa (L.) Spreng.		2	142,857	159,989	14,185	15,887
Bruguiera gymnorrhiza (L.) Lam.		2	22,800	24,580	162,424	175,107
Carica papaya L.		22	2,522,276	1,101,626	224,167	131,323
Cassia fistula L.		1	11,400	12,290	45,838	49,417
Casuarina equisetifolia L.		17	215,063	183,622	2,822,173	2,532,776
Cerbera dilatata Mgf.	chuti	1	11,400	12,290	21,138	22,789
Citrus ×aurantifolia (Christm.) Swingle		2	330,374	324,801		
Citrus hystrix DC.		47	6,215,306	6,960,696		
Claoxylon marianum Muell.-Arg.	katteknau, katot	1	132,241	148,100		
Cocos nucifera L.	niyok, coconut palm	16	176,910	102,146	2,213,227	1,311,222
Cynometra ramiflora L.		75	6,899,858	3,450,790	1,250,248	720,320
Delonix regia (Boj.) Raf.	flame tree, arbol del fuego	7	732,821	790,045	422,586	455,584
Discocalyx ponapensis Mez		13	1,906,823	1,266,316		
Drypetes spp.		4	528,962	592,400		
Elaeocarpus joga Merr.	joga	5	53,080	47,344	174,853	168,294
Erythrina variegata (L.) Merr.	gabgab, coral tree	10	113,998	122,900	1,267,520	1,366,499
Eugenia palumbis Merr.		12	1,586,887	1,184,799		
Eugenia stelechantha (Diels) Kaneh.	luluhut	10	1,651,872	1,624,006		
Ficus prolixa Forst. f.		66	3,809,830	2,295,211	5,355,185	4,617,736
Ficus spp. L.		2	21,232	23,778	48,825	54,680
Ficus tinctoria Forst. f.	hoda, tagete	7	732,038	777,846	112,779	94,147
Guamia mariannae (Safford) Merr.	paipai	39	5,099,250	2,863,701	97,072	62,077
Guettarda speciosa L.	pano	7	75,879	53,344	255,091	192,854

Table 1—Scientific names, common names, estimated number and gross volume, and standard errors for estimated totals of species measured as trees in the Commonwealth of the Northern Mariana Islands (continued)

Scientific name	Common name	Number measured	Estimated Number (≥ 1 inch diam.)	Standard error for estimated number (±)	Gross volume (≥ 5 inches diam.)	Standard error for estimated volume (±)
Hernandia sonora L.	nonak	23	365,792	274,392	2,296,609	1,688,288
Heterospathe elata (Becc.) Becc.		1	11,400	12,290	34,661	37,368
Hibiscus tiliaceus L.		17	1,058,426	841,806	401,349	381,486
Intsia bijuga (Colebr.) O. Ktze.	ifil	22	572,025	470,986	997,715	651,708
Leucaena leucocephala (Lam.) de Wit	tangantangan	300	38,815,714	10,814,962	1,727,600	649,115
Mammea odorata (Raf.) Kosterm.	chopak	1	12,769	12,899	25,099	25,356
Mangifera indica L.		1	10,616	11,889	91,305	102,255
Melanolepis multiglandulosa (Muell.-Arg.) Fosb.	alom	24	1,448,730	762,417	549,154	323,323
Morinda citrifolia L.	lada, indian mulberry	8	850,607	590,073	152,420	102,631
Morus alba L.		2	330,374	324,801		
Musa spp.		12	136,798	104,926		
Neisosperma oppositifolia (Lam.) Fosb. & Sachet	faag	6	192,733	148,112	227,565	130,711
Pandanus dubius Spr.	pahong	29	326,675	218,109	1,499,415	1,047,583
Pandanus tectorius Park.	kafu	115	4,626,326	1,741,831	3,079,227	1,198,506
Pipturus argenteus (Forst. f.) Wedd.	amahazan	2	297,428	219,790		
Pisonia grandis R. Br.	amumo	9	363,807	392,216	458,175	493,954
Pithecellobium dulce (Roxb.) Benth.	kamachiles	4	46,968	39,061	136,276	123,868
Pouteria obovata (R. Br.) Baehni	lalahag	1	11,400	12,290	75,945	81,876
Premna obtusifolia R. Br.	ahgao	57	1,073,804	396,058	3,404,918	1,409,201
Psychotria mariana Bartl. ex DC.	aplohkateng	10	403,207	305,073	312,235	315,435
Spathodea campanulata Beauv.		12	136,798	147,480	830,487	895,338
Unknown		14	1,729,743	1,937,188	49,046	54,929
Unknown 0		1	11,400	12,290	29,999	32,342
Unknown 1		1	142,004	153,093		
Unknown, other		2	330,374	324,801		
Total			89,749,736	13,954,793	34,927,848	8,386,049

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Figure 4—In areas where limestone has been eroded to expose the underlying volcanic core, volcanic soils have developed that support ravine forest. Repeated burning and loss of forest cover have led to soil erosion and slumping in these areas. Foresters in the Commonwealth of the Northern Mariana Islands are working to revegetate these areas and stabilize soils.

Pisonia grandis, Morinda citrifolia, Aglaia mariannensis, Pandanus dubius, Aidia cochinchinensis, Musa spp.*, Spathodea campanulata, Acacia confusa, Neisosperma oppositifolia, Erythrina variegata, Cocos nucifera, Adenanthera pavonina, Guettarda speciosa, Casuarina equisetifolia, Intsia bijuga, Bruguiera gymnorrhiza, Pithecellobium dulce, Cassia fistula, Heterospathe elata,* and *Pouteria obovata.*

Tangantangan (*Leucaena leucocephala*)—

Widely planted, *Leucaena* forests have become widespread, self-perpetuating stands. Dominant species within this type are *Leucaena leucocephala, Cynometra ramiflora, Carica papaya, Delonix regia, Albizia lebbeck, Annona* spp.*, Guamia mariannae, Melanolepis multiglandulosa, Psychotria mariniana, Premna obtusifolia, Pithecellobium dulce, Intsia bijuga, Cerbera dilatata,* and *Ficus prolixa.*

Other shrub and grass—

Some of the most common grasses, vines, and shrubs found in this type included *Pennisetum polystachyon, Mikania micrantha, P. purpureum, Urochloa maximum, Chromolaena odorata, Lantana camara, Macroptilium lathyroides, Antigonon leptopus, Nephrolepis hirsutula,* and *Solanum torvum.* Scattered among the shrubs

and grasses were trees including *Leucaena leucocephala, Eugenia stelechantha, Guamia mariannae, Intsia bijuga, Citrus ×aurantifolia, Ficus prolixa, Morus alba, Pipturus argenteus, Premna obtusifolia,* and *Neisosperma oppositifolia.*

Savanna complex—
The dominant tree species distributed within the savanna complex were *Morinda citrifolia, Leucaena leucocephala,* and *Neisosperma oppositifolia.* Dominant grasses include *Miscanthus floridulus,* and *Pennisetum* spp.

Urban and built-up areas—
Urban areas were dominated by *Albizia lebbeck,* and *Leucaena leucocephala.*

Casuarina thicket—
Casuarina equisetifolia forms monospecific stands in this type.

Inventory Methods

The CNMI inventory was based on the FIA inventory design that was implemented across the mainland United States beginning in 2000. We adapted the national design to include additional branching and rooting forms (fig. 5), additional tree crown measurements, and special-interest species ranging from invasive plants to

All photos Joseph Donnegan

Figure 5—Forest Inventory and Analysis protocols have been modified to capture rooting and branching forms unique to tropical tree species.

pathogens to culturally or economically important species of various life forms. Additionally, we used topography to define site productivity or drought resilience (for perhumid climates). In the mainland FIA program, plots are spaced within forest land on a 3.3-mile grid. With the assistance of the government of the CNMI, Department of Land and Natural Resources (CNMI-DLNR), plots were spaced across all vegetation types at about 1.9-mile intervals, yielding a triple intensification of the mainland inventory plot grid.

The FIA plot cluster is composed of four 24-foot-radius subplots (fig. 6). Three of those subplots are equally spaced, as if on spokes of a wheel, around the central subplot. The distance from the middle of the central subplot to the middle of each subplot on the three spokes is 120 feet.

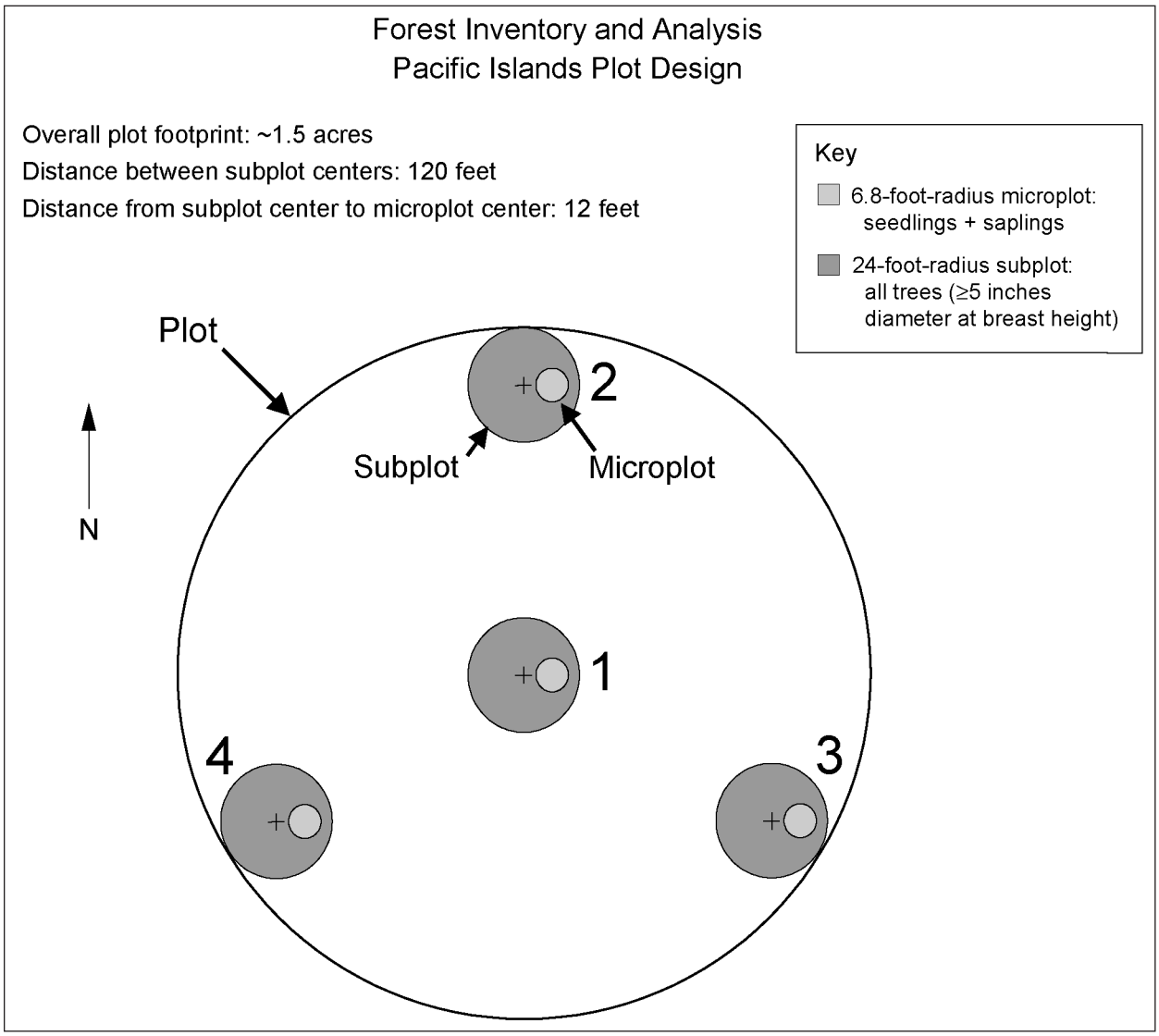

Figure 6—The plot design used for the continental U.S. Forest Inventory and Analysis program was adopted with slight simplification for the inventory in the Pacific Islands.

A variety of information was collected at the plot, subplot, and tree levels (USDA FS 2004). Differences in forest-type conditions are also mapped. For example, roads that intersect subplots are mapped, as are clear boundaries in forest tree size classes. The primary variables collected include plot location, slope, aspect, elevation, subplot slope position and shape, tree species, diameters, heights, damage, branching and rooting forms, decay, epiphytic loadings, crown characteristics, tree locations, and regeneration information. The fieldwork for this inventory was performed February to April 2004.

Analysis Methods

The FIA estimates derived for forest land are based on a system that uses aerial photography or satellite imagery to define different types of land (strata) across the landscape. The simplest stratification is separating land into forest and nonforest strata. However, stratifications can be assisted or refined by using ancillary data such as topography, soil information, life zone or climatically based information, and prior inventories of vegetation groups. Because boundaries and research questions often change through time, FIA generally chooses to post-stratify the plot sample by using a consistent spatial distribution of plots across forested landscapes.

The CNMI stratification for estimating numbers of trees, volume, biomass, and carbon was conducted via a classification of 2003 IKONOS satellite data. The initial land cover classification divided the landscape into forest, urban, nonforest vegetation, barren, and water land types. At least 10 percent tree cover was used as the basis for the forest-land classification, and includes both agroforests and mangrove forests. Nonforest vegetation includes other vegetation types with less than 10 percent tree cover. A geographic information system was used to sum acreage for each type. The acreage each field plot represents was derived by dividing the total acreage of forest by the number of field plots. Adjustments were made for plots that could not be visited owing to hazardous conditions or denial of access. Average stand size (mean diameters of trees) was expanded from the plots to the landscape level by using the same expansion factors.

Wood volume was estimated for individual trees by approximating the centroid method (Wood et al. 1990, Yavuz 1999) using tree height and two stem diameter measurements. These measurements are expanded to tree-level volume estimates by using equations for sections of a cone. Both gross stem volume and net stem volume estimates were calculated. Net stem volume subtracts damage and rotten defects from gross stem volume. Biomass for individual tree stems was estimated by using the specific gravity for known species (7 out of 57 species on the CNMI had known specific gravities). For species where specific gravity was not known, an average

specific gravity of 0.5 gram per cubic centimeter was used. These estimates of aboveground tree biomass are derived from bole volume and include only biomass for the main stem, excluding branches, roots, and foliage.

Traditional site productivity estimates require forest stand age, derived from the annual rings of forest trees. Because tropical trees do not produce consistent annual rings, a modified topographic relative moisture index (TRMI) (Parker 1982) was examined as a proxy for site productivity. The TRMI used a weighted, additive combination of slope steepness, slope shape, and slope position to assess the potential moisture retention in a forested stand. Remeasurement data from these plots at the next inventory cycle will provide a better estimate of productivity than TRMI. In very wet environments, TRMI may be best considered a drought-resilience proxy, predicting where soil and water accumulates, owing to topography, across a landscape. We also recognize moisture is not likely to be the only factor limiting tree growth and that a prolonged excess of moisture can be detrimental to the growth of many tree species. In highly porous limestone-derived soils and karst topography, drainage may occur very rapidly, making substrate water retention a limiting factor in plant growth.

Forest-type mapping was conducted independently by the Pacific Southwest Region's Remote Sensing Lab (S&PF-RSL) with support from FIA. Land cover polygons were generated from IKONOS and QuickBird imagery and labeled via low-elevation flights combined with ground survey through the cooperation of the CNMI-DLNR (Liu and Fischer 2007). Both the 2003 IKONOS and 2005 QuickBird satellite imagery were used for the detailed mapping and served as the basis for land cover estimates.

Reliability of FIA Data

The area of forested land cover types classified from the IKONOS and QuickBird satellite imagery was assumed to be accurate and used as the basis for the expansion of the numbers of trees, tree volume, and tree biomass from the plot to the forest-type scale. Possible sources of error not accounted for in our estimates include errors in the land cover map owing to incorrect interpretation of the image, errors from rounding when working with pixel-based imagery, and measurement errors on field plots. Standard errors for the expansion of our estimates from field plots to the forested landscape were calculated according to the proportion of area occupied by forest. Forest areas were treated as known rather than estimated, and variance was calculated by using methods in Cochran (1977). Using one standard error as our basis for evaluation gives a 68 percent chance that the true total gross tree stem volume for trees ≥5 inches in diameter on the CNMI lies between 26.5

and 43.3 million cubic feet. There is a 68-percent chance that the true number of trees (≥1 inch diameter) on the CNMI lies within the range of 75.8 to 103.7 million. Readers are cautioned to examine the standard errors associated with species-level estimates for the number of individuals and volume by tree species in table 1.

Resource Highlights

Land Cover

The CNMI is currently about 67 percent forested, which includes agroforest and *Leucaena* forest that had been classificed as secondary forest in the prior inventory (fig. 7, table 2). About 12 percent of the landscape was classified as urban land including roads, and about 20 percent was classified as nonforest vegetation including savanna and agricultural lands. The area used for land cover estimates totaled 75,407 acres.

A prior vegetation survey (Falanruw et al. 1989) delineated vegetation types by using 1976 aerial photography, and estimated forest cover to be 71 percent of total land, including secondary forest and agroforest (fig. 7, table 2). About 3 percent of the land area was classified as urban. Nonforest vegetation was estimated to be about 24 percent of the total land cover. Total acreage from the Falanruw et al. (1989) maps was 75,487 acres, calculated from the original maps that FIA scanned and digitized with support from S&PF-RSL.

The methodology and the area sampled for land cover estimates differ from those used for prior estimates. Falanruw et al. (1989) defined forested lands on the basis of a canopy cover of approximately ≥ 30 percent. The recent effort used a forest-land canopy threshold of ≥ 10 percent to remain consistent with the recent FIA work in American Samoa, Guam, and Palau. The current survey mapped roads as urban land.

Although the differences in interpretation methods and canopy cover thresholds between 1989 and 2005 must be considered, trends suggest conversions of forest and nonforest vegetation to urban land, especially on Saipan where urban land more than tripled.

Productivity and Drought Resilience

Site productivity estimates are difficult to obtain in tropical environments because of a lack of consistent annual tree rings. The standard premise for site productivity hinges on determining how height or diameter changes with respect to tree age under particular site conditions; depending on site quality, a given tree species is expected to grow to a certain diameter or height given a certain age. Remeasurement of individual trees at the next inventory cycle will provide better estimates

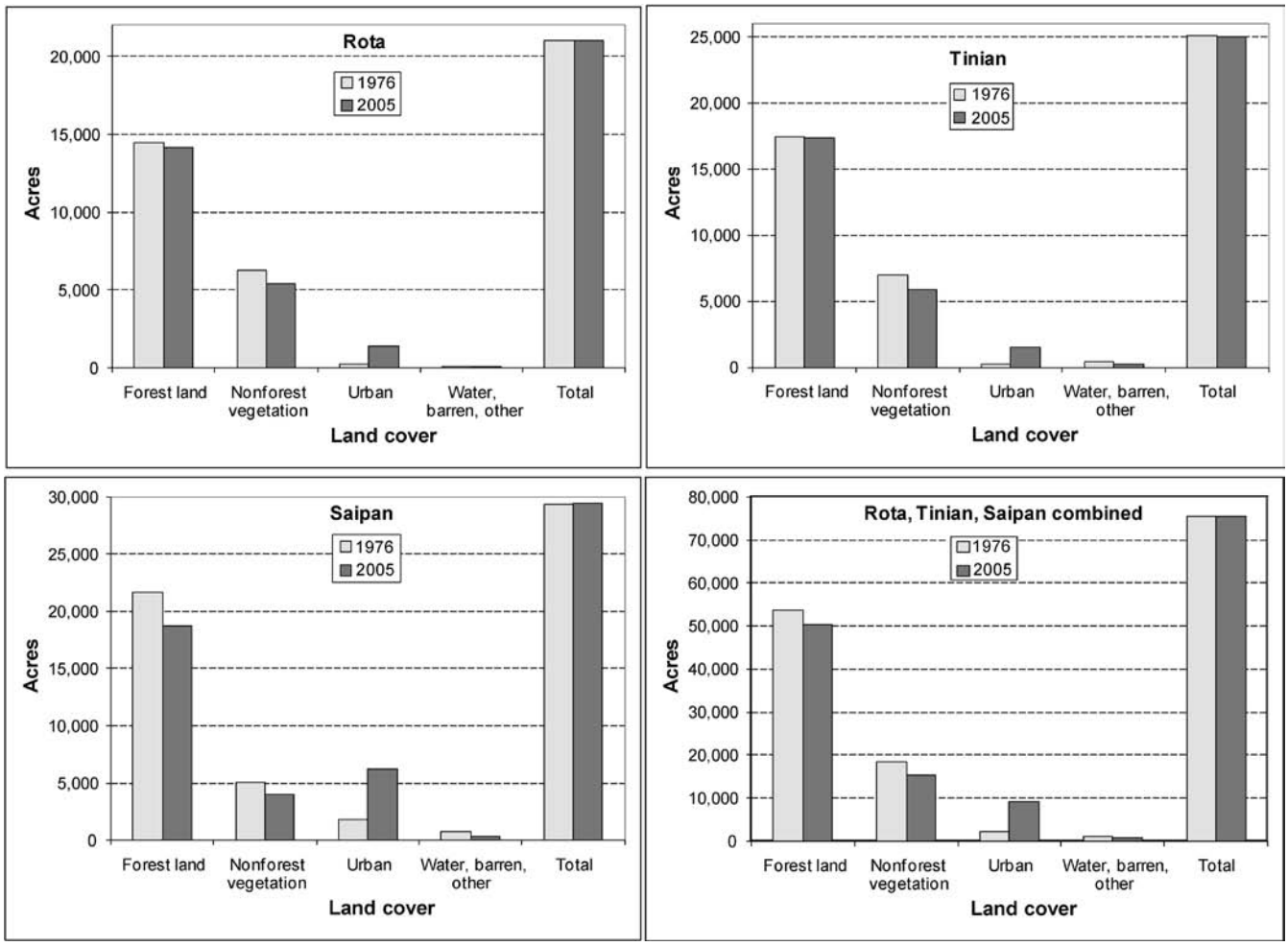

Figure 7—Forest land and nonforest vegetation appear to be losing area to urbanization, especially on Saipan. The population of the Commonwealth of the Northern Mariana Islands grew from an estimated 15,316 people in 1976 to 51,484 in 2009 (U.S. Census Bureau 2009).

Table 2—Estimated area by land cover by island in the Commonwealth of the Northern Mariana Islands, 1976[a] and 2005[b]

	1976					2005			
	Rota	Saipan	Tinian	Total		Rota	Saipan	Tinian	Total
	Acres					*Acres*			
Land cover type[c]					Land cover type[c]				
Limestone forest	12,196	1,181	1,710	15,087	Native limestone forest	10,943	255	1,355	12,553
Mangrove forest		18		18	Ravine forest	204			204
Atoll forest	81	11		92	Mixed introduced forest	1,833	12,801	7,002	21,635
Introduced forest	289	7,880	2,513	10,682	Casuarina thicket		76	359	434
Casuarina thicket	454	1,125	1,810	3,389	Agroforest	240	89	42	371
Agroforest	35	94	4	133	Agroforest—coconut	574	312	56	942
Coconut	1,057	3,015	282	4,355	*Leucaena leucocephala*	330	5,221	8,528	14,078
Secondary vegetation, forest	344	8,399	11,130	19,873					
Nonforest vegetation					Nonforest vegetation				
Savanna	3,121	3,352	2,957	9,430	Savanna		1,278		1,278
Secondary vegetation	2,374	456	2,428	5,257	Other shrub and grass	4,814	2,314	4,966	12,094
Strand	674	1,084	1,127	2,885	Strand	250	205	551	1,006
Cropland	128	222	474	824	Cropland	353	234	332	918
Urban	210	1,844	204	2,259	Urban and built-up	629	2,511	991	4,131
Unknown	35	2	12	49	Urban vegetation	761	3,745	530	5,036
Barren	41	300	363	704	Barren, beach, rocks	74	257	200	531
Marsh		360	42	402	Wetland		29	65	94
Water		45	5	50	Water	6	96		103
Forested subtotals	14,456	21,722	17,449	53,627	Forested subtotals	14,124	18,753	17,341	50,218
Total	21,040	29,386	25,061	75,487	Total	21,011	29,421	24,976	75,407

[a] Figures for maps derived from 1976 aerial photography differ slightly from those published by Falanruw et. al (1989). Figures here were derived by scanning the historical maps and aggregating area totals with a geographic information system.

[b] Figures for 2005 were summarized from the work of Liu and Fischer (2005), aggregating area totals with a geographic information system.

[c] Note that classification schemes differ slightly from the 1989 to 2005 map summaries.

of site productivity by using growth over the specific period. For the present work, we estimated productivity as an additive index based on a site's potential moisture accumulation owing to local topography (TRMI) (Parker 1982). The topographic relative moisture index may have utility in very wet environments as a predictor of resilience to occasional drought, because TRMI predicts moisture accumulation (and likely sediment/soil accumulation as well) based on topography. By using TRMI in this context, we classified nearly 60 percent of the forested lands in the CNMI as highly drought resilient (fig. 8). This high percentage demonstrates that the topography of the three southern islands is characterized by a relatively flat series of benches separated by narrow cliffs. However, owing to the porosity of the dominant limestone soils and geology, drought resilience is likely overestimated because of rapid infiltration and low moisture holding capacity.

In a region of moderately high precipitation, such as the CNMI, the TRMI estimate of productivity may be much less reliable than productivity estimates based on detailed soil mapping. For example, differences among forest and savanna soils are dramatic with respect to soil organic matter, cation exchange capacity, and potential aluminum toxicity for plant growth. In volcanic landscapes, a succession of soil

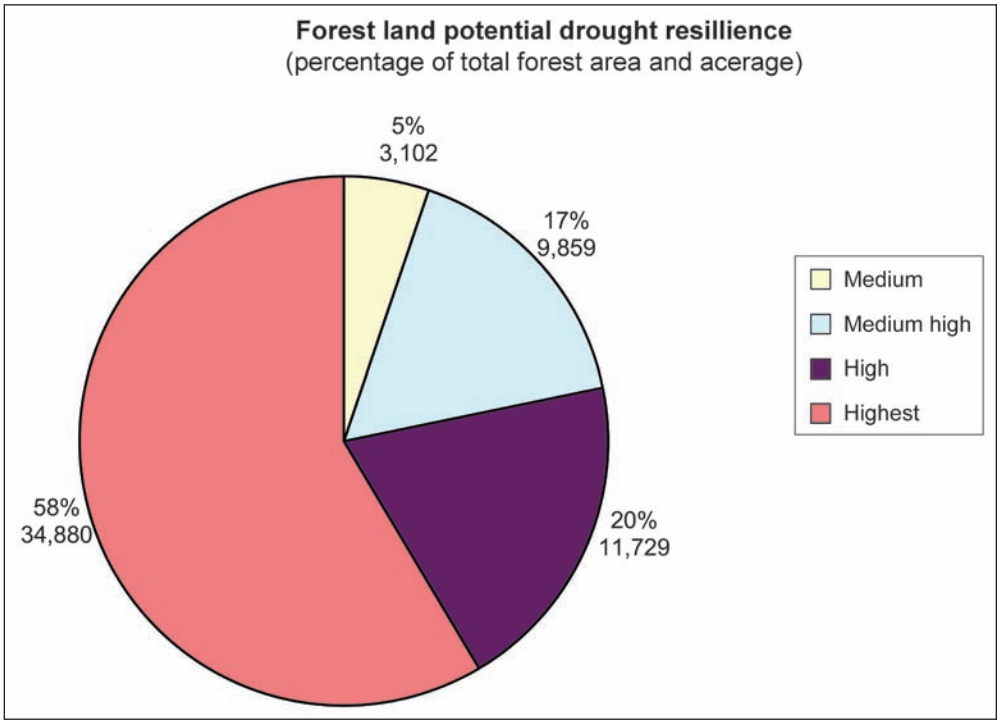

Figure 8—A topographic relative moisture index was used to predict drought resilience in the perhumid climate of the Commonwealth of the Northern Mariana Islands. Owing to the series of plateaus and escarpments that characterize Rota, Tinian, and Saipan, the degree of drought resilience estimated is higher than would be expected for porous limestone soils and karst topography.

degradation can occur from forest soils to savanna and badland soils through processes of land clearing, repeated burning, and subsequent erosion and leaching of topsoil nutrients (e.g., see Smith and Babik 1988). Aluminum toxicity to plants may be an issue in the limited extent of volcanic soils on the CNMI, but it is not a problem on limestone-derived soils where the soil pH is high enough to prevent aluminum from becoming soluble.

Forest Structure

For this inventory, we estimated stand size class on forested field plots to capture the predominant diameter of live trees in forest stands. In the CNMI, the dominant size class tends to be small, in the less-than-5-inch diameter category (fig. 9, table 3). About 45 percent of acreage in the CNMI is made up of stands in the 5- to 10.9-inch category, and only about 2 percent of acreage is dominated by larger trees in the 11- to 19.9-inch category. No plots were sampled that included stands in the largest diameter category of 20 inches and greater.

Forest stands on the CNMI are dominated by small-diameter trees (fig. 10). This "reverse-J" distribution of tree diameter is typical where regeneration is abundant, especially following frequent disturbance. Through time, many small trees die before they grow into the larger diameter classes. For trees at least 5 inches in diameter, tree heights are predominantly in the 20- to 29-foot height classes (fig. 11). The tallest tree on an FIA plot, an *Albizia lebbeck*, measured 12.6 inches in diameter

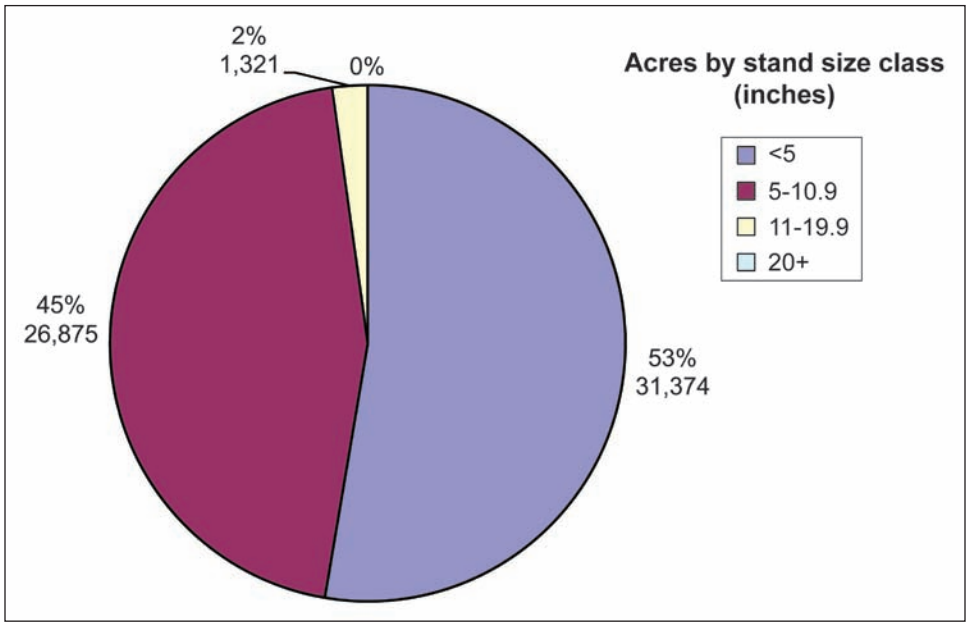

Figure 9—The stands that characterize the Commonwealth of the Northern Mariana Islands' forests tend to be somewhat small, primarily in the less than 11-inch diameter category.

Table 3—Estimated number of live trees on forest land by species and diameter class

Species	Diameter class (inches)													
	< 5.0	5.0–6.9	7.0–8.9	9.0–10.9	11.0–12.9	13.0–14.9	15.0-16.9	17.0–18.9	19.0–20.9	21.0–22.9	23.0–24.9	25.0–26.9	27.0–28.9	29.0+	All classes
	Number of trees														
Acacia confusa	132,241														132,241
Adenanthera pavonina				22,800							11,400				34,199
Aglaia mariannensis	998,839	12,769													1,011,607
Aidia cochinchinensis	142,004														142,004
Albizia lebbeck	1,582,323	138,575	37,573	11,400	11,400					11,400					1,792,671
Allophylus timorensis	132,241														132,241
Annona spp.	142,004														142,004
Artocarpus altilis						10,616	21,232								31,848
Barringtonia asiatica		10,616	10,616			10,616									31,848
Barringtonia racemosa	132,241	10,616													142,857
Bruguiera gymnorrhiza			11,400	11,400											22,800
Carica papaya	2,460,268	49,240	12,769												2,522,276
Cassia fistula			11,400												11,400
Casuarina equisetifolia		13,087	47,406	36,790	52,347	52,347	13,087								215,063
Cerbera dilatata		11,400													11,400
Citrus ×aurantifolia	330,374														330,374
Citrus hystrix	6,215,306														6,215,306
Claoxylon marianum	132,241														132,241
Cocos nucifera			22,016	87,279	44,815	22,800									176,910
Cynometra ramiflora	6,566,153	251,369	44,032	12,769	12,769			12,769							6,899,858
Delonix regia	710,022				11,400	11,400									732,821
Discocalyx ponapensis	1,906,823														1,906,823
Drypetes spp.	528,962														528,962
Elaeocarpus joga		31,848	21,232												53,080
Erythrina variegata		22,800	34,199	22,800	11,400	22,800									113,998
Eugenia palumbis	1,586,887														1,586,887
Eugenia stelechantha	1,651,872														1,651,872
Ficus prolixa	3,327,541	298,336	126,369	22,016	12,769				11,400				11,400		3,809,830
Ficus spp.		21,232													21,232
Ficus tinctoria	710,022	11,400			10,616										732,038
Guamia mariannae	5,051,697	47,553													5,099,250
Guettarda speciosa		44,032	21,232	10,616											75,879
Hernandia sonora	132,241	74,312	74,312	10,616	31,848	10,616		21,232					10,616		365,792
Heterospathe elata		11,400													11,400
Hibiscus tiliaceus	945,212	79,015	22,800	11,400											1,058,426
Intsia bijuga	330,374	125,608	47,406	55,551	13,087										572,025
Leucaena leucocephala	38,193,490	609,455	12,769												38,815,714
Mammea odorata		12,769													12,769
Mangifera indica				10,616											10,616

Table 3—Estimated number of live trees on forest land by species and diameter class (continued)

Species	Diameter class (inches)													
	< 5.0	5.0–6.9	7.0–8.9	9.0–10.9	11.0–12.9	13.0–14.9	15.0–16.9	17.0–18.9	19.0–20.9	21.0–22.9	23.0–24.9	25.0–26.9	27.0–28.9	29.0+	All classes
	Number of trees														
Melanolepis multiglandulosa	1,255,384	167,809	25,537												1,448,730
Morinda citrifolia	813,670	25,537	11,400												850,607
Morus alba	330,374														330,374
Musa spp.		79,799	56,999												136,798
Neisosperma oppositifolia	132,241	36,790	23,703												192,733
Pandanus dubius		259,844	66,831												326,675
Pandanus tectorius	3,702,736	881,126	42,464												4,626,326
Pipturus argenteus	297,428														297,428
Pisonia grandis	284,009	56,999			22,800										363,807
Pithecellobium dulce		35,568	11,400												46,968
Pouteria obovata			11,400												11,400
Premna obtusifolia	460,113	382,532	158,853	23,385	10,616	12,769			12,769	12,769					1,073,804
Psychotria mariana	301,059	76,611	25,537												403,207
Spathodea campanulata		56,999	56,999	11,400	11,400										136,798
Unknown	1,719,127		10,616												1,729,743
Unknown 0		11,400													11,400
Unknown 1	142,004														142,004
Unknown, other	330,374														330,374
Total	83,809,894	3,958,443	1,059,266	360,835	257,265	153,963	34,319	34,000	24,168	24,168	11,400		22,016		89,749,736

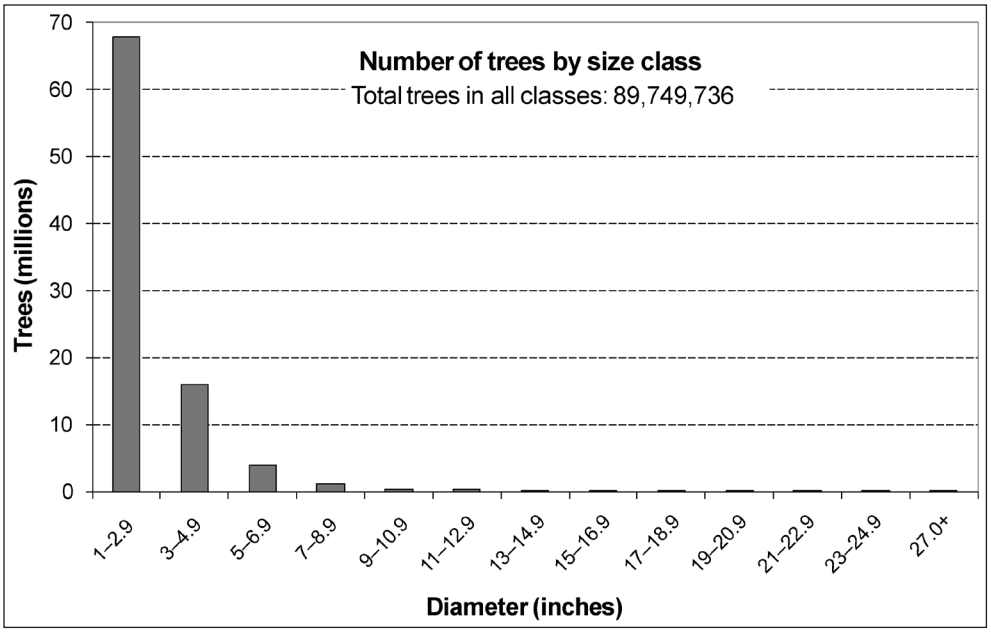

Figure 10—Small trees are very common in the Commonwealth of the Northern Mariana Islands, indicating disturbance and regeneration are abundant.

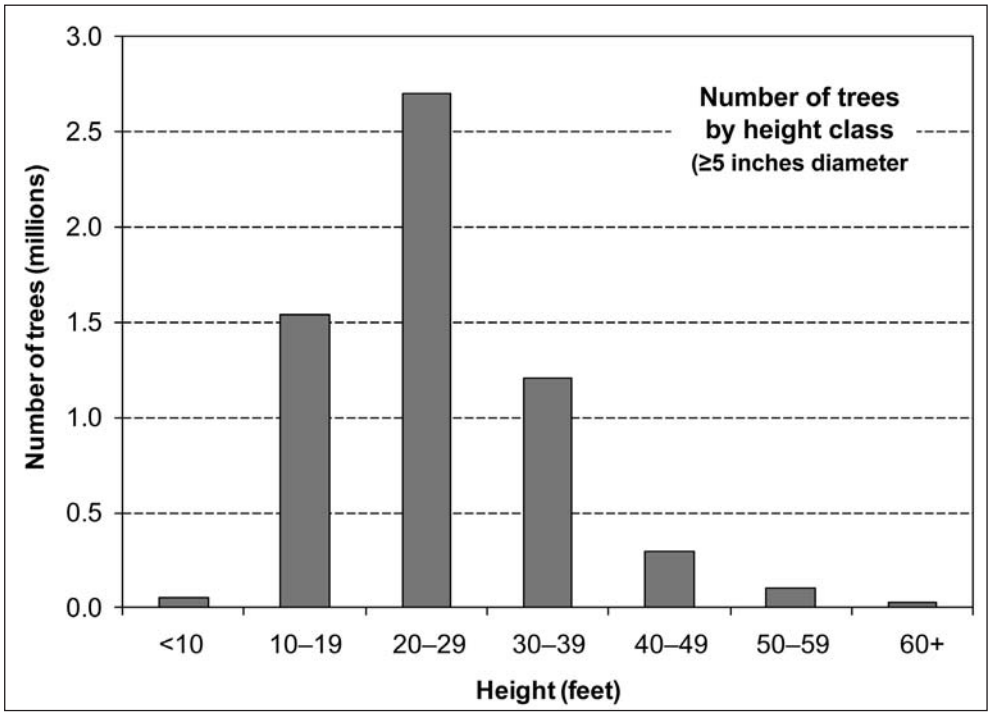

Figure 11—For trees greater than or equal to 5 inches in diameter, the most common heights attained range from 20 to 29 feet tall.

and about 67 feet tall. The largest diameter tree was a *Ficus prolixa* measuring 28 inches in diameter and 54 feet tall.

Wood volume (fig. 12, tables 1, 4, and 5), biomass (fig. 13, table 6), and carbon storage (table 7) follow a similar distribution as the "reverse-J" seen for the number of trees according to diameter (fig. 10). Most of the volume, biomass, and carbon is accounted for in the smaller diameter classes owing to the relatively high number of trees in those size classes.

Number of Canopy and Understory Species

In addition to counting and measuring overstory trees, understory vegetation cover and layer heights were estimated for shrubs, forbs, vines, and grasses on FIA subplots where a species occupied at least 3 percent cover on that subplot (table 8). Tree seedlings that are less than or equal to 1 inch in diameter are also estimated

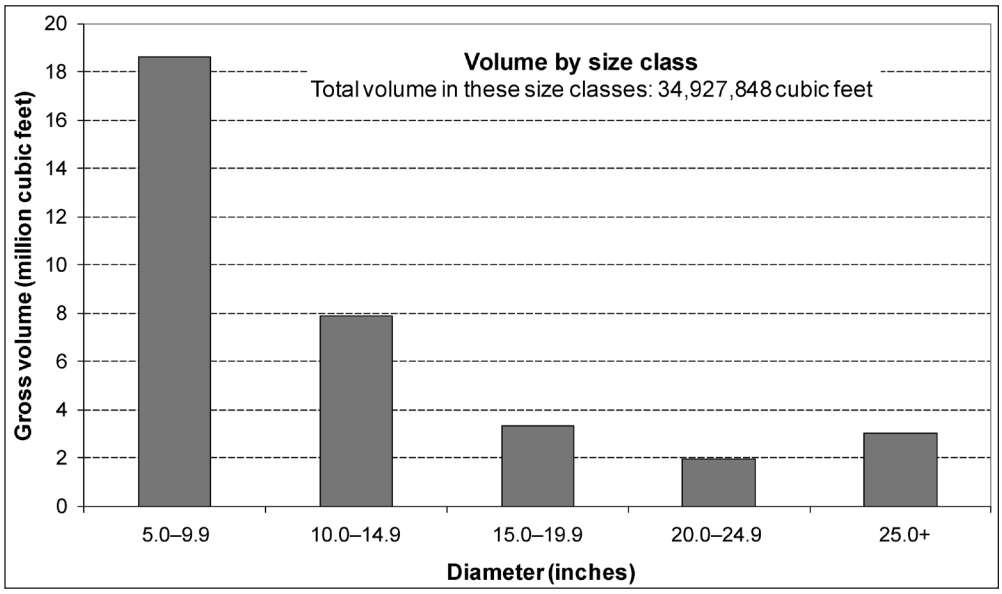

Figure 12—As with numbers of trees, gross volume of wood tends to be concentrated in the smaller diameter classes. However, some larger diameter trees contribute to the volume in those size classes.

Table 4—Estimated volume of live trees on forest land by diameter class

	Diameter class (inches)					
	< 5	**5–9.9**	**10–14.9**	**15–19.9**	**≥ 20**	**All sizes**
			Cubic feet			
Gross volume	31,592,041	18,641,936	7,893,647	3,349,492	5,042,772	66,519,888
Net volume (≥ 5 in)		18,612,869	7,862,086	3,301,640	4,922,072	34,698,667

Table 5—Estimated gross volume of live trees ≥ 5 inches diameter at breast height on forest land by species and diameter class

Species	Diameter class (inches)												All classes
	5.0–6.9	7.0–8.9	9.0–10.9	11.0–12.9	13.0–14.9	15.0–16.9	17.0–18.9	19.0–20.9	21.0–22.9	23.0–24.9	25.0–26.9	27.0–28.9	29.0+	
	Cubic feet													
Adenanthera pavonina			264,650							844,086				1,108,736
Aglaia mariannensis	27,663													27,663
Albizia lebbeck	389,256	208,802	114,238	262,499					712,926					1,687,721
Artocarpus altilis					239,435	821,178								1,060,613
Barringtonia asiatica	18,116	35,328			123,158									176,601
Barringtonia racemosa	14,185													14,185
Bruguiera gymnorrhiza		66,024	96,400											162,424
Carica papaya	157,309	66,858												224,167
Cassia fistula		45,838												45,838
Casuarina equisetifolia	39,970	285,899	386,706	670,989	1,029,251	409,357								2,822,173
Cerbera dilatata	21,138													21,138
Cocos nucifera		147,509	922,527	528,819	614,373									2,213,227
Cynometra ramiflora	579,828	250,209	83,969	109,287			226,955							1,250,248
Delonix regia				172,230	250,356									422,586
Elaeocarpus joga	78,719	96,134												174,853
Erythrina variegata	66,838	162,168	215,931	191,269	631,314									1,267,520
Ficus prolixa	932,736	650,919	204,278	166,345				1,042,417				2,358,489		5,355,185
Ficus spp.	48,825													48,825
Ficus tinctoria	36,336			76,442										112,779
Guamia mariannae	97,072													97,072
Guettarda speciosa	113,040	87,547	54,504											255,091
Hernandia sonora	186,616	315,740	68,701	346,541	152,119		530,365					696,527		2,296,609
Heterospathe elata	34,661													34,661
Hibiscus tiliaceus	221,806	97,321	82,222											401,349
Intsia bijuga	311,158	198,619	373,450	114,490										997,715
Leucaena leucocephala	1,684,029	43,571												1,727,600
Mammea odorata	25,099													25,099
Mangifera indica			91,305											91,305
Melanolepis multiglandulosa	434,952	114,201												549,154
Morinda citrifolia	66,405	86,016												152,420
Neisosperma oppositifolia	114,139	113,425												227,565
Pandanus dubius	1,070,765	428,649												1,499,415
Pandanus tectorius	2,859,948	219,280												3,079,227
Pisonia grandis	181,121			277,054										458,175
Pithecellobium dulce	80,287	55,989												136,276
Pouteria obovata		75,945												75,945
Premna obtusifolia	1,379,089	834,140	154,791	112,364	174,571			319,220	430,743					3,404,918
Psychotria mariana	195,168	117,067												312,235
Spathodea campanulata	197,427	345,790	137,943	149,326										830,487
Unknown		49,046												49,046
Unknown 0	29,999													29,999
Total	11,693,701	5,198,035	3,251,615	3,177,655	3,214,576	1,230,535	757,320	1,361,637	1,143,670	844,086		3,055,016		34,927,848

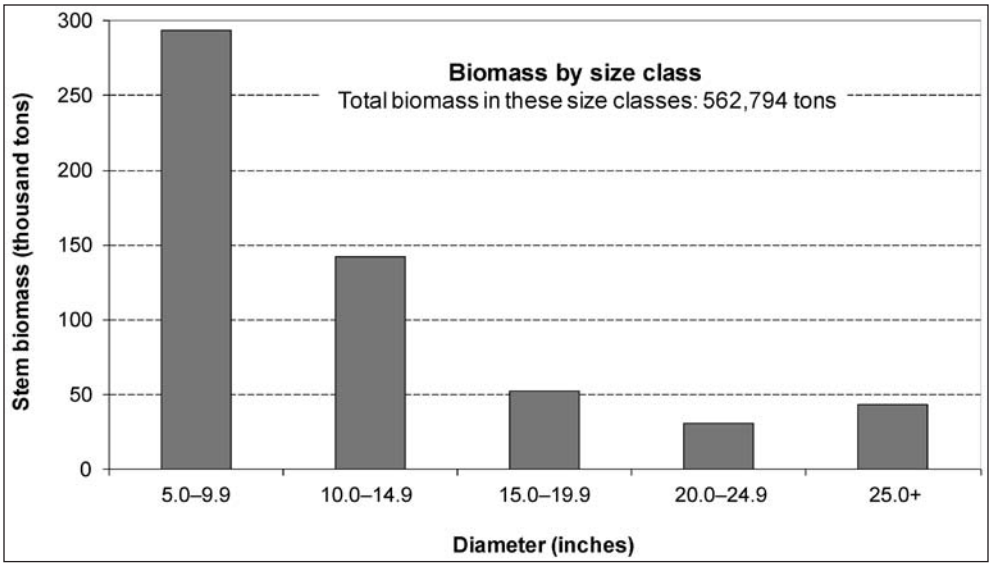

Figure 13—Biomass is also concentrated in the smaller size classes.

Table 6—Estimated aboveground dry stem weight of live trees ≥ 5 inches diameter at breast height on forest land by species and diameter class

Species	Diameter class (inches)												All classes
	5.0 6.9	7.0– 8.9	9.0– 10.9	11.0– 12.9	13.0– 14.9	15.0– 16.9	17.0– 18.9	19.0– 20.9	21.0– 22.9	23.0– 24.9	25.0– 26.9	27.0– 28.9	29.0+	
	Tons													
Adenanthera pavonina			4,131							13,174				17,305
Aglaia mariannensis	432													432
Albizia lebbeck	6,075	3,259	1,783	4,097					11,127					26,341
Artocarpus altilis					3,737	12,817								16,554
Barringtonia asiatica	283	551			1,922									2,756
Barringtonia racemosa	221													221
Bruguiera gymnorrhiza		1,030	1,505											2,535
Carica papaya	2,455	1,043												3,499
Cassia fistula		715												715
Casuarina equisetifolia	1,036	7,407	10,019	17,384	26,666	10,606								73,118
Cerbera dilatata	330													330
Cocos nucifera		2,302	14,398	8,254	9,589									34,543
Cynometra ramiflora	9,050	3,905	1,311	1,706			3,542							19,513
Delonix regia				2,688	3,907									6,596
Elaeocarpus joga	1,229	1,500												2,729
Erythrina variegata	1,043	2,531	3,370	2,985	9,853									19,783
Ficus prolixa	14,558	10,159	3,188	2,596				16,270				36,810		83,581
Ficus spp.	488													488
Ficus tinctoria	442			931										1,373
Guamia mariannae	1,515													1,515
Guettarda speciosa	1,764	1,366	851											3,981
Hernandia sonora	1,689	2,858	622	3,137	1,377		4,801					6,305		20,790
Heterospathe elata	541													541
Hibiscus tiliaceus	3,946	1,732	1,463											7,141
Intsia bijuga	5,925	3,782	7,111	2,180										18,998
Leucaena leucocephala	26,283	680												26,964
Mammea odorata	392													392
Mangifera indica			1,425											1,425
Melanolepis multiglandulosa	6,789	1,782												8,571
Morinda citrifolia	1,036	1,342												2,379
Neisosperma oppositifolia	1,781	1,770												3,552
Pandanus dubius	16,712	6,690												23,402
Pandanus tectorius	44,637	3,422												48,059
Pisonia grandis	2,827			4,324										7,151
Pithecellobium dulce	1,253	874												2,127
Pouteria obovata		1,185												1,185
Premna obtusifolia	21,524	13,019	2,416	1,754	2,725			4,982	6,723					53,142
Psychotria mariana	3,046	1,827												4,873
Spathodea campanulata	3,081	5,397	2,153	2,331										12,962
Unknown		765												765
Unknown 0	468													468
Total	182,852	82,898	55,745	54,366	59,777	23,422	8,343	21,252	17,850	13,174		43,115		562,794

Table 7—Estimated carbon mass of live trees ≥ 5 inches diameter at breast height on forest land by species and diameter class

Species	Diameter class (inches)												All classes
	5.0–6.9	7.0–8.9	9.0–10.9	11.0–12.9	13.0–14.9	15.0–16.9	17.0–18.9	19.0–20.9	21.0–22.9	23.0–24.9	25.0–26.9	27.0–28.9	29.0+	
	Tons													
Adenanthera pavonina			2,065							6,587				8,652
Aglaia mariannensis	216													216
Albizia lebbeck	3,038	1,629	891	2,048					5,563					13,171
Artocarpus altilis					1,868	6,408								8,277
Barringtonia asiatica	141	276			961									1,378
Barringtonia racemosa	111													111
Bruguiera gymnorrhiza		515	752											1,268
Carica papaya	1,228	522												1,749
Cassia fistula		358												358
Casuarina equisetifolia	518	3,704	5,009	8,692	13,333	5,303								36,559
Cerbera dilatata	165													165
Cocos nucifera		1,151	7,199	4,127	4,794									17,271
Cynometra ramiflora	4,525	1,953	655	853			1,771							9,757
Delonix regia				1,344	1,954									3,298
Elaeocarpus joga	614	750												1,365
Erythrina variegata	522	1,266	1,685	1,493	4,927									9,891
Ficus prolixa	7,279	5,080	1,594	1,298				8,135				18,405		41,791
Ficus spp.	244													244
Ficus tinctoria	221			465										686
Guamia mariannae	758													758
Guettarda speciosa	882	683	425											1,991
Hernandia sonora	845	1,429	311	1,569	689		2,401					3,153		10,395
Heterospathe elata	270													270
Hibiscus tiliaceus	1,973	866	731											3,571
Intsia bijuga	2,962	1,891	3,555	1,090										9,499
Leucaena leucocephala	13,142	340												13,482
Mammea odorata	196													196
Mangifera indica			713											713
Melanolepis multiglandulosa	3,394	891												4,285
Morinda citrifolia	518	671												1,189
Neisosperma oppositifolia	891	885												1,776
Pandanus dubius	8,356	3,345												11,701
Pandanus tectorius	22,318	1,711												24,030
Pisonia grandis	1,413			2,162										3,575
Pithecellobium dulce	627	437												1,063
Pouteria obovata		593												593
Premna obtusifolia	10,762	6,509	1,208	877	1,362			2,491	3,361					26,571
Psychotria mariana	1,523	914												2,437
Spathodea campanulata	1,541	2,698	1,076	1,165										6,481
Unknown		383												383
Unknown 0	234													234
Total	91,426	41,449	27,872	27,183	29,888	11,711	4,172	10,626	8,925	6,587		21,558		281,397

Table 8—Average understory vegetation cover[a] on Forest Inventory and Analysis field subplots by species

Scientific name	Cover	Number of subplots	Standard deviation across subplots where species was found
	Percent		
Abrus precatorius L.	3.8	17	3.6
Achyranthes aspera L.	1.7	3	1.2
Alocasia cucullata (Lour.) G. Don	1.0	1	
Aloe sp. L.	1.0	1	
Antigonon leptopus Hook. & Arn.	15.7	3	21.2
Antrophyum plantagineum (Cav.) Kaulf.	2.0	1	
Asplenium nidus L.	1.9	16	1.4
Asplenium pellucidum Lam.	1.0	2	0.0
Asplenium polyodon G. Forst.	1.7	3	0.6
Axonopus compressus (Sw.) Beauv.	3.3	3	1.5
Bidens alba (L.) DC.	21.3	14	29.0
Bikka mariannensis Brongniart	6.3	3	6.1
Bixa orellana L.	6.0	1	
Blechum pyramidatum (Lam.) Urb.	9.2	16	8.0
Bougainvillea sp. Comm. ex Juss	1.0	1	
Brachiarai mutica (Forsk.) Stapf	28.0	1	
Brassica sp. L.	30.0	1	
Bulbophyllum longiflorum Thouars	1.0	5	0.0
Callicarpa candicans (Burm. f.) Hochr.	2.7	3	2.1
Calopogonium mucunoides Desv.	3.0	1	
Capparis cordifolia Lam.	1.0	1	
Capsicum annuum var. *annuum* L.	3.0	38	2.1
Cayratia trifolia (L.) Domin	1.0	1	
Centrosema pubescens Benth.	9.3	8	9.2
Cheilanthes tenuifolia (Burmann) Swartz	2.0	3	1.0
Chromolaena odorata (L.) King & H.E. Robins.	5.8	40	7.0
Coccinia grandis (L.) Voigt	22.4	10	23.9
Coelogyne guamensis Ames	1.0	1	
Colocasia sp. Schott	6.0	1	
Colubrina asiatica (L.) Brongn.	1.9	13	0.8
Combined ferns	3.0	1	
Commelina benghalensis L.	24.0	2	29.7
Commelina diffusa Burm. f.	1.0	2	0.0
Cyperus compressus L.	4.0	1	
Cyperus polystachyos var. *polystachyos* (Rottb.) Beauv.	1.0	2	0.0
Davallia solida (Forster fil.) Swartz. Schrad	5.8	6	10.4
Dichanthium bladhii (Retz.) S.T. Blake	35.0	2	0.0
Digitaria ciliaris (Retz.) Koel.	2.0	1	
Digitaria insularis (L.) Mez ex Ekman	26.0	4	29.6
Euphorbia heterophylla L.	12.0	1	

Table 8—Average understory vegetation cover[a] on Forest Inventory and Analysis field subplots by species (continued)

Scientific name	Cover	Number of subplots	Standard deviation across subplots where species was found
	Percent		
Flagellaria indica L.	3.6	27	3.4
Freycinetia mariannensis Merrill	3.7	6	2.1
Freycinetia sp. Gaud.	1.0	1	
Gleichenia linearis (Luers.) Fosberg	14.0	2	8.5
Heterogonium pinnatum (Copel.) Holtt.	20.0	1	
Ipomea obscura (L.) Ker-Gawl	6.0	1	
Ipomoea indica (Burm.f.) Merr.	1.0	1	
Ipomoea littoralis Blume	6.0	1	
Justicia procumbens L.	20.1	7	30.7
Lantana camara L.	8.7	34	16.1
Macroptilium lathyroides (L.) Urban	11.6	7	8.5
Merremia peltata (L.) Merrill	9.0	22	9.4
Microsorum scolopendria (Burm. f.)	5.5	37	5.7
Mikania micrantha Kunth	13.5	47	14.1
Mimosa diplotricha C. Wright ex Sauvalle Mart., non Mart. ex Colla	1.3	4	0.5
Mimosa pudica L.	1.8	4	1.0
Mimosa sp. L.	2.3	6	1.6
Momordica charantia L.	4.1	19	3.0
Nephrolepis biserrata (Sw.) Schott	38.5	2	30.4
Nephrolepis hirsutula (J.R. Forst.) K. Presl	8.3	13	7.0
Nephrolepis sp. Schott	3.0	4	1.6
Nerium oleander L.	1.0	1	
Nesogenes sp. A. DC.	1.0	2	0.0
Operculina turpethum (L.) Silva Manso	12.4	5	21.1
Oplismenus hirtellus (L.) Beauv. var. *setarius* (Lam.) F.M. Bailey	11.4	7	19.3
Paspalum conjugatum Berg.	4.0	3	3.5
Passiflora foetida L.	4.0	3	2.7
Passiflora suberosa L.	7.1	16	6.5
Pennisetum polystachyon (L.) J.A. Schultes	29.8	14	37.1
Pennisetum purpureum Schumacher	22.9	17	27.4
Pennisetum setaceum (Forsk.) Chiov.	8.0	2	9.9
Physalis angulata L.	1.0	1	
Piper betel L.	2.0	1	
*Piper guahamens*e C. DC.	5.5	10	5.2
Poaceae unknown	13.0	2	17.0
Polygala paniculata L.	1.0	1	
Polypodium cyathoides Sw.	12.0	2	11.3
Polypodium punctatum Thunb. ex Murray	4.0	2	4.2
Psychotria mariniana Bartling ex DC	2.5	4	1.9

Table 8—Average understory vegetation cover[a] on Forest Inventory and Analysis field subplots by species (continued)

Scientific name	Cover	Number of subplots	Standard deviation across subplots where species was found
	Percent		
Pteris tripartita Sw.	4.0	1	
Pueraria montana (Lour.) Merr.	3.0	1	
Rivina humilis L.	14.3	4	17.2
Ruellia prostrata Poir.	16.0	5	19.5
Scaevola sericea Vahl var. *taccada* (Gaertn.) Thieret & B. Lipscomb	34.0	4	43.8
Sida rhombifolia L.	4.0	2	2.8
Solanum americanum P. Mill	2.7	3	0.6
Solanum melongena L.	1.0	1	
Solanum torvum Sw.	5.3	7	6.7
Spathoglottis plicata Blume	1.0	1	
Stachytarpheta jamaicensis (L.) Vahl	8.0	1	
Stachytarpheta sp. Vahl	1.0	1	
Stachytarpheta urticifolia Sims	20.8	9	24.9
Stictocardia tiliifolia (Desr.) Hallier f.	11.0	2	12.7
Tectaria crenata Cav.	2.7	3	1.5
Thelypteris gretheri (W. Wagner) Stone	1.0	2	0.0
Thelypteris truncata (Poir.) K. Iwats.	3.0	1	
Urochloa maxima (Jacq.) R. Webster	17.3	9	19.7
Verbena litoralis Kunth	1.0	2	0.0
Unknown fern 1	10.0	1	
Unknown fern 3	2.0	1	
Unknown forb	3.2	26	2.4
Unknown grass 1	2.0	2	1.4
Unknown perrenial grass 1	5.3	9	5.2
Unknown perrenial grass 2	2.0	4	2.0
Unknown shrub	6.0	31	5.2
Unknown sp.	3.0	1	
Unknown vine	6.3	24	6.9

[a] Percentage cover of "1" indicates cover less than or equal to 1 percent. Cover estimates are averaged among subplots where each species was found. A total of 138 subplots were surveyed for vegetation cover. The number of subplots where a species was found and the standard deviation for cover estimates provide an idea of spatial variability for each species across the island group.

as understory vegetation cover (table 9). Special interest species (e.g., rare, endangered, medicinal, or invasive) identified by island foresters were also noted when found. However, if a species covered less than 3 percent of a subplot and was not listed as special interest, it was not enumerated.

For the 2004 inventory, 57 tree species and 107 understory species were measured on FIA plots. On a per-plot basis (approximately one-sixth acre), the mean number of tree species found was five (fig. 14).

Tree Damage and Mortality

We estimated about 32 percent of the individual trees on the CNMI show some sign of damage (table 10). The most prevalent damage types are vines in crowns, lost apical dominance (damage to the primary growing leader), and conks (shelf-fungus indicating rot) (fig. 15). Vines in tree crowns are common (44 percent of damaged trees), although their effect on their supporting tree hosts was not quantified. Effects ranged from some additional weight to instances of strangulation, smothering (especially *Antigonon leptopus, Coccinia grandis,* and *Mikania micrantha*), and breaking of branches. For the identifiable damaging agents, damage by other vegetation, weather, and insects ranked as the most prevalent primary damage agents (fig. 16).

Less than one half of 1 percent of the trees sampled during the inventory were dead. The most prevalent, identifiable dead trees were *Premna obtusifolia* (27.9 percent of total dead), *Pandanus tectorius* (15.2 percent), *Intsia bijuga* (14.5 percent), and *Albizia lebbeck* (9.4 percent) (fig. 17).

Epiphytes

In the moist environment of the tropics, many plant species are found growing on longer lived trees. These epiphytes use the trees primarily for support, but they also use space, moisture, and nutrients that might otherwise be used by the tree. When the epiphytes accumulate over many years, their weight can be excessive, leading to the breakage of branches and occasionally snapping the stems of trees. In the CNMI, we rated epiphytic loading on trees as a summation of loading on the bole, branches, and canopy. We estimate that about 59 percent of the trees in the CNMI had few to no epiphytes, and 41 percent of the trees had moderate to high amounts of epiphytes (table 11).

Forest Dynamics

Forest structure and species composition change through time as a result of forest succession and disturbance dynamics. The forests of the CNMI have been strongly

Table 9—Average understory tree cover[a] on Forest Inventory and Analysis field subplots by species

Scientific name	Cover	Number of subplots	Standard deviation across subplots where species was found
	Percent		
Acacia confusa	2.0	2	1.4
Adenanthera pavonina	15.0	1	
Aglaia mariannensis	1.6	16	1.0
Aidia cochinchinensis	1.7	3	1.2
Albizia lebbeck	3.6	10	4.3
Annona sp.	1.0	1	
Annona squamosa L.	13.0	1	
Areca catechu L.	5.0	1	
Artocarpus altilis	4.0	2	1.4
Carica papaya	1.6	16	0.9
Casuarina equisetifolia	2.0	2	1.4
Citrus hystrix	14.7	7	13.0
Citrus sp.	9.0	1	
Claoxylon marianum	1.7	3	1.2
Cocos nucifera	5.9	14	5.0
Coffea arabica L.	1.0	1	
Commersonia bartramia (L.) Merr.	1.0	1	
Cynometra ramiflora	8.4	16	7.5
Delonix regia	3.0	1	
Discocalyx ponapensis	1.0	2	0.0
Elaeocarpus joga	1.0	1	
Eugenia palumbis	2.9	15	3.1
Eugenia reinwardtiana (Blume) DC.	2.0	1	
Eugenia stelechantha Merr.	2.2	5	1.6
Eugenia thompsonii	1.0	1	
Ficus prolixa	1.8	16	0.8
Ficus sp.	1.0	1	
Ficus tinctoria	2.0	4	0.8
Guamia mariannae	3.6	31	3.6
Guettarda speciosa	3.0	1	
Hernandia sonora	2.3	4	1.3
Hibiscus tiliaceus	2.5	2	2.1
Leucaena leucocephala	4.2	65	7.1
Macaranga thompsonii Merr.	1.0	1	
Mammea odorata	1.5	2	0.7
Melanolepis multiglandulosa	1.6	22	0.9
Morinda citrifolia	1.7	19	1.6
Neisosperma oppositifolia	1.8	5	1.3
Pandanus dubius	7.7	13	10.6

Table 9—Average understory tree cover[a] on Forest Inventory and Analysis field subplots by species (continued)

Scientific name	Cover	Number of subplots	Standard deviation across subplots where species was found
	Percent		
Pandanus tectorius	12.7	24	16.4
Pemphis acidula J.R. Forst. & G. Forst.	59.3	3	9.0
Pipturus argenteus	3.3	3	2.5
Pithecellobium dulce	1.0	1	
Pouteria obovata	1.8	6	1.0
Premna obtusifolia	1.3	6	0.5
Psidium guajava L.	1.3	3	0.6
Psychotria mariniana	3.0	17	3.0
Spathodea campanulata	2.5	2	0.7
Streblus pendulinus (Endl.) F. Muell.	1.0	1	
Thespesia populnea (L.) Sol. ex Correa	1.0	1	
Unknown	1.0	1	
Unknown 0	1.0	2	0.0
Unknown 1	1.0	1	
Unknown 30	2.7	3	2.9
Unknown 50	1.0	1	
Unknown, other	2.0	1	

[a] Percentage cover of "1" indicates cover less than or equal to 1 percent. Cover estimates are averaged among subplots where each species was found. A total of 138 subplots were surveyed for vegetation cover. The number of subplots where a species was found and the standard deviation for cover estimates provide an idea of spatial variability for each species across the island group.

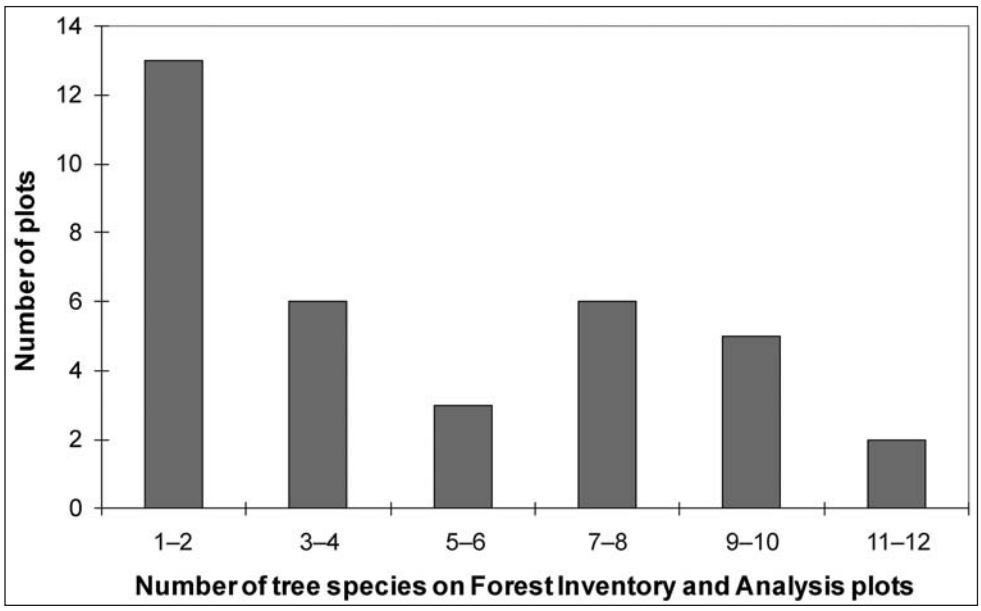

Figure 14—The mean number of tree species found per one-sixth-acre plot was five.

Table 10—Number of trees by primary damage type and species for all trees (≥1 inch diameter at breast height; includes dead trees)

Species	No damage	Broken bole	Broken or dead branches	Broken roots	Brooms	Conks	Cracks/ seams	Damaged foliage/ shoots	Loss of apical dominance	Open wounds	Other	Vines in crown	All damages
							Number of trees						
Acacia confusa	132,241												
Adenanthera pavonina	22,800									11,400			11,400
Aglaia mariannensis	747,126											264,481	264,481
Aidia cochinchinensis	142,004												
Albizia lebbeck	558,224		165,187			26,174			307,192			735,895	1,234,448
Allophylus timorensis												132,241	132,241
Annona spp.	142,004												
Artocarpus altilis	31,848												
Barringtonia asiatica									31,848				31,848
Barringtonia racemosa							132,241		10,616				142,857
Bruguiera gymnorrhiza	11,400					11,400							11,400
Carica papaya	2,511,660								10,616				10,616
Cassia fistula	11,400												
Casuarina equisetifolia	149,629					39,260			13,087	13,087			65,434
Cerbera dilatata	11,400												
Citrus ×aurantifolia	330,374												
Citrus hystrix	2,777,052		132,241						1,057,925			2,248,090	3,438,255
Claoxylon marianum									132,241				132,241
Cocos nucifera	143,494							10,616				22,800	33,416
Cynometra ramiflora	5,671,455	12,769				602,802			294,625			318,208	1,228,403
Delonix regia	732,821												
Discocalyx ponapensis	1,774,582								132,241				132,241
Drypetes spp.	528,962												
Elaeocarpus joga	21,232								31,848				31,848
Erythrina variegata	91,198											22,800	22,800
Eugenia palumbis	793,443	132,241	132,241						132,241			396,722	793,443
Eugenia stelechantha	991,123								165,187			495,562	660,749
Ficus prolixa	2,741,736		142,004			31,848			596,559	152,620		145,062	1,068,094
Ficus spp.	21,232												
Ficus tinctoria	579,417		142,004						10,616				152,620
Guamia mariannae	3,294,003	132,241							694,149			978,857	1,805,247
Guettarda speciosa	22,800					31,848			10,616			10,616	53,080
Hernandia sonora	106,160		10,616			84,928			164,088				259,632
Heterospathe elata	11,400												
Hibiscus tiliaceus	914,785					11,400			132,241				143,640
Intsia bijuga	408,577					58,021			39,260			66,167	163,449
Leucaena leucocephala	26,172,949	159,054	852,478			4,080,479			2,785,711	668,688		4,096,355	12,642,765

Table 10—Number of trees by primary damage type and species for all trees (≥1 inch diameter at breast height; includes dead trees) (continued)

Species	No damage	Broken bole	Broken or dead branches	Broken roots	Brooms	Conks	Cracks/ seams	Damaged foliage/ shoots	Loss of apical dominance	Open wounds	Other	Vines in crown	All damages
						Number of trees							
Mammea odorata	12,769												
Mangifera indica						10,616							10,616
Melanolepis multiglandulosa	325,227					11,400						1,112,104	1,123,503
Morinda citrifolia	839,207					11,400							11,400
Morus alba	330,374												
Musa spp.	136,798												
Neisosperma oppositifolia	182,117									10,616			10,616
Pandanus dubius	272,811	10,616		21,232	10,616	11,400							53,864
Pandanus tectorius	4,313,614	31,848	164,088	10,616		31,848			53,080			21,232	312,712
Pipturus argenteus	132,241											165,187	165,187
Pisonia grandis	221,803											142,004	142,004
Pithecellobium dulce	46,968												
Pouteria obovata	11,400												
Premna obtusifolia	197,823			10,616		205,037			97,696	10,616	11,400	540,616	875,981
Psychotria mariana	231,384					12,769						159,054	171,823
Spathodea campanulata	91,198								11,400	11,400		22,800	45,599
Unknown	1,057,925	264,481							142,857			264,481	671,819
Unknown 0						11,400							11,400
Unknown 1						142,004							142,004
Unknown, other												330,374	330,374
Total	61,004,189	743,249	1,740,860	42,464	10,616	5,426,032	132,241	10,616	7,057,938	878,427	11,400	12,691,706	28,745,547

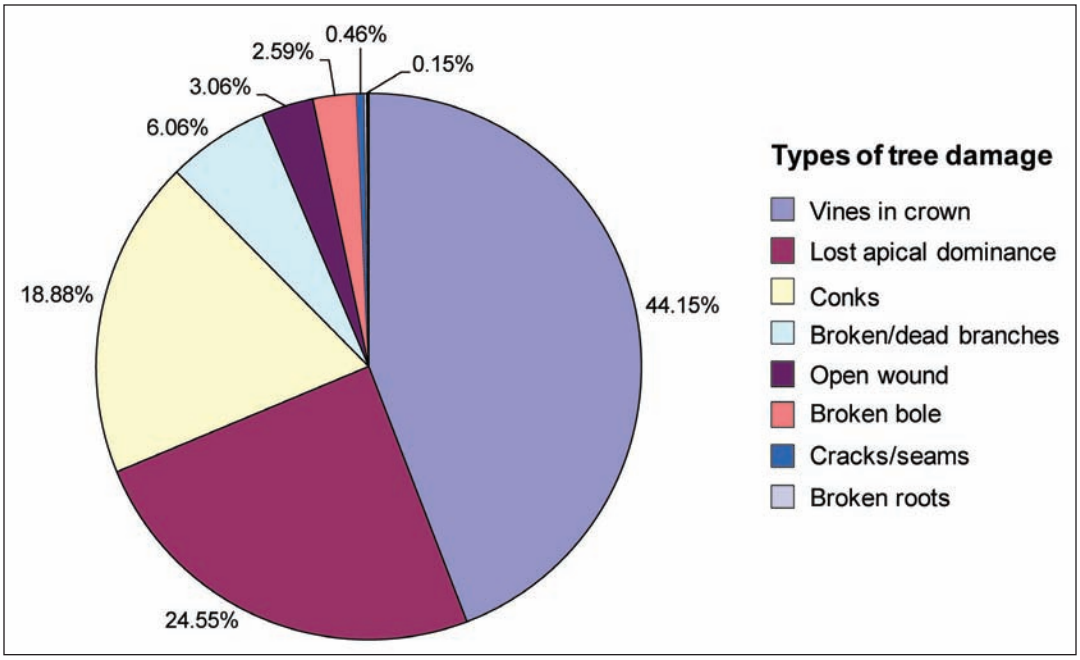

Figure 15—Vines in the crowns of trees are very common in the Commonwealth of the Northern Mariana Islands. Damage from vines was recorded when the vines occupied 20 percent or more of the crown. Lost apical dominance, and conks (fruiting shelf fungi indicating rot), were also common damages.

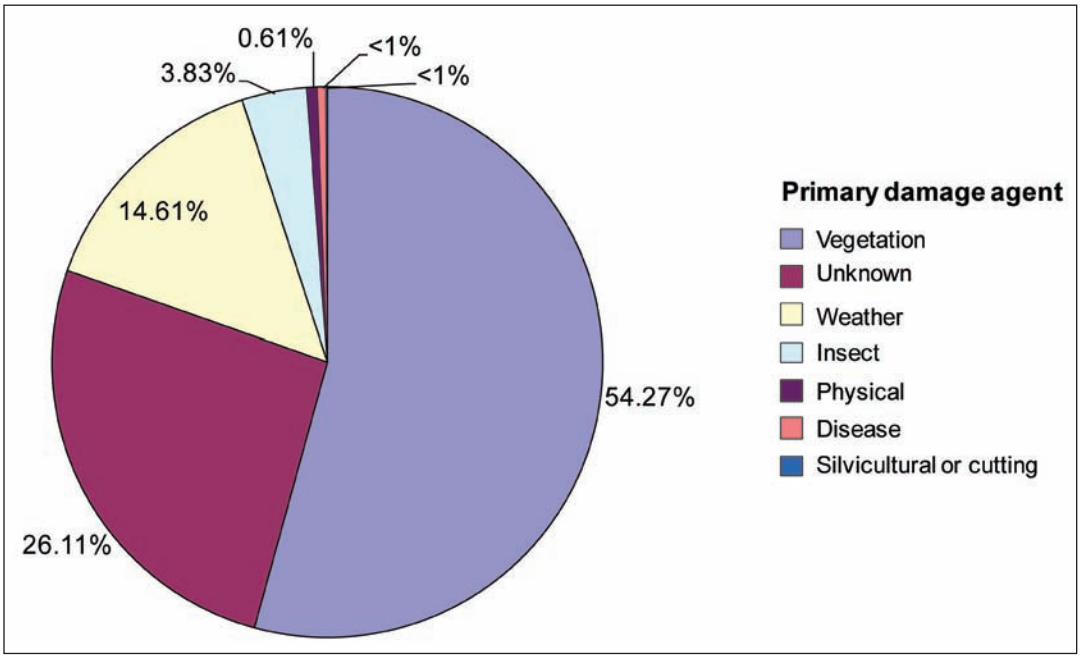

Figure 16—Disturbance from other vegetation and weather were the most common identifiable damaging agents for trees.

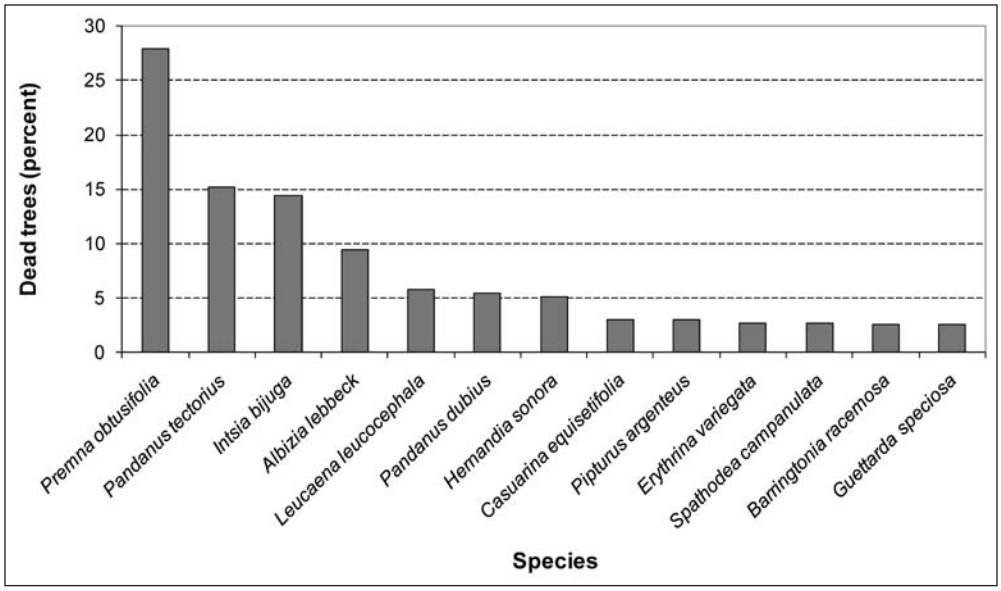

Figure 17—Dead trees were not abundant in the Commonwealth of the Northern Mariana Islands. *Premna obtusifolia*, *Pandanus tectorius*, and *Intsia bijuga* were the most common dead trees of those identified.

Table 11—Estimated number of live trees (≥ 5 inches diameter at breast height) on forest land by epiphyte loading (amounts of nontree vegetation in the canopy and branches) and species

	Epiphyte loadings				
Species	**None**	**Low**	**Moderate**	**High**	**All loadings**
			Number of trees		
Adenanthera pavonina		22,800	11,400		34,199
Aglaia mariannensis		12,769			12,769
Albizia lebbeck	48,973	73,460	50,342	37,573	210,348
Artocarpus altilis		31,848			31,848
Barringtonia asiatica			31,848		31,848
Barringtonia racemosa			10,616		10,616
Bruguiera gymnorrhiza		11,400	11,400		22,800
Carica papaya	36,471	25,537			62,008
Cassia fistula	11,400				11,400
Casuarina equisetifolia	143,955	60,492	10,616		215,063
Cerbera dilatata			11,400		11,400
Cocos nucifera	44,815	97,895	22,800	11,400	176,910
Cynometra ramiflora	85,273	79,600	120,496	48,337	333,706
Delonix regia	22,800				22,800
Elaeocarpus joga	10,616		10,616	31,848	53,080
Erythrina variegata	22,800	68,399		22,800	113,998
Ficus prolixa	48,337	107,289	259,048	67,615	482,289
Ficus spp.			21,232		21,232
Ficus tinctoria		11,400		10,616	22,016
Guamia mariannae	36,937	10,616			47,553

Table 11—Estimated number of live trees (≥ 5 inches diameter at breast height) on forest land by epiphyte loading (amounts of nontree vegetation in the canopy and branches) and species (continued)

Species	Epiphyte loadings				
	None	Low	Moderate	High	All loadings
	Number of trees				
Guettarda speciosa		22,800		53,080	75,879
Hernandia sonora		84,928	138,008	10,616	233,552
Heterospathe elata		11,400			11,400
Hibiscus tiliaceus	45,599	56,215	11,400		113,214
Intsia bijuga	12,769	52,347	116,043	60,492	241,651
Leucaena leucocephala	109,760	184,588	136,348	191,528	622,224
Mammea odorata	12,769				12,769
Mangifera indica			10,616		10,616
Melanolepis multiglandulosa	11,400	11,400	25,537	145,010	193,346
Morinda citrifolia	12,769	24,168			36,937
Musa spp.	113,998	22,800			136,798
Neisosperma oppositifolia	21,232	26,174	13,087		60,492
Pandanus dubius	67,615	236,260	22,800		326,675
Pandanus tectorius	106,160	552,031	201,704	63,696	923,590
Pisonia grandis	11,400	56,999	11,400		79,799
Pithecellobium dulce	34,199		12,769		46,968
Pouteria obovata	11,400				11,400
Premna obtusifolia	88,011	214,165	198,261	113,254	613,691
Psychotria mariana	12,769	63,843	12,769	12,769	102,148
Spathodea campanulata	22,800	79,799	11,400	22,800	136,798
Unknown				10,616	10,616
Unknown 0		11,400			11,400
Total	1,207,023	2,324,819	1,493,952	914,048	5,939,842

influenced by a long history of disturbance, both human-caused and climatic disturbance. Human populations and land use on the CNMI have changed, resulting in differing influences on forest vegetation. Within the last century, the most important land use changes have involved the conversion of forests to agriculture and urban uses. The changes have been rapid. In addition to loss of forest to urbanization, invasive weeds have also become a threat to forests in the CNMI. Some of the most prevalent understory species recorded were weedy vines that smother the forest canopy (fig. 18). Foresters in the CNMI have developed and implemented strong invasive species programs to educate the public, assess threats and current status, and to eradicate several plants threatening forest sustainability. As a result of continuing efforts to eradicate invasive species, reforest degraded lands, and conserve existing forests, we expect to see concomitant increases in wood volume per acre and the basal area covered by trees (table 12).

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Figure 18—Smothering invasive vines have become widespread throughout the Pacific Islands. Foresters on the Commonwealth of the Northern Mariana Islands have implemented several education and eradication programs.

Table 12—Estimated number of trees per acre, basal area per acre, net volume per acre, and standard errors (SE) for trees ≥ 5 inches diameter, 2004

	Estimate	SE
Trees per acre	100	15
Basal area (square feet per acre)	33	6
Volume (cubic feet per acre)	582	133

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Metric Equivalents

When you know:	Multiply by:	To find:
Inches	2.54	Centimeters
Feet	.305	Meters
Miles	1.609	Kilometers
Acres	.405	Hectares
Square miles	2.59	Square kilometers
Cubic feet	.028	Cubic meters
Tons	907	Kilograms
Tons per acre	2.24	Tonnes or megagrams per hectare
Cubic feet per acre	.07	Cubic meters per hectare
Trees per acre	2.471	Trees per hectare
Degrees Fahrenheit	(˚F - 32) / 1.8	Degrees Celsius

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