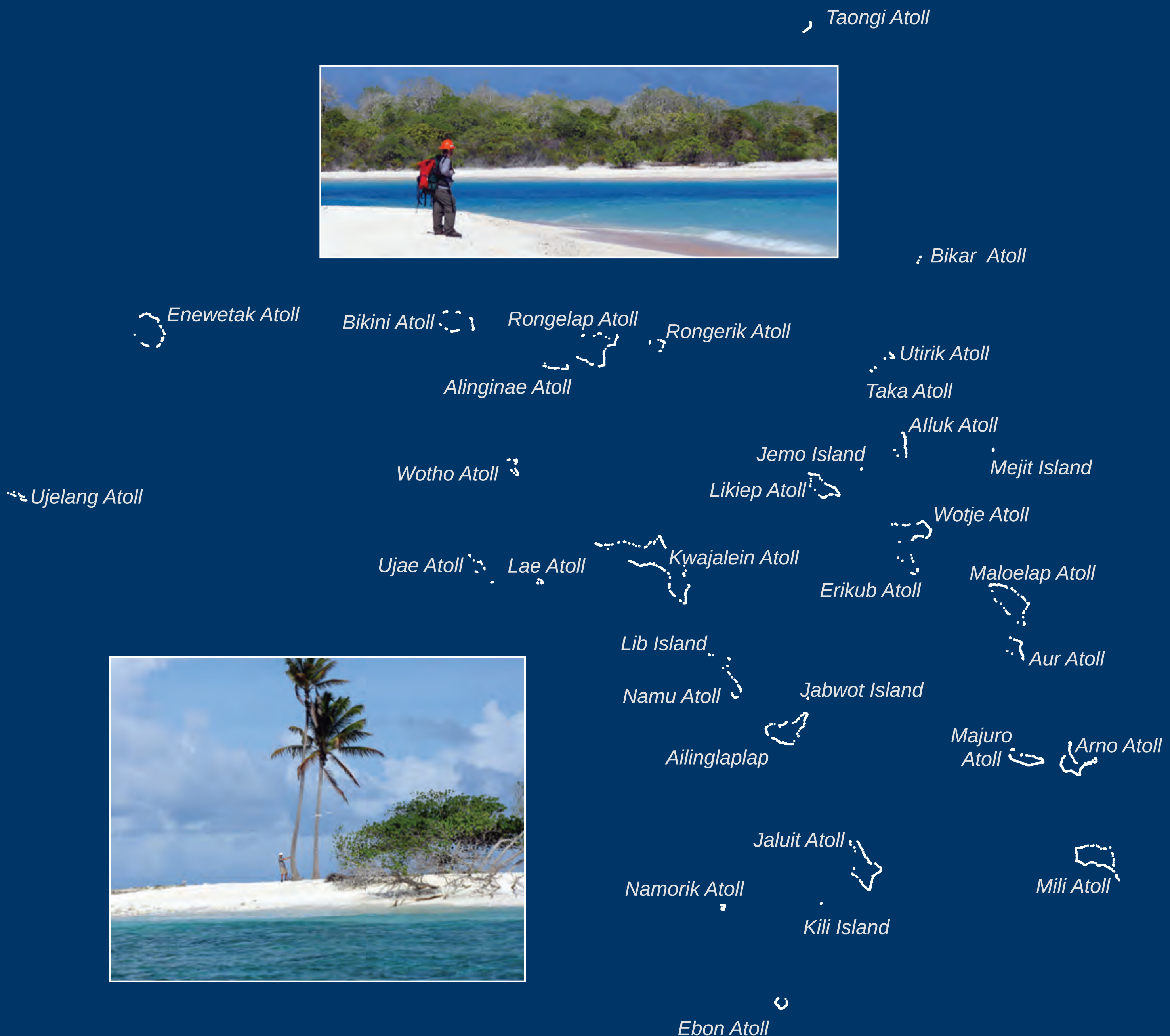
Republic of the Marshall Islands' Forest Resources, 2008

Joseph A. Donnegan, Steven T. Trimble, Karness Kusto,
Olaf Kuegler, and Bruce A. Hiserote



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Cover: photographs by Steven Trimble.

Abstract

Donnegan, Joseph A.; Trimble, Steven T.; Kusto, Karness; Kuegler, Olaf; Hiserote, Bruce A. 2011. Republic of the Marshall Islands' forest resources, 2008. Resour. Bull. PNW-RB-263. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 29 p.

The Forest Inventory and Analysis program collected, analyzed, and summarized field data on 44 forested field plots for the 10 largest atoll groups in the Republic of the Marshall Islands (RMI): Ailinglaplap, Arno, Jaluit, Kwajalein, Likiep, Majuro, Maloelap, Mili, Rongelap, and Wotje. 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. A variety of tables with graphical highlights provide a summary of RMI's forest resources and a comparison to prior vegetation mapping and inventory work.

Keywords: RMI, Ailinglaplap, Arno, Jaluit, Kwajalein, Likiep, Majuro, Maloelap, Mili, Rongelap, Wotje, biomass, damage, Forest Inventory and Analysis (FIA), forest inventory, volume, land cover.

Summary

In 2008, the Forest Inventory and Analysis (FIA) program conducted a systematic inventory for the forests of the Republic of the Marshall Islands (RMI), including Ailinglaplap, Arno, Jaluit, Kwajalein, Likiep, Majuro, Maloelap, Mili, Rongelap, and Wotje. We estimated forest area, tree stem volume, biomass, carbon storage, tree damages, and the composition and percentage cover of understory vegetation species. Forty-four permanent field plots were installed in a variety of forest types. In partnership with the Pacific Southwest Region's Remote Sensing Lab, we acquired high-resolution satellite imagery and their staff mapped land cover into five broad classes: forest, nonforest vegetation, urban, barren, and inland water. Our estimates for this inventory are derived from a sample based on 33,212 acres on the 10 largest atoll groups in the RMI (74 percent of the total land area). Forest, including agroforest and coconut plantations, covers about 70 percent of the RMI. About 12 percent of the landscape was classified as urban land. We estimated gross tree stem volume to be about 56 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 854,000 tons. About 37 percent of the trees sampled in the inventory had some form of damage. Damage by insects was the most prevalent damage agent, with damage by other vegetation following in prevalence. The most frequently identified damage types were damaged foliage, vines in the crown, and discoloration of foliage. The RMI's forests are characterized by a unique bimodal distribution of tree diameters owing to the dominance of coconut plantation combined with regeneration of other species. Species diversity is somewhat low compared to other Pacific Island groups. A total of 17 tree species and 45 understory species were measured on the FIA plots. The average number of tree species per one-sixth-acre plot was four. The Chief Forester for the RMI Ministry of Resources and Development partnered with FIA for planning and data collection, and was especially helpful with species identification in the field, knowledge of the landscape, and assistance with private and communal land access.

Introduction

This report on the forest resources of the 10 largest atoll groups of the Republic of the Marshall Islands (RMI) (fig. 1) was based on a cooperative forest inventory conducted in 2008 by the U.S. Department of Agriculture Forest Service, Pacific Northwest Forest Inventory and Analysis (FIA) program[1] and the RMI Ministry of Resources and Development. 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 RMI foresters and mainland U.S. foresters and ecologists.

Through the FIA-RMI partnership, we conducted a sample-based field inventory for forested lands in the RMI and provided support to create maps that estimate land cover and area. We provide information on understory species composition, detailed tree size distribution, biomass, carbon mass, and damages for living and dead trees by species. 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, plan sustainable supplies of wood, control invasive species, control erosion, as well as manage disturbances such as fire, and mitigate damages caused by humans and other animals.

Objectives

The objectives of this inventory are to:

- Estimate the current area of forest land by forest type group and stand size class.
- Estimate tree volume, biomass, and carbon storage by species and 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.

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

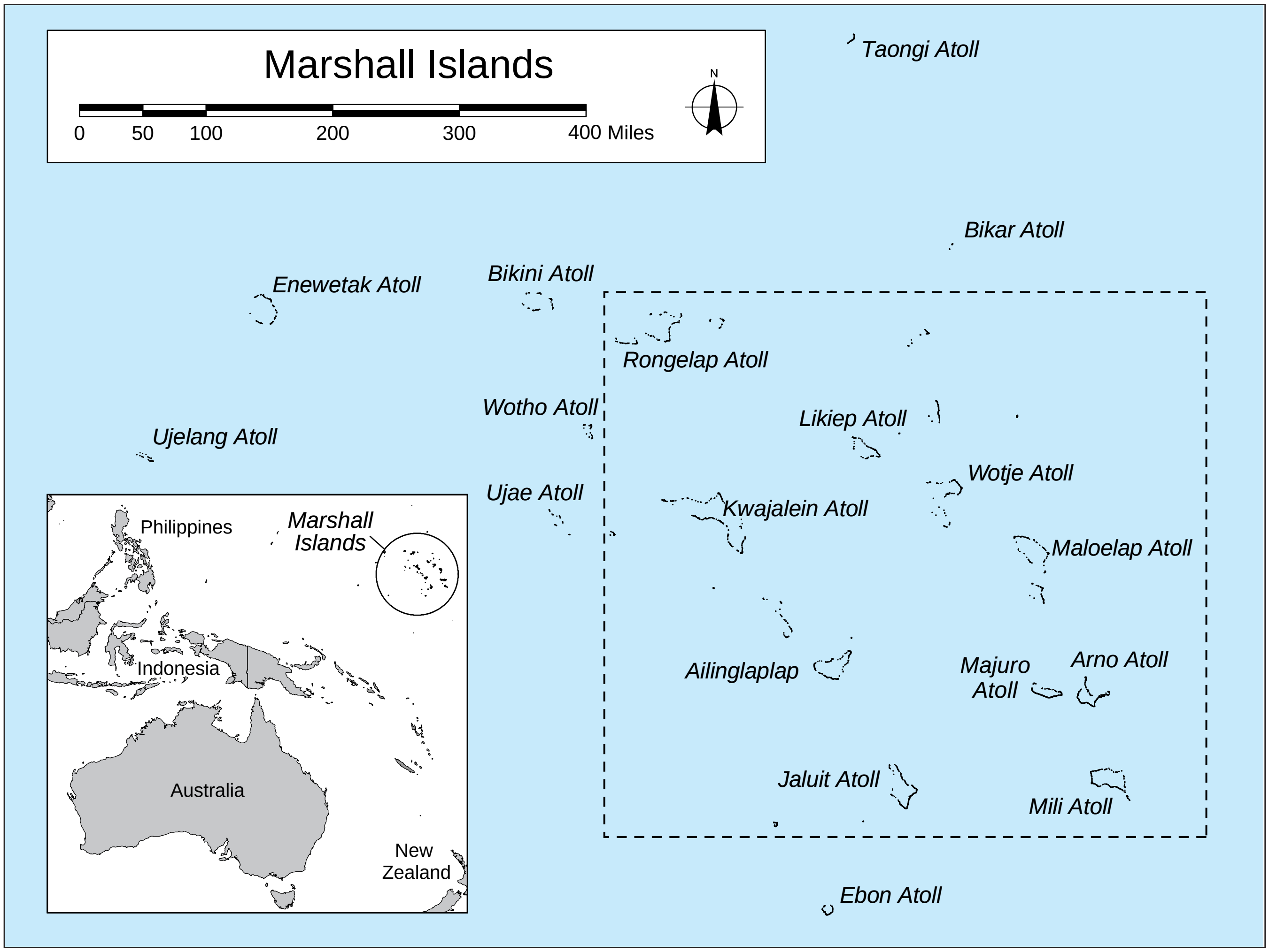

Figure 1—The Republic of the Marshall Islands spans an oceanic area of 750,000 mi^2 in the northwestern Pacific Ocean. The Forest Inventory and Analysis program collected data on the 10 largest atoll groups within the dashed line on the map: Ailinglaplap, Arno, Jaluit, Kwajalein, Likiep, Majuro, Maloelap, Mili, Rongelap, and Wotje.

Methods

Site Description

The RMI is an independent nation located in the northwestern Pacific Ocean. It comprises two primary atoll chains, the Ratak (sunrise) and Ralik (sunset) chains. Twenty-nine atolls and five islands or table reefs are spread out across 750,000 square miles of ocean. The RMI and the United States signed a Compact of Free Association[2] in 1986 and regularly enter into resource conservation and sustainability partnerships.

[2] The Compact of Free Association grants the RMI sovereignty in domestic and foreign affairs and assistance implementing a variety of social, economic, and environmental programs, while granting the United States defense rights in the islands.

This forest inventory is based on data from 44 permanent field plots and covers the 10 largest atoll groups in the RMI (Ailinglaplap, Arno, Jaluit, Kwajalein, Likiep, Majuro, Maloelap, Mili, Rongelap, and Wotje), making up about 33,212 acres (74 percent) of the total land area. The atoll groups are made up of small, narrow, and often long islets strung together along coral reef. Each islet is generally less than a half mile in width and ranges in length from less than a half mile to several miles long (fig. 2). On average, elevations are only 3 to 6 feet above sea level with maximum elevations reaching about 15 to 20 feet on dunes and cobble or boulder accumulations.

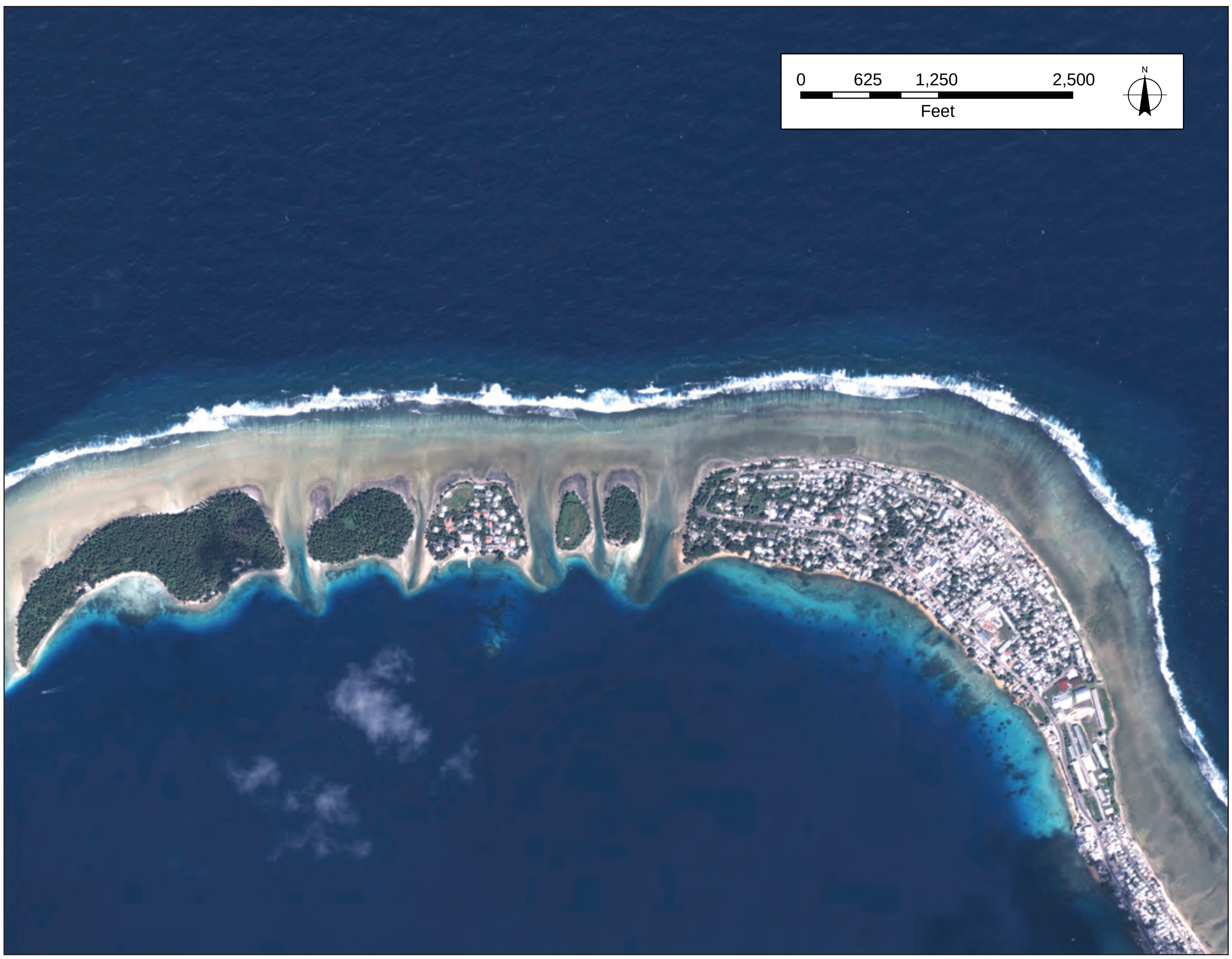

Figure 2—The northeast corner of Majuro is characterized by a mixture of urban and agroforest lands. The islets are narrow and range from very short to long, typical of the atolls throughout the Marshall Islands.

Across over 700 miles north to south in the RMI, a strong climatic gradient exists with Hadley-cell precipitation influences: moist and warm equatorial air rises over the southern atolls. The moisture in the air condenses and drops as rainfall in the south and then the air spreads out in the upper atmosphere where it descends as dry air over the northern atolls. This convective cycle is also responsible for the increase in trade winds moving from south to north in the Marshall Islands. In the southern atolls, precipitation amounts are higher, and average temperatures generally are warmer with greater seasonal consistency than in the northernmost atolls (figs. 3 and 4) (Western Regional Climate Center 2009).

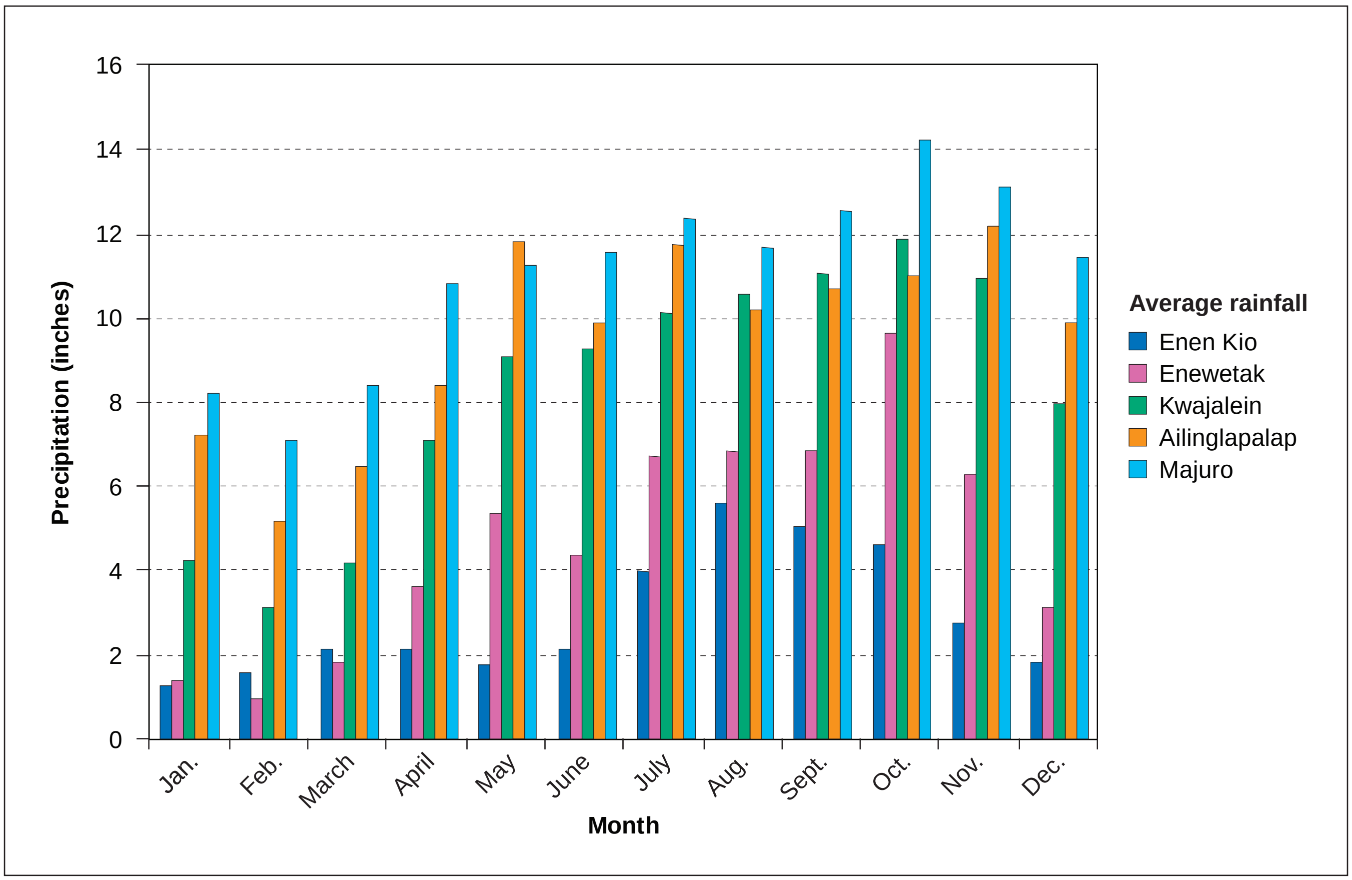

Figure 3—Precipitation increases from north to south (Enen Kio, Enewetak, Kwajalein, Ailinglaplap, to Majuro) in the Marshall Islands (Western Regional Climate Center 2009).

The Marshall Islands are distant from the main typhoon track in the western Pacific Ocean and rarely experience severe typhoons. However, occasional storm surges have been known to wash across low-lying islands, wiping out vegetation and structures. Changes in sea level and the frequency of coastal surges has become an immediate concern for Pacific Island inhabitants, with food and water security topping the list of issues.

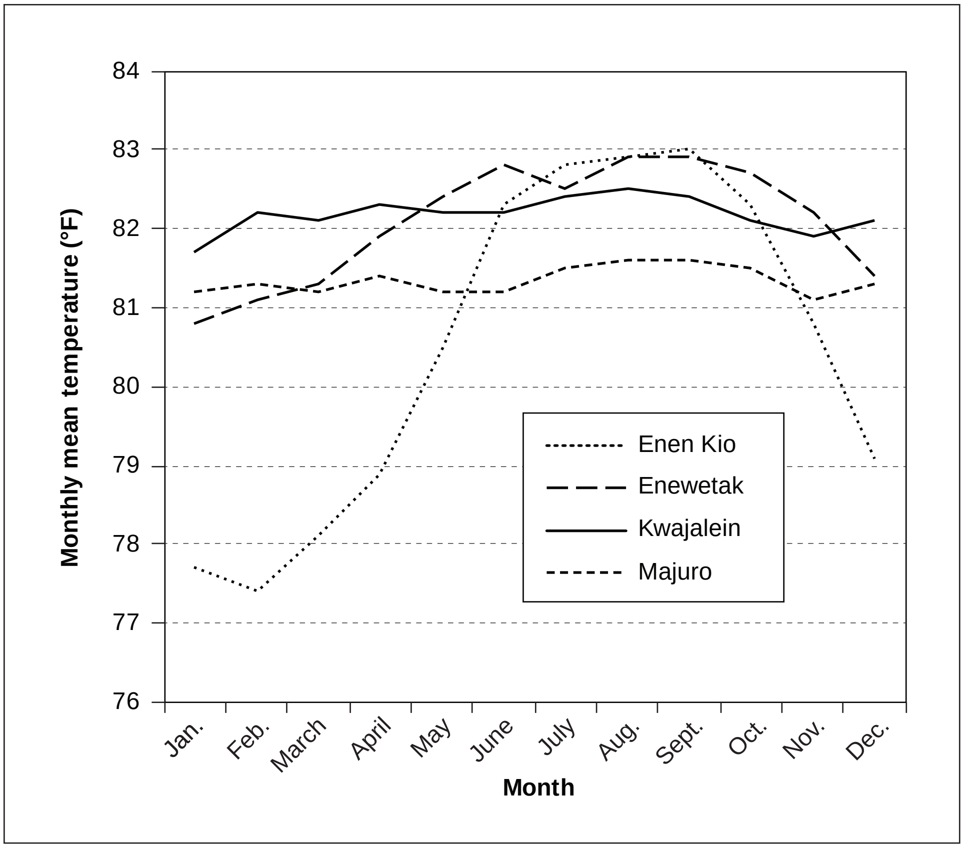

Figure 4—The northern islands (not mapped or inventoried) of Enen Kio (Wake Island) and Enewetak show a more seasonal pattern of mean monthly temperature in comparison to the southern islands of Kwajalein and Majuro. No temperature data are available for Ailinglaplap (Western Regional Climate Center 2009).

The soils in the Marshall Islands are calcareous sand and tend to be well-drained fine sand to coarse cobble (Laird 1989). The soils are generally poor in nutrients and of low moisture holding capacity but are the plant's source for nearly all water and nutrients absorbed through the roots (Deenik and Yost 2006). Soils under some interior vegetation are underlain by phosphitic hardpans from accumulations of bird droppings (Fosberg 1954, Mueller-Dombois and Fosberg 1998). Organic soils also are found in the limited mangrove areas and in areas where soils have been amended for growing food crops like taro.

Vegetation Types

The native forests of the Marshall Islands have largely been replaced by agroforest, especially coconut plantations (fig. 5). Native vegetation remains in some of the undisturbed atolls, commonly a mixed-broadleaf forest, *Neisosperma* forest, *Pisonia grandis* forest, *Tournefortia argentea* forest, and *Pemphis acidula* forest (Mueller-Dombois and Fosberg 1998) (see table 1 for scientific and common names of trees).

Table 1—Scientific names, common names,[a] estimated number and gross volume, and standard errors for estimated totals of species measured as trees in the Marshall Islands

Scientific name	Common names	Number measured	Estimated number (≥ 1 inch diameter)	Standard error for estimated number (±)	Gross volume (≥ 5 inches diameter)	Standard error for estimated volume (±)
Allophylus timorensis (DC.) Bl.	kutaak	8	183,520	136,009	63,860	46,489
Artocarpus altilis (Park.) Fosb.	ma	5	16,780	8,531	727,825	513,728
Artocarpus mariannensis Trec.	Marianas breadfruit	6	20,055	20,055	671,271	671,271
Bruguiera gymnorrhiza (L.) Lam.	jon, jong	28	369,029	272,531	2,513,566	2,112,181
Cocos nucifera L.	ni, nimaro, nimir, nimur, niram, nirik, niwinmej, jiwollab	465	1,692,388	237,650	36,735,968	5,699,386
Cordia subcordata Lam.	kono	32	112,021	86,817	1,062,305	959,485
Guettarda speciosa L.	bwikow utlomar, utilomar, wut, wutilomar	141	1,795,278	551,157	3,080,481	850,114
Intsia bijuga (Colebr.) O. Ktze.	kubok, kubuk	5	18,623	14,523	131,331	109,941
Morinda citrifolia L.	nen, nin	37	1,415,394	552,008	30,417	20,472
Neisosperma oppositifolia (Lam.) Fosb. & Sachet	kish par, kojbar	66	765,015	424,609	1,318,141	659,503
Pandanus tectorius Park.	bob, bop, mwajaal	176	728,697	198,914	3,355,805	801,764
Pemphis acidula Forst.	kone, jungi	22	106,646	72,052	536,011	354,330
Pisonia grandis R. Br.	kanae, kanal, kangae, knagal	66	573,757	364,842	2,812,103	1,169,813
Premna serratifolia L.	kaar, kar	14	318,318	198,604	88,243	63,960
Scaevola taccada (Gaertn.) Roxb.	konnat, kunat, mar kinat	80	4,113,344	1,338,238	35,598	25,430
Terminalia samoensis Rech.	ekkon, ekun, kiking, kokon, kukung, kung	9	38,636	23,442	128,244	75,441
Tournefortia argentea L. f.	kiden, kirin	27	162,463	95,537	1,398,956	886,344
Total		1,187	12,429,963	2,050,217	54,690,124	6,782,115

[a] Common names follow Falanruw et al. (1990).

Figure 5—Coconut plantations are abundant throughout the Marshall Islands and have replaced the majority of native forest vegetation.

The vegetation types described below use the FIA field plots as the basis for classification. Forest types were identified in the field trying to capture the dominant types that encompassed field plots.

Lowland mixed tropical forest—

Field crews found the following tree species (in descending order of abundance by forest type, as is the case for all types in this section) in interior forests on RMI atolls: *Morinda citrifolia, Cocos nucifera, Neisosperma oppositifolia, Guettarda speciosa, Scaevola taccada, Pandanus tectorius, Pisonia grandis, Bruguiera gymnorrhiza, Tournefortia argentea, Allophylus timorensis, Premna serratifolia, Artocarpus mariannensis, Intsia bijuga, Cordia subcordata, Artocarpus altilis,* and *Terminalia samoensis.*

Strand or halophytic vegetation—

Dominant species found on FIA plots here include *Scaevola taccada, Guettarda speciosa, Pisonia grandis, Cocos nucifera, Pemphis acidula, Cordia subcordata, Pandanus tectorius, Tournefortia argentea, Terminalia samoensis,* and *Intsia bijuga*.

Mangrove forest—

Mangroves occur in limited areas around the margins of some atolls in the RMI. Although limited in extent, combined with the shallow reef system, they help to buffer storms, preserve the coastline, and offer wood and food resources. Dominant species found within this type were *Bruguiera gymnorrhiza* and *Cocos nucifera*.

Agroforest—

Typical agroforest in the tropical Pacific is characterized by an abundance of fruit and nut trees interspersed with other canopy species. Agroforest tends to occur within and near settlements. In the Marshall Islands, coconut plantations dominate the agroforest areas. Some of the most common species found in this type include *Cocos nucifera, Morinda citrifolia, Guettarda speciosa, Premna serratifolia, Allophylus timorensis, Pandanus tectorius, Pisonia grandis, Terminalia samoensis, Tournefortia argentea, Cordia subcordata, Artocarpus altilis,* and *Scaevola taccada*.

Inventory Methods

The RMI inventory was based on the FIA inventory design that was implemented across the mainland United States beginning in 2000. Adaptations were made to the national design to include additional branching and rooting forms, additional tree crown measurements, and special-interest species ranging from invasive plants to pathogens to culturally or economically important species of various life forms. In the mainland FIA program, plots are spaced within forest land on a 3.3-mile grid. With the assistance of the RMI Ministry of Resources and Development, plots were distributed at approximately 12 times the spatial intensity 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.

A variety of information was collected at the plot, subplot, and tree levels (USDA FS 2005). 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,

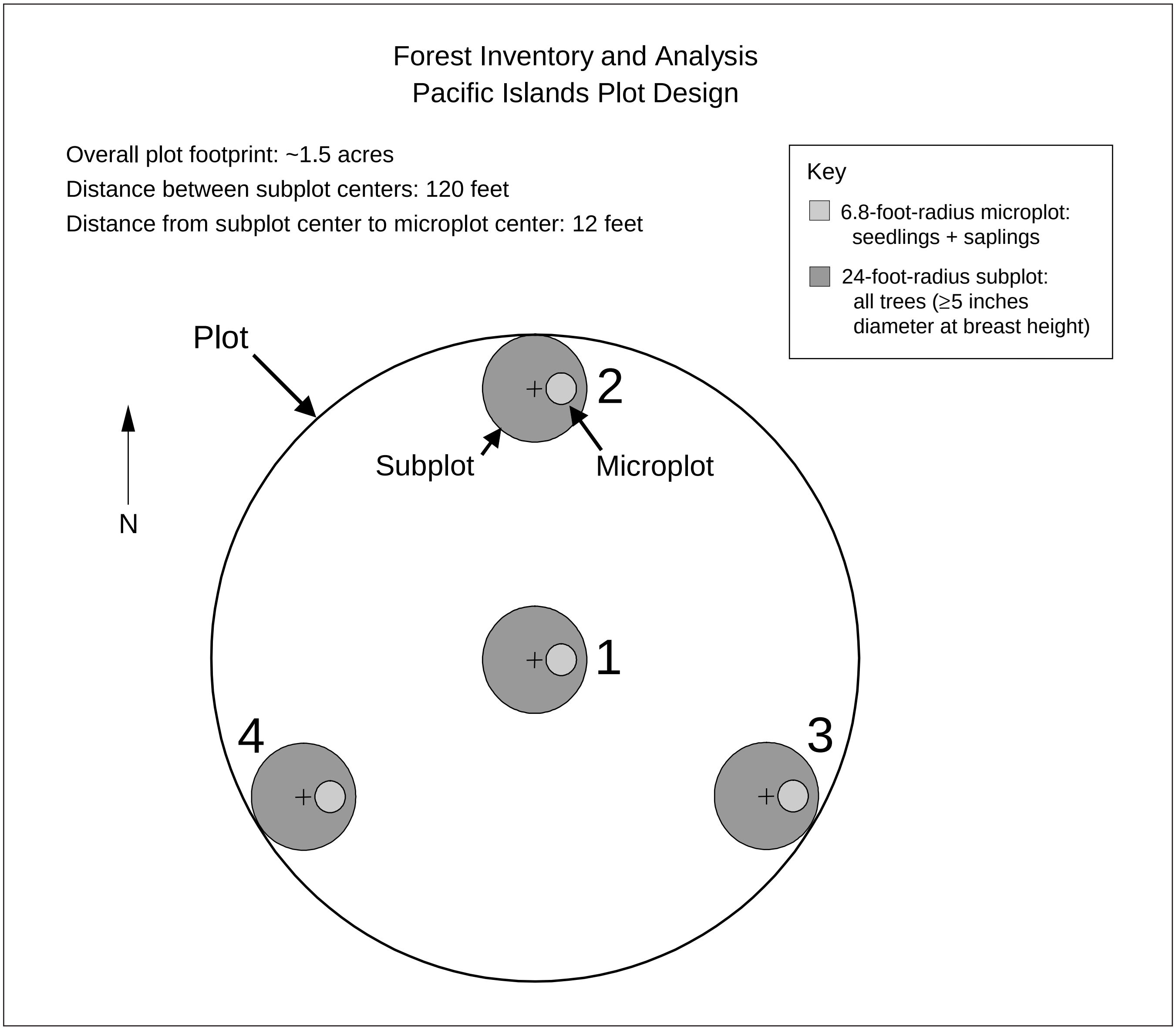

Figure 6—The plot design used for the continental U.S. Forest Inventory and Analysis program was adopted with slight simplification for the inventory in the Pacific Islands.

slope, aspect, elevation, subplot slope position and shape, tree species, diameters, heights, damages, branching and rooting forms, decay, epiphytic loadings, crown characteristics, tree locations, and regeneration information. The fieldwork for this inventory was performed from February to April 2008.

Analysis Methods

The forest land, volume, biomass, and carbon estimates that FIA derives 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 RMI stratification for estimating numbers of trees, volume, biomass, and carbon was conducted via a classification of 2006 QuickBird satellite data. The land cover classification divided the landscape into forest, urban, nonforest vegetation, barren, and water 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 represented 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. The analysis also accounted for the linear atoll features via adjustment of expansion factors. Average stand size (mean diameters of trees) was expanded from the plots to the landscape level by using the same expansion factors. Note that the FIA stratification area differs from that of the area mapped for the vegetation classification.

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. For species where specific gravity was not known, an average specific gravity of 0.5 grams 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. However, tropical trees do not produce consistent annual rings. Previously we had used a modified topographic relative moisture index (TRMI) (Parker 1982) as a proxy for site productivity in other Pacific Island groups. However, because TRMI uses a weighted, additive combination of slope steepness, slope shape, and slope position to assess the potential moisture retention in a forested stand, we opted not to use the TRMI in the essentially flat atolls of the Marshall Islands. Remeasurement data from these plots at the next inventory cycle will provide an estimate of productivity. Until then, soil mapping and nutrient analyses (Deenik and Yost 2006, Laird 1989) remain the best estimate of site productivity for the Marshall Islands.

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 QuickBird imagery and labeled with assistance from RMI foresters. The 2006 QuickBird satellite imagery was used for the mapping and served as the basis for land cover estimates (fig. 7).

Figure 7—Land cover was mapped via a Forest Service partnership with the Pacific Southwest Region's Remote Sensing Lab by using very high resolution 2006 QuickBird satellite data. Image data were obtained through a U.S. Department of Agriculture consortium with the Foreign Agriculture Service and the Natural Resources Conservation Service.

Reliability of FIA Data

The area of forested land cover classified from the 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-population 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 (≥5 inch diameter) for the RMI lies between 47.9 and 61.5 million cubic feet. There is a 68 percent chance that the true number of trees (≥1 inch diameter) for the RMI lies within the range of 10,379,746 to 14,480,180. 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 RMI is currently about 70 percent forested, which includes native, agroforest, and coconut plantation forests (fig. 8, table 2). About 12 percent of the landscape was classified as urban land including roads, and about 4 percent was classified as nonforest vegetation including savanna and agricultural lands. The area used for land cover estimates totaled 33,212 acres.

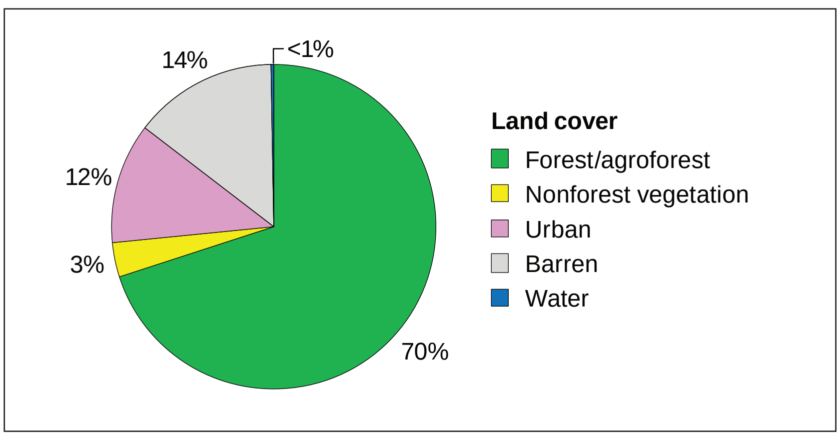

Figure 8—Seventy percent of the Marshall Islands is estimated to be forested in a mixture of agroforest and native species. Urban lands account for 12 percent of the land cover.

Table 2—Estimated area by land cover by island in the Marshall Islands, 2006[a]

	Atoll group										
Land cover	Ailinglaplap	Arno	Jaluit	Kwajalein	Likiep	Majuro	Maloelap	Mili	Rongelap	Wotje	Total
					Acres						
Forest/agroforest	3,068	3,242	2,699	2,530	2,140	1,196	1,813	2,900	1,567	2,097	23,252
Nonforest vegetation	32	55	48	264	133	56	256	82	131	78	1,134
Urban	156	95	142	1,480	102	1,583	85	124	100	116	3,983
Barren	382	462	434	639	415	343	430	748	514	385	4,751
Water	9	2	3	10		28	1	38	0		92
Total	3,648	3,856	3,326	4,924	2,790	3,205	2,585	3,892	2,311	2,676	33,212

[a] Figures for 2006 were summarized from the work of Liu and Fischer (2007), aggregating area totals with a geographic information system.

Forest Structure

To capture the predominant diameter of live trees in forest stands, we estimated stand size class for forested field plots in the RMI. The dominant size class (60 percent of acreage) tends to be moderate-sized stands, in the 11- to 19.9-inch diameter category (fig. 9). About 28 percent of acreage in the RMI is made up of stands in the 5- to 10.9-inch category, and only about 12 percent of acreage is dominated by very small trees in the less-than-5-inches category.

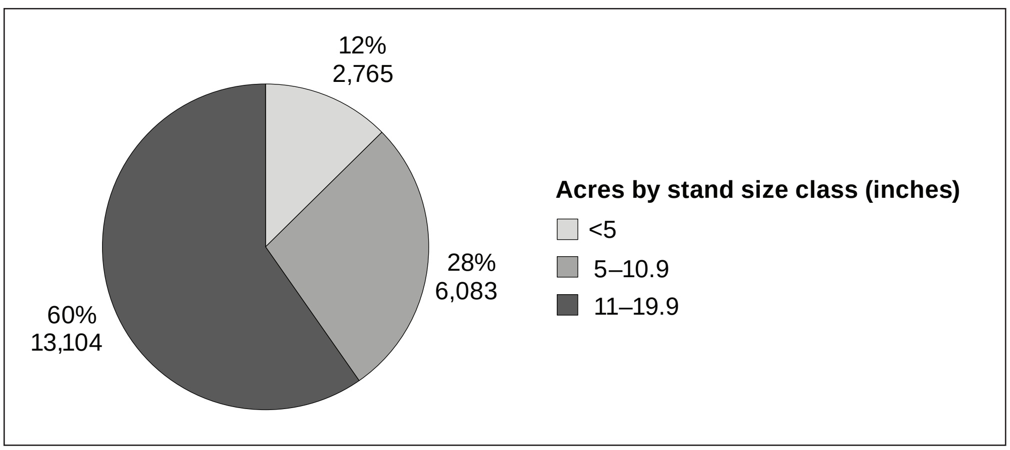

Figure 9—The dominant size class for forested stands tends to reflect the dominance and maturity of coconut plantations. Sixty percent of the acreage is characterized by stands in the 11- to 19-9-inch diameter category.

The diameter distribution for trees in the RMI shows a "reverse-J" distribution, demonstrating that regeneration is abundant (fig. 10, table 3). The distribution is slightly bimodal showing not only small size classes are well represented, but that trees in the 11- to 14.9-inch categories are also well represented. The trees in the 11- to 14.9-inch category are primarily coconut, representing a cohort of mature plantation trees (fig. 11). Coconut is well represented in the larger size classes;

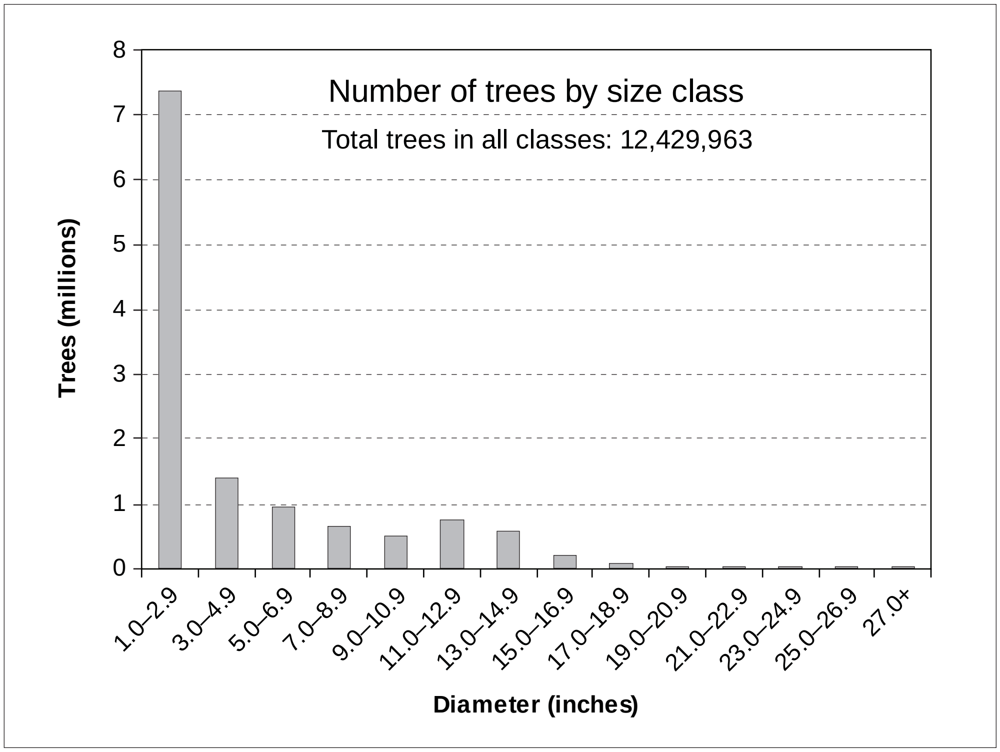

Figure 10—Regeneration of small trees is abundant in the Marshall Islands. Trees in the 11- to 14.9-inch diameter category are also well represented.

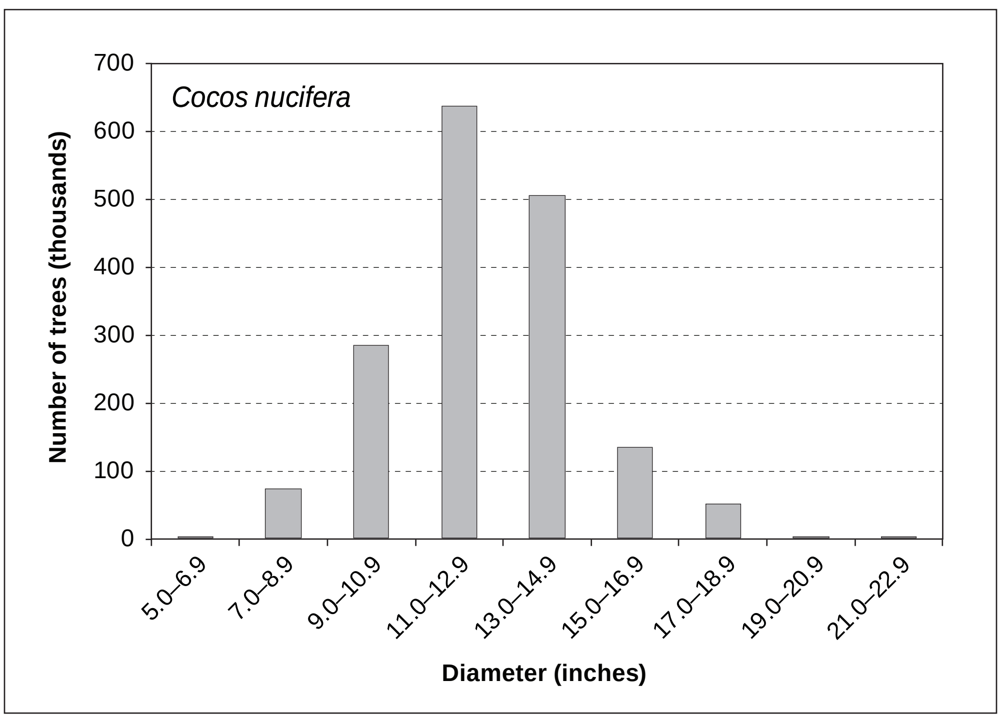

Figure 11—Coconut (*Cocos nucifera*) dominates the size class distribution for the moderate-sized diameter range. The lack of smaller diameter trees demonstrates that plantations are maturing and not being replaced on a large-scale basis.

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

Species	Diameter class (inches)														All classes
	< 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+	
	Number of trees														
Allophylus timorensis	169,945	6,821	3,411	3,342											183,520
Artocarpus altilis		3,342	3,342				3,342	3,342				3,411			16,780
Artocarpus mariannensis			6,685			6,685	3,342				3,342				20,055
Bruguiera gymnorrhiza	297,404	10,232	10,232	3,411	10,232	13,643	6,821	3,411	6,821	3,411	3,411				369,029
Cocos nucifera		3,411	72,905	284,870	635,763	504,593	133,911	50,183	3,342	3,411					1,692,388
Cordia subcordata		43,944	27,149	17,054	6,821	6,821	6,821			3,411					112,021
Guettarda speciosa	1,384,473	170,377	121,389	58,989	39,904	10,164	5,129		4,854						1,795,278
Intsia bijuga		3,411	8,391	6,821											18,623
Morinda citrifolia	1,404,293	7,758	3,342												1,415,394
Neisosperma oppositifolia	578,378	104,145	55,274	13,575	3,411		10,232								765,015
Pandanus tectorius	127,459	345,719	200,950	44,338	3,411	6,821									728,697
Pemphis acidula		55,472	23,933	7,195	20,046										106,646
Pisonia grandis	379,825	64,735	44,271	27,149	16,985	10,164	10,164	13,643		3,411				3,411	573,757
Premna serratifolia	294,853	16,780	6,685												318,318
Scaevola taccada	4,105,088	4,457	3,799												4,113,344
Terminalia samoensis		30,805	4,420	3,411											38,636
Tournefortia argentea		69,109	43,412	13,882	8,6 60	5,056	14,726		4,166		3,452				162,463
Total	8,741,717	940,518	639,591	484,035	745,233	563,947	194,489	70,579	19,183	13,643	10,205	3,411		3,411	12,429,963

however, sustained copra (the dried meat, or kernel, of the coconut) production may require replacement of older senescing trees.

For trees at least 5 inches in diameter, tree heights are predominantly in the 30- to 39-foot and 40- to 49-foot height classes (fig. 12). The tallest tree on an FIA plot was found on Majuro, a *Cocos nucifera* that measured 15.6 inches in diameter and approximately 105 feet tall. The largest diameter tree was found on Arno, a *Pisonia grandis* measuring 31 inches in diameter and 96 feet tall.

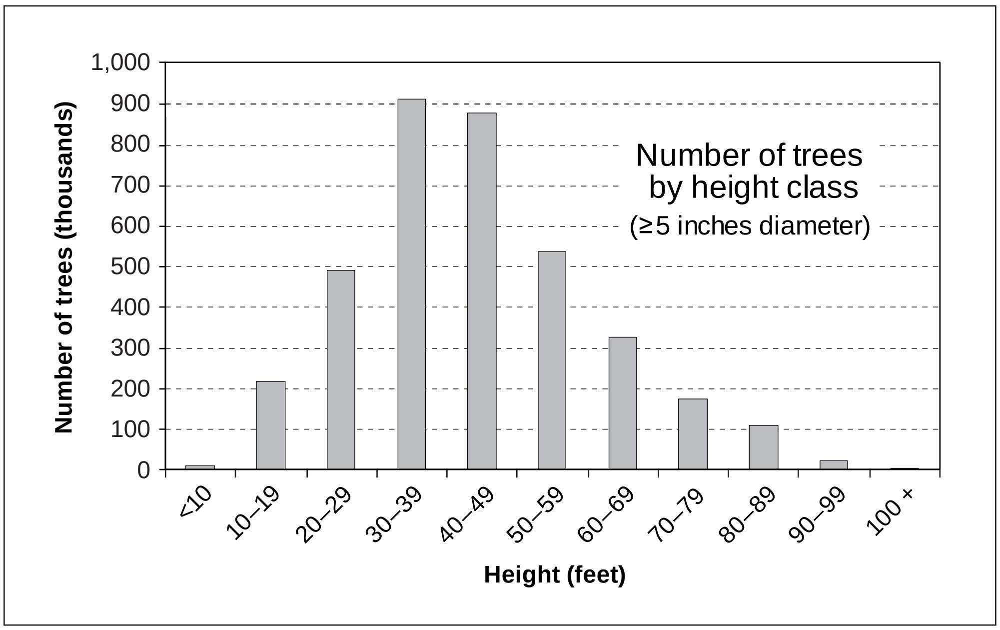

Figure 12—Tree heights are well distributed with heights of 30 to 49 feet dominating forested stands.

Wood volume (fig. 13, tables 4, 5, and 6), biomass (fig. 14, table 7), and carbon storage (table 8) tend to be concentrated in the medium-sized diameter classes in the RMI and reflect the abundance of coconut and the dominant-sized cohort of the plantations.

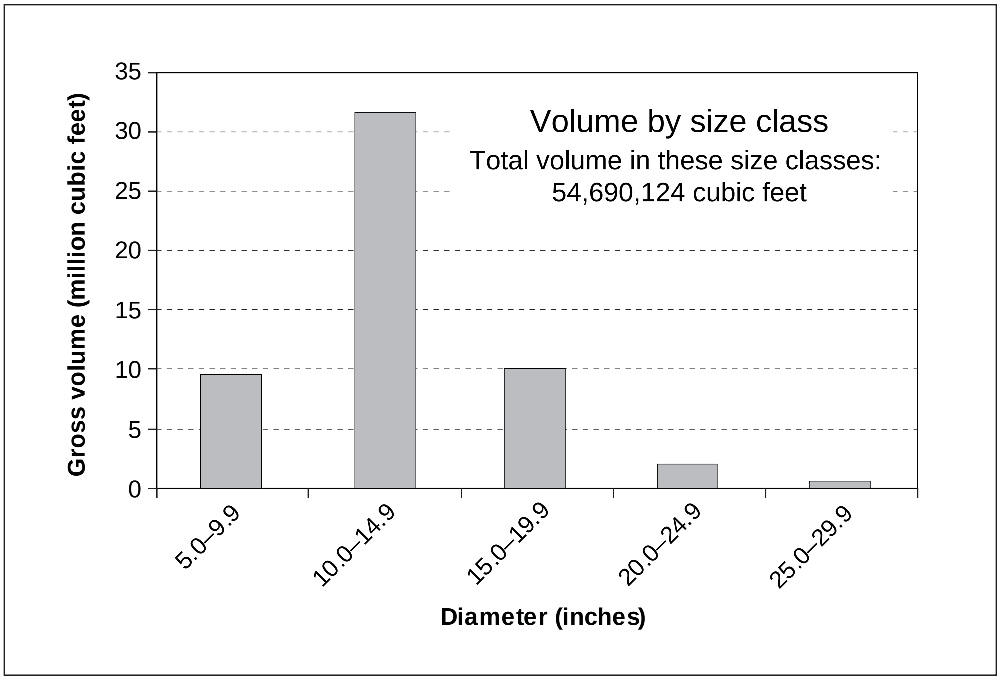

Figure 13—Wood volume is concentrated in the 10- to 14.9-inch diameter category.

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	1,373,017	9,663,923	31,731,109	10,159,628	3,135,464	56,063,141
Net volume (≥ 5 in)		9,636,236	31,671,365	10,080,721	2,538,794	53,927,117

Table 5—Estimated number of trees per acre, basal area per acre, net volume per acre, and standard errors (SE) for trees ≥5 inches, 2008

	Estimate	SE
Trees per acre	168	13
Basal area (square feet per acre)	107	9
Volume (cubic feet per acre)	2,457	242

Table 6—Estimated gross volume of all live trees ≥5 inches diameter at breast height on forest land by species and diameter class

	Diameter class (inches)													
Species	**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**
	Cubic feet													
Allophylus timorensis	18,875	20,871	24,114											63,860
Artocarpus altilis	7,042	18,430				127,852	129,564				444,937			727,825
Artocarpus mariannensis		61,354			158,223	116,991				334,702				671,271
Bruguiera gymnorrhiza	34,464	83,528	29,343	211,853	428,467	309,827	195,026	426,274	424,474	370,309				2,513,566
Cocos nucifera	9,287	483,156	3,521,500	12,185,631	13,287,599	4,832,018	2,136,817	114,147	165,814					36,735,968
Cordia subcordata	152,351	179,272	149,875	114,925	127,258	189,631			148,992					1,062,305
Guettarda speciosa	621,069	853,340	650,193	559,366	189,064	93,205		114,245						3,080,481
Intsia bijuga	16,827	41,800	72,704											131,331
Morinda citrifolia	11,246	19,171												30,417
Neisosperma oppositifolia	399,051	384,696	150,395	57,523		326,476								1,318,141
Pandanus tectorius	1,386,857	1,284,892	487,695	52,276	144,085									3,355,805
Pemphis acidula	187,221	116,382	44,748	187,659										536,011
Pisonia grandis	194,080	254,997	260,312	217,015	259,604	227,980	523,681		192,891				681,544	2,812,103
Premna serratifolia	48,895	39,348												88,243
Scaevola taccada	13,102	22,496												35,598
Terminalia samoensis	87,132	19,774	21,338											128,244
Tournefortia argentea	219,075	196,724	113,152	119,991	82,319	316,152		211,753		139,790				1,398,956
Total	3,406,575	4,080,231	5,525,369	13,706,239	14,676,618	6,540,133	2,985,088	866,419	932,171	844,801	444,937		681,544	54,690,124

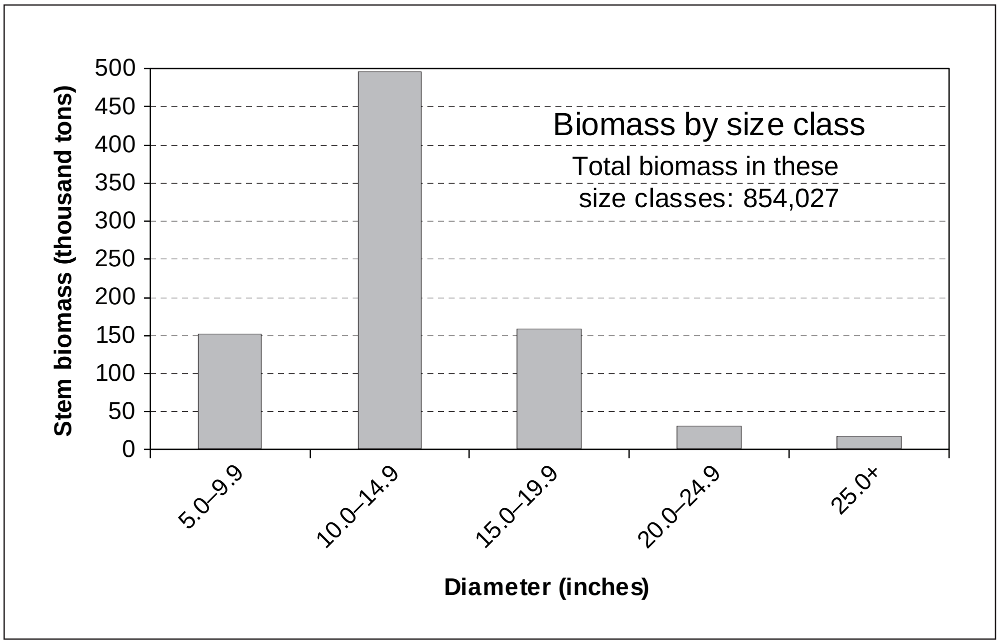

Figure 14—The distribution of stem biomass reflects the wood volume dominance in the 10- to 14.9-inch diameter category.

Table 7—Estimated aboveground dry stem weight of live trees ≥5 inches diameter at breast height on forest land by species and diameter class

	Diameter class (inches)													
Species	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
						Tons								
Allophylus timorensis	295	326	376											997
Artocarpus altilis	110	288				1,995	2,022				6,944			11,360
Artocarpus mariannensis		958			2,469	1,826				5,224				10,477
Bruguiera gymnorrhiza	538	1,304	458	3,306	6,687	4,836	3,044	6,653	6,625	5,780				39,230
Cocos nucifera	145	7,541	54,962	190,187	207,386	75,416	33,350	1,782	2,588					573,357
Cordia subcordata	2,378	2,798	2,339	1,794	1,986	2,960			2,325					16,580
Guettarda speciosa	9,693	13,319	10,148	8,730	2,951	1,455		1,783						48,079
Intsia bijuga	320	796	1,384											2,501
Morinda citrifolia	176	299												475
Neisosperma oppositifolia	6,228	6,004	2,347	898		5,095								20,573
Pandanus tectorius	21,645	20,054	7,612	816	2,249									52,376
Pemphis acidula	2,922	1,816	698	2,929										8,366
Pisonia grandis	3,029	3,980	4,063	3,387	4,052	3,558	8,173		3,011				10,637	43,890
Premna serratifolia	763	614												1,377
Scaevola taccada	204	351												556
Terminalia samoensis	1,360	309	333											2,002
Tournefortia argentea	3,419	3,070	1,766	1,873	1,285	4,934		3,305		2,182				21,834
Total	53,226	63,826	86,487	213,920	229,065	102,075	46,590	13,523	14,549	13,185	6,944		10,637	854,027

Table 8—Estimated carbon mass of live trees ≥5 inches diameter at breast height on forest land by species and diameter class

	Diameter class (inches)													
Species	**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**
							Tons							
Allophylus timorensis	147	163	188											498
Artocarpus altilis	55	144				998	1,011				3,472			5,680
Artocarpus mariannensis		479			1,235	913				2,612				5,238
Bruguiera gymnorrhiza	269	652	229	1,653	3,344	2,418	1,522	3,327	3,312	2,890				19,615
Cocos nucifera	72	3,770	27,481	95,094	103,693	37,708	16,675	891	1,294					286,678
Cordia subcordata	1,189	1,399	1,170	897	993	1,480			1,163					8,290
Guettarda speciosa	4,847	6,659	5,074	4,365	1,475	727		892						24,039
Intsia bijuga	160	398	692											1,250
Morinda citrifolia	88	150												237
Neisosperma oppositifolia	3,114	3,002	1,174	449		2,548								10,286
Pandanus tectorius	10,823	10,027	3,806	408	1,124									26,188
Pemphis acidula	1,461	908	349	1,464										4,183
Pisonia grandis	1,515	1,990	2,031	1,694	2,026	1,779	4,087		1,505				5,319	21,945
Premna serratifolia	382	307												689
Scaevola taccada	102	176												278
Terminalia samoensis	680	154	167											1,001
Tournefortia argentea	1,710	1,535	883	936	642	2,467		1,652		1,091				10,917
Total	26,613	31,913	43,243	106,960	114,533	51,038	23,295	6,761	7,274	6,593	3,472		5,319	427,014

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 9). Tree seedlings that are less than or equal to 1 inch in diameter are also estimated as understory vegetation cover (table 10). 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 2008 inventory, 24 tree species (including seedlings) and 45 understory species were measured on FIA plots. On a per-plot basis (approximately one-sixth acre), the mean number of tree species found was 4 (fig. 15).

Tree Damage and Mortality

We estimated about 37 percent of the individual trees in the RMI show some sign of damage (table 11). The most prevalent damage types are damaged foliage, vines in crowns, and discolored foliage (fig. 16). For the identifiable damaging agents, damage by insects, other vegetation, and weather ranked as the most prevalent primary damage agents (fig. 17).

Table 9—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		
Asplenium nidus L.	8.7	44	8.1
Bidens pilosa L.	10.6	7	7.2
Boerhavia tetrandra G. Forst.	1.1	8	0.4
Bothriochloa bladhii (Retz.) S.T. Blake	10.0	1	
Caesalpinna bonduc (L.) Roxb.	1.0	1	
Canavalia cathartica Thouars	10.2	25	8.6
Cassytha filiformis L.	9.8	36	9.7
Centella asiatica (L.) Urb.	2.5	4	0.6
Chamaesyce prostrata (Aiton) Small	1.0	2	0
Clerodendrum inerme (L.) Gaertn.	3.5	4	4.4
Conyza canadensis (L.) Cronquist	4.9	7	6.7
Cordyline fruticosa (L.) A. Chev	1.0	1	
Crinum asiaticum L.	3.0	1	
Digitaria setigera Roth ex Roem. & Schult.	1.5	4	0.6
Dodonaea viscosa (L.) Jacq.	6.0	7	4.7
Eleusine indica (Linnaeus) Gaertn.	7.2	5	5.2
Epipremnum pinnatum (L.) Engl.	1.0	1	
Eragrostis amabilis (L.) Wight & Arn. ex Nees	2.0	1	
Euphorbia cyathophora Murray	1.0	1	
Eustachys petraea (Sw.) Desv.	7.4	12	9.3
Fimbristylis cymosa R. Br.	3.3	29	3.0
Hedyotis sp. L.	3.0	1	
Hemigraphis reptans (G. Forst.) T. Anderson ex Hemsl.	23.3	3	14.4
Ipomoea sp. L.	3.0	1	
Ipomoea violacea L.	10.5	23	14.6
Lepturus repens (G. Forst.) R. Br.	5.1	28	6.5
Nephrolepis acutifolia (Desv.) Christ	3.2	14	2.7
Nephrolepis hirsutula (J.R. Forst.) K. Presl	6.4	10	3.3
Oldenlandia biflora L.	2.0	2	1.4
Osmorhiza mexicana Griseb. ssp. bipatriata (Constance & Shan) Lowry & A.G. Jones	2.0	1	
Paspalum setaceum Michx.	6.1	8	5.0
Phyllanthus amarus Schumach. & Thonn.	2.0	1	
Phymatosorus grossus (Langsd. & Fisch.) Brownlie	3.2	78	2.7
Portulaca lutea Sol. ex G. Forst.	3.0	2	0.0
Soulamea amara Lam.	21.6	5	18.2
Sphagneticola trilobata (L.) Pruski	4.0	3	1.0
Tacca leontopetaloides (L.) Kuntze	2.4	10	1.2
Thuarea involuta (G. Forst.) R. Br. ex Roem. & Schult.	6.0	17	7.7
Triumfetta procumbens G. Forst.	2.3	15	1.4
Turnera ulmifolia L.	1.0	1	
Unknown annual grass 1	1.0	4	0
Unknown forb	3.0	5	1.2
Unknown perrenial grass 1	3.1	11	2.9
Vigna marina (Burm.) Merrill	13.6	20	14.4
Wollastonia biflora (L.) Dc.	10.7	40	13.9

[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 135 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.

Table 10—Average understory tree cover[a] on Forest Inventory and Analysis field subplots by species

Scientific name	Common name	Cover	Number of subplots	Standard deviation across subplots where species was found
		Percent		
Aidia cochinchinensis Lour.	randia	3.0	2	0
Allophylus timorensis	kutaak	3.1	9	1.8
Artocarpus altilis	ma	1.0	1	
Artocarpus mariannensis	Marianas breadfruit	3.0	1	
Barringtonia asiatica (L.) Kurz	wop	1.0	1	
Bruguiera gymnorrhiza	jon, jong	35.0	4	17.8
Calophyllum inophyllum L.	luech, luwej	1.0	1	
Cocos nucifera	ni, nimaro, nimir, nimur, niram, nirik, niwinmej, jiwollab	13.0	114	14.2
Cordia subcordata	kono	2.0	4	1.4
Erythrina variegata (L.) Merr.	coral tree, tiger claw	5.0	1	
Guettarda speciosa	bwikow utlomar, utilomar, wut, wutilomar	2.3	42	1.7
Intsia bijuga	kubok, kubuk	2.0	2	1.4
Morinda citrifolia	nen, nin	3.0	53	3.9
Musa spp. L.	kebran, banana	1.0	1	
Neisosperma oppositifolia	kish par, kojbar	13.3	11	18.0
Pandanus tectorius	bob, bop, mwajaal	4.6	72	5.5
Pipturus argenteus (Forst. f.) Wedd.	arame, arme	2.0	2	1.4
Pisonia grandis	kanae, kanal, kangae, kangal	3.6	7	3.1
Premna serratifolia	kaar, kar	3.3	9	2.7
Scaevola taccada	konnat, kunat, mar kinat	5.4	36	5.8
Suriana maritima L.	kalane, newe, ngiangi, niani, kekun, rekung	8.0	1	
Terminalia samoensis	ekkon, ekun, kiking, kokon, kukung, kung	2.2	13	1.2
Tournefortia argentea	kiden, kirin	10.0	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 135 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.

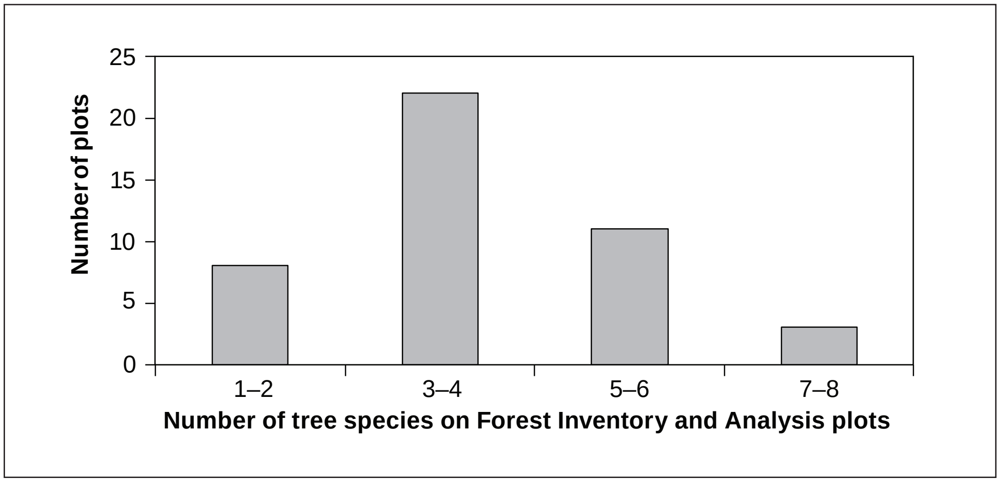

Figure 15—Relative to other Pacific Island groups, the number of tree species per one-sixth-acre plot is somewhat low, averaging about four tree species per plot in the Marshall Islands. The small size of the islets and great distance from larger land masses reduces the probability for colonization with new species.

Table 11—Number of trees by primary damage type and species for all trees

Species	No damage	Broken bole	Broken or dead	Broken roots	Conks	Cracks/ seams	Damaged foliage/shoots
				Number of trees			
Allophylus timorensis	134,212		3,411	3,411	42,486		
Artocarpus altilis	10,027					3,411	
Artocarpus mariannensis	20,055						
Bruguiera gymnorrhiza	338,332				6,821		
Cocos nucifera	1,587,366			16,849			6,753
Cordia subcordata	29,232						
Guettarda speciosa	735,767	87,465	32,175			2,859	648,930
Intsia bijuga	8,391		3,411				3,411
Morinda citrifolia	777,936		41,636				
Neisosperma oppositifolia	681,869					10,232	
Pandanus tectorius	671,471	3,411	10,232				
Pemphis acidula	70,577					5,974	
Pisonia grandis	68,512			86,614			3,411
Premna serratifolia	134,212						180,764
Scaevola taccada	2,509,228						1,292,549
Terminalia samoensis	8,250						
Tournefortia argentea	107,786	3,411	21,677			8,158	
Total	7,893,223	94,286	1,013,291	106,874	49,308	30,635	2,135,818

Species	Loss of apical dominance	Open wounds	Vines in crown	Canker/ gall	Discolored foliage	Other	All damages
				Number of trees			
Allophylus timorensis							49,308
Artocarpus altilis					3,342		6,753
Artocarpus mariannensis							
Bruguiera gymnorrhiza	6,821			17,054			30,696
Cocos nucifera		25,208	3,411		30,303	22,499	105,023
Cordia subcordata		55,503			20,464	6,821	82,789
Guettarda speciosa	6,690	84,250	119,218		42,486	35,438	1,059,512
Intsia bijuga		3,411					10,232
Morinda citrifolia	4,416		591,406				637,457
Neisosperma oppositifolia	3,411	53,763		3,411		12,329	83,146
Pandanus tectorius	16,502	3,342	13,643			10,096	57,226
Pemphis acidula		30,095					36,070
Pisonia grandis	3,411	6,821	30,696		374,292		505,245
Premna serratifolia		3,342					184,106
Scaevola taccada	56,648		254,918				1,604,115
Terminalia samoensis		7,913				22,473	30,386
Tournefortia argentea		16,374				5,056	54,677
Total	97,898	290,024	1,013,291	20,464	470,888	114,713	4,536,740

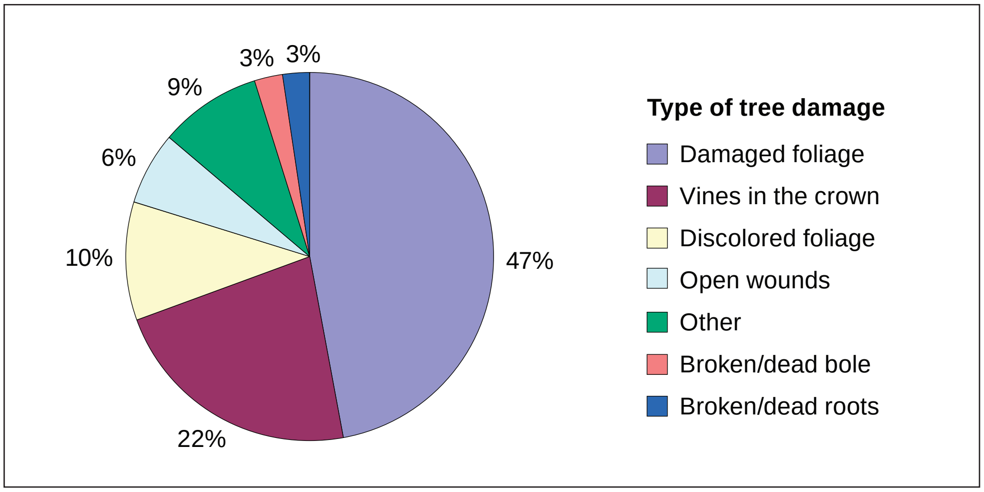

Figure 16—Damaged foliage is prevalent on coconut trees. Vines in crowns are also common in the Marshall Islands.

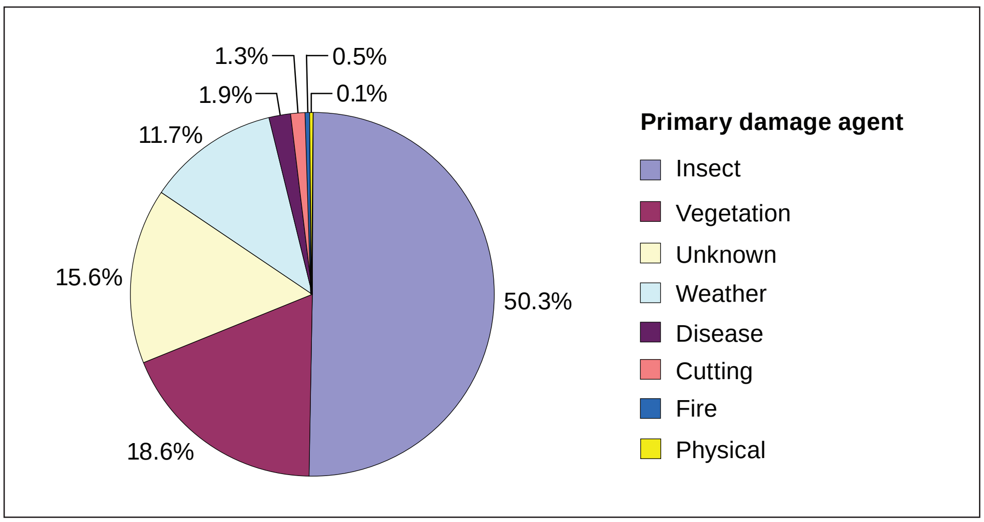

Figure 17—Insects and damage by other vegetation were the most common identifiable damaging agents in the Marshall Islands.

About 1.2 percent of the trees sampled during the inventory were dead. The most prevalent, identifiable dead trees were *Cocos nucifera* (49.6 percent of total dead), *Guettarda speciosa* (13.2 percent), and *Neisosperma oppositifolia* (8.9 percent) (fig. 18).

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

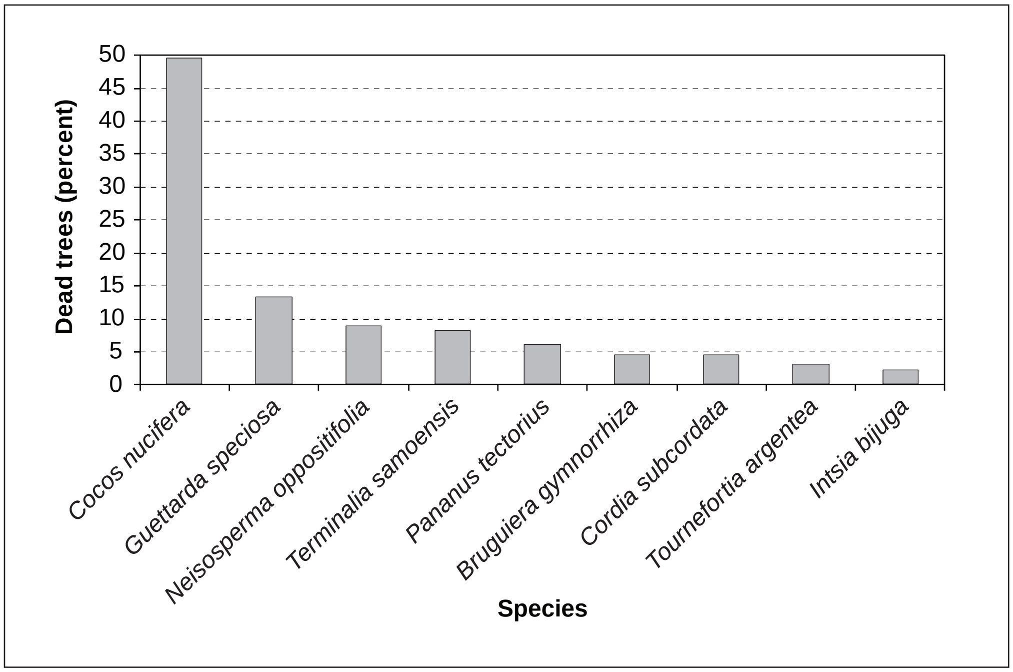

Figure 18—Dead coconut (*Cocos nucifera*) trees were the most common of the dead species identified. *Guettarda speciosa, Neisosperma oppositifolia,* and *Terminalia samoensis* followed in prevalence as the most common dead trees.

to the breakage of branches and occasionally snapping the stems of trees. In the RMI, we rated epiphytic loading on trees as a summation of loading on the bole, branches, and canopy. We estimate that about 92 percent of the trees ≥ 5 inches diameter at breast height in the RMI had few to no epiphytes, and less than 8 percent of the trees had moderate to high amounts of epiphytes (table 12).

Forest Dynamics

In the Marshall Islands, there is a wide range of forest characteristics and successional sere depending on latitude. In the drier northern atolls, we would expect slower successional replacement of species than in the wetter southern atolls, thus, recovery from disturbance may be quicker in the south. Over many of the atolls, the native vegetation has been replaced with coconut plantations (fig. 19). Other areas remain a mix of scrub and agroforest with species composition dependent on salt spray tolerance and rainfall amount (fig. 20).

Human populations have shifted and subsistence agroforestry is being replaced with a cash economy that relies on imported food, medicines, and building materials. Disturbance by military actions and the urbanization surrounding military installations have dramatically changed the vegetation of Kwajalein and Majuro. Food and water security have become important concerns for the atolls that are facing the loss of arable lands through urbanization and inundation from changes in sea level.

Table 12—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		
Allophylus timorensis	10,232	3,342			13,575
Artocarpus altilis	13,370	3,411			16,780
Artocarpus mariannensis		13,370	3,342	3,342	20,055
Bruguiera gymnorrhiza	23,875	23,875	23,875		71,625
Cocos nucifera	1,211,371	454,624	26,393		1,692,388
Cordia subcordata	91,816	11,110	9,095		112,021
Guettarda speciosa	225,386	109,582	55,505	20,332	410,805
Intsia bijuga	13,643	4,980			18,623
Morinda citrifolia	7,758	3,342			11,100
Neisosperma oppositifolia	162,057	7,867	16,712		186,637
Pandanus tectorius	434,861	88,995	57,742	19,640	601,238
Pemphis acidula	103,236	3,411			106,646
Pisonia grandis	143,045	16,780	30,696	3,411	193,932
Premna serratifolia	13,438		10,027		23,465
Scaevola taccada	8,256				8,256
Terminalia samoensis	29,756	8,880			38,636
Tournefortia argentea	111,790	41,915	3,702	5,056	162,463
Total	2,603,890	795,486	237,090	51,780	3,688,246

Steven T. Trimble

Figure 19—Coconut plantations dominate the skyline of the Marshall Islands.


Steven T. Trimble

Figure 20—The composition of native vegetation is determined by salt spray tolerance and drought tolerance.

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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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