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Republic of the Marshall Islands' Forest Resources: Forest Inventory and Analysis, 2018

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Cover photo: A field crew hikes to a forested plot at low tide. USDA Forest Service photo by Seth Ayotte.

Abstract

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In 2018, the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis program collected forest and tree measurements from 71 plots on 13 atolls and one island (Mejit) of the Republic of the Marshall Islands (RMI). Of these, 44 were remeasured plots first established in 2008, and 27 were newly established plots including 17 plots established in cooperation with the Micronesia Challenge program. We recorded a total of 20 tree species and 53 dominant vascular plant species, including three invasive plant species. We inventoried four forest communities (lowland rainforest, agroforest, strand forest, and mangrove) across the RMI.

Weather was the most prevalent disturbance category in 2018, and overall disturbance declined from about two-thirds of forest area in 2008 to one-tenth of forest area disturbed in 2018. Strand forest was the most disturbed forest community and the only community with more than one disturbance type. Invasive plant species covered about 1 percent of RMI forest area, and there were no invasive tree species observed. Damage from brown root rot (caused by the fungus *Phellinus noxius*) was observed in *Cocos nucifera* (ni, coconut palm) and *Pandanus tectorius* (bōb) trees. Pig damage to trees, vegetation, and soil was observed in <1 percent of forest area.

Forests in the RMI were moderately dense with about 700 stems per acre and were mostly composed of trees <3.0 inches in diameter at breast height. Mean tree diameter, tree height, and stem density per acre for RMI overall did not change significantly between 2008 and 2018, but mean basal area increased by about 7 square feet per acre. There was a slight decrease in the percentage of trees in the 13.0–14.9-inch diameter at breast height class, which is likely due to ongoing senescence and mortality of planted *Cocos nucifera* trees across the country.

KEYWORDS:
Republic of the Marshall Islands
Atoll
Coconut plantation
Strand forest
Micronesia
Carbon
Forest monitoring

Highlighted Forest Inventory and Analysis Statistics, Republic of the Marshall Islands

- Estimated total forest area (13 atolls and one island sampled): 23,993 acres
- Estimated total number of live trees (≥1 inch in diameter at breast height): 17,426,587 trees
- Estimated number of live *Cocos nucifera* (ni, coconut palm) trees: 1,929,847 trees
- Estimated number of live *Pandanus tectorius* (bōb) trees: 1,296,427 trees
- Estimated total live, aboveground tree carbon: 768,859 tons

Preface

U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) is one of the largest ground-based forest monitoring programs in the world, continuously measuring forest structure and health across 49 of the United States and collecting forest data in Hawai‘i, U.S. territories, and the U.S.-Affiliated Pacific Islands about every 10 years. The FIA program began working with the U.S.-Affiliated Pacific Islands and other U.S. territories in 2001. The first forest inventory in the Republic of the Marshall Islands began in 2008, and these plots were remeasured in 2018 (Agricultural Act 2014).

Differences Between 2008 and 2018 Inventories and Reports

There were some differences in the methodologies between the 2008 and 2018 inventories, and differences in reporting of summary results. Percentage of live canopy cover for the entire plot, percentage of subplot area with pig damage, and percentage of cover of invasive species were not measured in the 2008 inventory, and percentage of forest area by disturbance, dominant species, growth habit, and canopy cover were not mentioned in the 2008 report.

The percentage of cover of culturally and economically important species (covering at least 1 percent of area) was not recorded in the 2018 inventory, and the topographic relative moisture index of forests in the RMI was not recalculated for the 2018 report.

In 2012, the national office of the FIA program instituted a procedural revision adopted nationally across the FIA program to improve the quality and repeatability of tree damage data (Randolph et al. 2021). Therefore, procedures for recording a specific damage agent (location, type, severity) on individual trees changed between the 2008 and 2018 field visits.

The number of subplots, mean percentage of forest area cover, and standard deviation of understory species and tree seedlings were listed for all species in the 2008 report, but only the 15 most common understory and tree sapling/seedling species are listed by percentage of forest area covered in the 2018 report.

Contents

Introduction

This summary of forest resources of the Republic of the Marshall Islands (RMI) is based on forest inventories conducted in 2008 and 2018 by the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) program in partnership with the RMI Ministry of Natural Resources and Commerce, and the Micronesia Conservation Trust. The inventory was designed to generate information at the national scale about the status and trends of forested ecosystems, to provide data to resource managers for making informed forest management decisions, and to share forestry skills among jurisdictions and agencies. The forest resources in the RMI are described in detail in the national forest action plan (RMI 2020), which describes forests and ecosystem services; priority landscapes; and the primary issues threatening the health of trees, forests, and terrestrial wildlife in the RMI. A multinational crew from the RMI, the Federated States of Micronesia, Guam, and Alaska conducted fieldwork for the 2018 inventory.

Table 1—Sample size of measured USDA Forest Service, Forest Inventory and Analysis forest plots by atoll region and atoll in the Republic of the Marshall Islands, 2018

Region	Atoll/island name	Number of forest plots sampled in 2018
Northern atolls	Rongelap	3
	Ailuk	9
	Aur	6
	Kwajalein	8
	Likiep	5
	Maloelap	3
	Mejit	2
	Wotje	5
Southern atolls	Ailinglaplap	4
	Arno	9
	Jaluit	6
	Majuro	3
	Mili	8

Geography and Climate

The RMI is composed of 29 atolls and five solitary islands, which altogether consist of more than 1,200 islands and islets. The atolls are aligned into two, primarily north-south chains—the eastern is known as the Ratak (sunrise), and the western is known as the Ralik (sunset). Atolls are also distinguished by whether they occur in the dry, northern or wet, southern regions of the country (table 1). We compare attributes of these northern and southern atoll regions throughout this report. The nation covers 750,000 square miles of water in the Northwestern Pacific Ocean region, of which only 70 square miles (0.01 percent) is land. The sampled areas reported in this inventory of the RMI cover 71.4 percent of the total land area.

The base FIA plots were located on 10 of the largest atolls in the RMI. We increased the number of islands sampled and inventoried in 2018 to include plots on Aur and Ailuk atolls, and Mejit Island.

Most islands and islets in the RMI are flat with an elevation of up to 6 feet. They have areas of dunes created by wind, beach ridges created by waves, and cobble and boulder deposits up to 15 feet tall left by storms (fig. 1) (Mueller-Dombois and Fosberg 1998). The soils are essentially all well-drained sand or limestone

Figure 1—Aerial view of southwestern Majuro atoll. USDA Forest Service photo by Seth Ayotte.

rubble, which come almost entirely from coral. There are considerable areas of consolidated limestone and smaller areas of hard phosphatic rock from seabird guano, as well as semidecomposed humus under pure stands of *Pisonia grandis* (Laird 1989, Mueller-Dombois and Fosberg 1998). There are also areas of agroforest, house gardens, taro pits, and mangrove depressions where organic matter has accumulated and mixed with the sandy soils through the actions of humans over centuries of habitation.

The RMI has a tropical climate with hot conditions throughout the year; most atolls and islands experience mean temperatures that change relatively little during the day and throughout the year. The mean daily maximum and minimum temperatures (86 and 78 °F, respectively) per month vary annually by <2 °F (fig. 2) (NCEI 2020a, 2020b, 2020c, 2020d).

Precipitation is much more variable and seasonal than temperature in the RMI, with southern atolls like Majuro receiving more than twice the mean annual rainfall of northern atolls with semiarid conditions, such as Enewetak, but showing the same general seasonal rainfall pattern (fig. 3) (NCEI 2020b, 2020d). This north-south climatic gradient has obvious effects on the atoll vegetation, which is characterized overall by a limited set of ecologically resilient tree and plant species (Mueller-Dombois and Fosberg 1998). While lacking the typhoon frequency of the far Western Pacific, the region is nevertheless periodically affected by tropical storms which can inundate islands. This is thought to contribute to some islets being dominated by a single tree species (Mueller-Dombois and Fosberg 1998), usually *Pisonia grandis* or *Neisosperma oppositifolia*, which is unusual for a tropical forest.

The most obvious feature of forests on RMI atolls is the presence of *Cocos nucifera* (ni, coconut palm), which was introduced many centuries ago by early Micronesian settlers and mostly planted for the copra (dried coconut flesh) industry more than a hundred years ago (Merlin et al. 2018). *Cocos nucifera* palms replaced much of the native vegetation and copra production remains central to the economies of the outer atolls. In areas where copra is collected, the forests are extensively managed for this purpose.

Some of the atolls have experienced military invasions, bombardments, buildups, and nuclear testing, as well as installations of commercial and government infrastructure, all of which further reduced or eliminated most of the native plants and animals. Most of what remains of RMI's native forests can be found in strand forests, on the more remote atolls, or in recovering forests abandoned after nuclear testing (Mueller-Dombois and

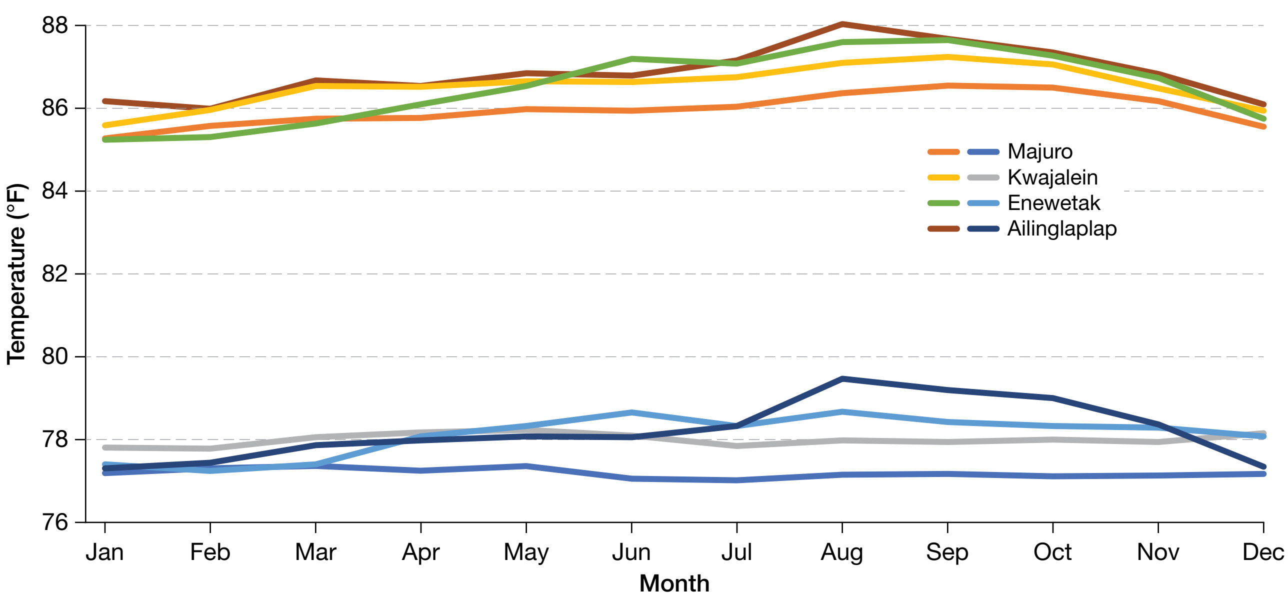

Figure 2—Daily mean maximum and minimum temperatures by month on four atolls in the Republic of the Marshall Islands from February 1955 through October 2020 on Majuro, from January 1953 through February 1968 on Enewetak, from January 1953 through August 2020 on Kwajalein, and from January 2014 through October 2020 on Ailinglaplap (NCEI 2020a, 2020b, 2020c, 2020d).

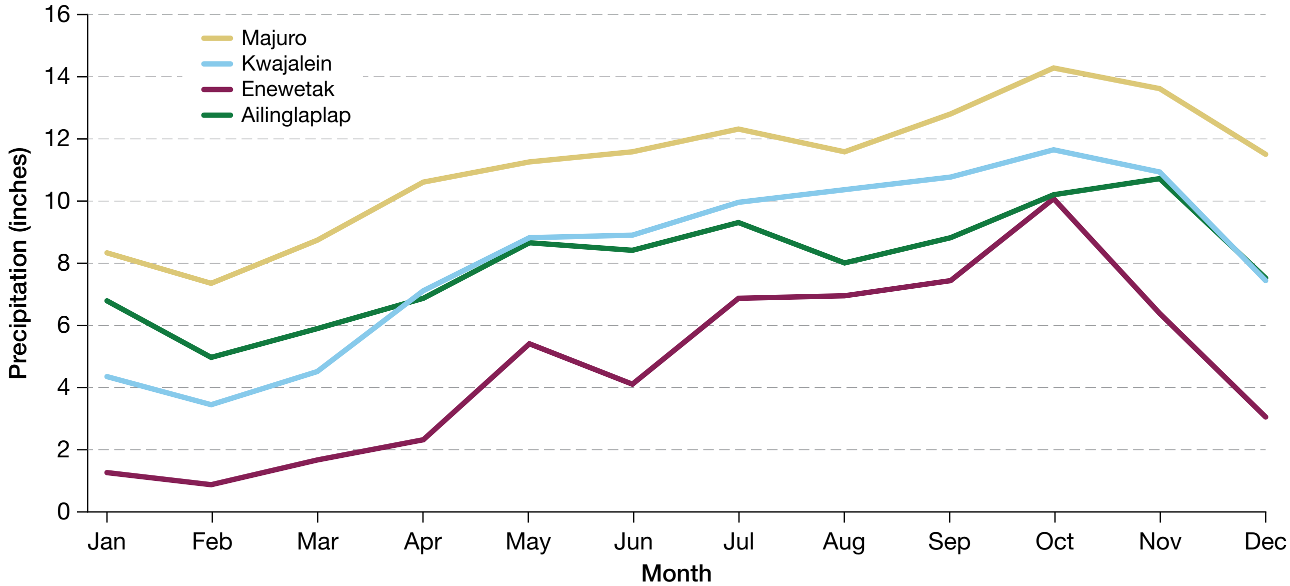

Figure 3—Mean precipitation by month on four atolls in the Republic of the Marshall Islands from January 1953 through June 1969 on Enewetak, from December 1955 through October 2020 on Ailinglaplap, from January 1953 through August 2020 on Kwajalein, and from February 1955 through October 2020 on Majuro (NCEI 2020a, 2020b, 2020c, 2020d).

Fosberg 1998). While not intentionally planted as such, native strand forest and vegetation is left intact on windward islets to serve as windbreaks which protect *Cocos nucifera* plantations and taro patches from windblown salt spray (Thomas et al. 1988). Additionally, as the plantations senesce, some return of native species is occurring as we describe here.

Forest Inventory and Analysis Program

Because of the smaller scale of RMI forested ecosystems, the FIA program increased the standard plot sampling intensity by a factor of 12, and plots were sampled every 500 acres rather than every 6,000 acres like they are in U.S. mainland inventories. The intensified sampling design located plots on 13 of the 29 atolls across the RMI (fig. 4) but not on many of the more remote northern atolls because of complex logistics and the high cost of boat transport in the country. The Micronesia Conservation Trust, with funding from the Forest Service's Landscape Scale Restoration Program, provided support to add plots on previously unsampled atolls (Ailuk and Aur) and a solitary island (Mejit) as part of the 2018 inventory. These islands were added because the Ministry of Natural Resources and Commerce is interested in the forest health and resources in drier forests found in the northern atolls. This plot network thus enhanced overall monitoring of forests under the Micronesia Challenge to conserve forests across the region (Dendy et al. 2020).

The FIA plot cluster covers a total area of about 1 acre and is composed of four 24-foot fixed-radius subplots, with three subplots equidistant from a central subplot like spokes on a wheel (fig. 5). For each plot, field crews assigned condition classes and their proportions to the accessible forest land area sampled. The forest condition characteristics measured on accessible forest land and estimated for each condition on the entire plot footprint included forest disturbances and treatments, forest type, and dominant tree species. Crews measured live and dead trees ≥5 inches in diameter at breast height (DBH) in the subplots, with a cumulative area of about $^{1}/_{6}$ of an acre or 676 square meters (0.07 hectares). Crews measured live and dead trees <5 inches but ≥1 inch in DBH in the microplots, with a cumulative area of about $^{1}/_{75}$ of an acre, or 53 square meters (0.005 hectares). In addition to diameter, crews measured tree height, identified tree species, and recorded tree damages from subplots and microplots. Crews estimated percentage of cover on each subplot for the four most dominant species (dominant species must meet a 3-percent cover threshold) in each different growth habit: graminoids, shrubs, forbs, and trees. In 2018, crews estimated percentage of invasive plant species cover and percentage of live tree canopy cover, and they recorded the presence of tree pathogens and pests unique to this region.

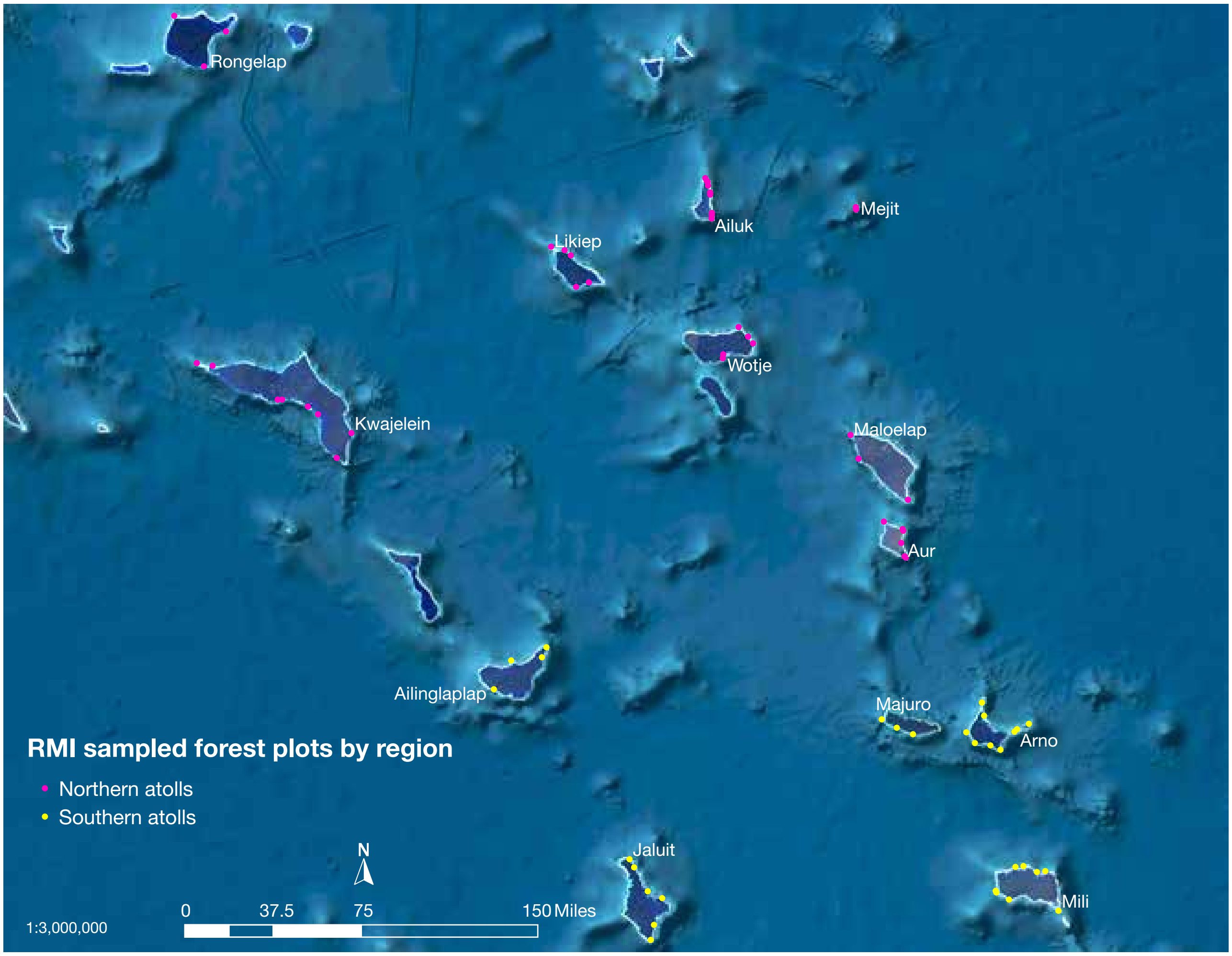

Figure 4—Republic of the Marshall Islands (RMI) atoll regions and USDA Forest Service, Forest Inventory and Analysis sampled forest plots (including Micronesia Challenge), 2018. Plot locations are approximate. Enewetak atoll is about 280 miles west of Rongelap atoll.

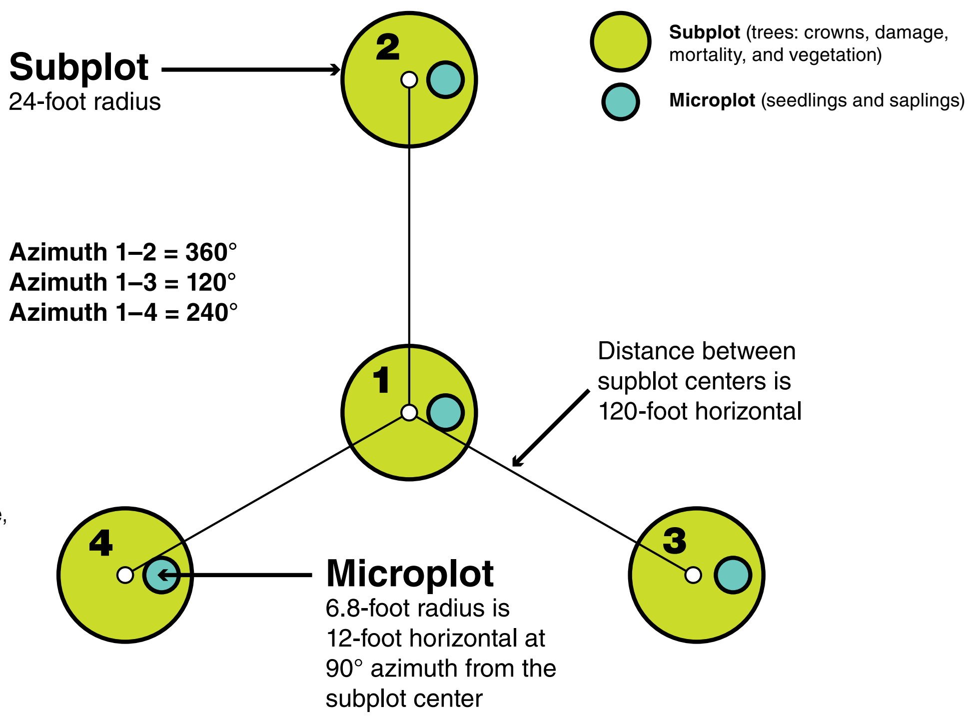

Figure 5—USDA Forest Service, Forest Inventory and Analysis plot diagram.

The FIA program uses a statistical method called post-stratification (based on the number of forest pixels in the satellite image used for each measurement cycle) to generate the estimated totals at the jurisdictional level from the plot-level data. This allows for estimates of total numbers or percentages of trees by species or diameter class; forest area by jurisdiction; or percentage of total forest area by forest community, disturbance, canopy cover, dominant tree species, or stand size class. We calculated estimates based on the FIA stratification and estimation procedures (Bechtold and Patterson 2005). We calculated growth, removals, and mortality of trees, and change in forest area over time by using a stratification that links measurements from at least two inventories.

The high diversity and variability of tropical forests and the small land area of the Pacific Islands tend to result in high sample error (SE) values for FIA estimates in the region. Therefore, for this report, we mostly include estimates with SE values smaller than the mean, because mean estimates with equivalent or larger SE values are unreliable. We encourage readers to compare estimates with SE values and review appendix 2.

Forest Area and Community

According to RMI vegetation maps from 2007–2009 (USDA FS 2010), about 70.9 percent of land area in the RMI is forested, and 11.1 percent is urban (table 2). Plots were located in four forest communities—27 in agroforest, 24 in strand forest (strand or halophytic vegetation), 23 in lowland rainforest (lowland tropical rainforest), and 1 in mangrove (mangrove swamp). Based on that random sampling, there were 23,993 acres of forest (SE = 2,084) in the RMI (specifically, in the 13 atolls and islands inventoried), of which about 39 percent (SE = 9.3) was lowland rainforest, 32 percent (SE = 7.9) was agroforest, 28 percent (SE = 7.6) was strand forest, and 2 percent (SE = 1.5) was mangrove (table 3). Although more strand forest, lowland rainforest, and overall forest area occurred in northern atolls, most of the agroforest occurred in southern atolls (table 4). While agroforest generally coincides with areas of human habitation, many uninhabited islets have agroforest that is periodically visited and harvested, particularly for copra (Pollock 1974).

Table 2—Land cover estimates by land cover class in the Republic of the Marshall Islands (RMI) from the most recent available vegetation maps (USDA FS 2010)

Land cover class	RMI land area
	PERCENT
Forest	70.9
Barren	14.2
Urban	11.1
Rangeland	3.4
Water	0.3

Table 3—Forest area by forest community in the Republic of the Marshall Islands

	Area			
Forest community	Mean	SE	Mean	SE
	ACRES		PERCENT	
Lowland rainforest	9,422	2,561	39.3	9.3
Agroforest	7,605	2,062	31.7	7.9
Strand forest	6,603	1,698	27.5	7.6
Mangrove	363	474	1.5	1.5
Total	23,993	2,084	100	

SE = sample error.

Table 4—Forest area by forest community and region in the Republic of the Marshall Islands

	Northern atolls		Southern atolls		RMI	
Forest community	Mean	SE	Mean	SE	Mean	SE
	PERCENT OF FOREST AREA					
Lowland rainforest	25.8	8.2	11.7	6.6	39.3	9.3
Agroforest	10.4	5.2	21.3	7.2	31.7	7.9
Strand forest	21.0	7.0	6.6	3.7	27.5	7.6
Mangrove	–	–	1.5	1.5	1.5	1.5
Total	57.2	8.6	41.1	8.7	100	

– = not observed, SE = sample error.

Live and Missing Canopy Cover

Multilayered forest vegetation with high percentage of canopy cover maintains understory moisture and temperature, provides the three-dimensional matrix within which diverse life forms carry out their life cycles, and protects erodible soils from intense tropical rains (Mueller-Dombois and Fosberg 1998). The FIA program defines forest as areas that have 10 percent or greater live and missing forest canopy cover (USDA FS 2018). Missing canopy cover estimates are based on canopy cover that existed before disturbance or tree harvesting in the past 30 years.

In 2018, 8.3 percent (SE = 3.9) of total forest area in the RMI had <50 percent live canopy cover, 87.8 percent (SE = 4.9) had >70 percent live canopy cover, and 50.1 percent (SE = 9.3) had ≥90 percent live canopy cover (fig. 6). Mean canopy cover overall was 82 percent (SE = 2.6). There was no difference in mean percentage of canopy cover overall between the northern and southern regions, but there was 14.1 percent (SE = 9) more forest area with >70 percent live canopy cover in the southern atolls. Among forest communities, lowland rainforest had the highest live percentage of canopy cover values, and agroforest had the lowest values (fig. 7). Forest area with missing

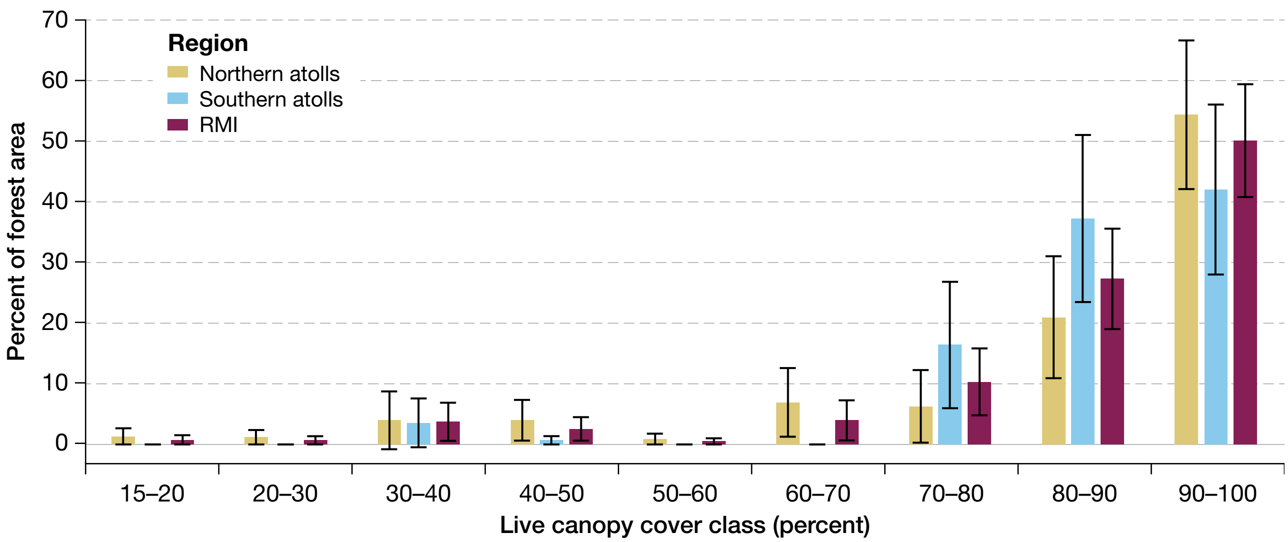

Figure 6—Forest area by live canopy cover class and region in the Republic of the Marshall Islands (RMI), 2018. Error bars represent 68-percent confidence level.

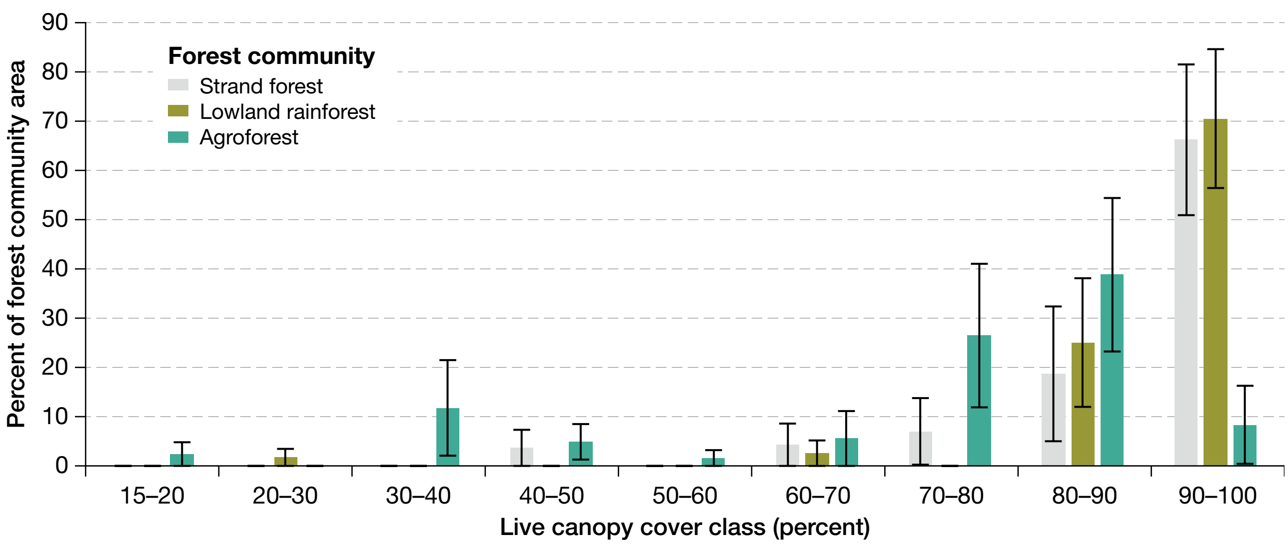

Figure 7—Forest community area by live canopy cover class in the Republic of the Marshall Islands, 2018. Error bars represent 68-percent confidence level.

canopy cover accounted for 3.8 percent (SE = 2.4) of total forest area in the RMI (5–25 percent missing).

Disturbance

Natural and human disturbances to tropical forests affect canopy cover, structure, and plant species diversity and composition, with varied outcomes depending on the disturbance type, duration and intensity, and the timescale afterward (Mueller-Dobmois and Fosberg 1998). Forest disturbances can be either natural or human-caused and must meet some minimum criteria to be recorded. They must be at least 1 acre in size and affect 25 percent of all trees, soil surface, or understory vegetation in the stand. If the disturbance affects only one species, then 50 percent of individuals of this species must be affected for the disturbance to be recorded (USDA FS 2018).

More than 90 percent of RMI forests were undisturbed in 2018 (table 5). Weather was the only disturbance with a statistically reliable estimate and accounted for the most forest disturbance overall, but only in strand forest (table 6). Strand forest was the most disturbed community overall and the only community with more than one disturbance type recorded. Human disturbance was only observed in agroforest. This is a drastic improvement from 2008, when 62.8 percent (SE = 7.4) of RMI forest area was disturbed (Donnegan et al. 2011). There was no human disturbance observed in 2008, but insect damage affected about half of all forest, and weather and vegetation suppression disturbed slightly more forest area than in 2018. Specifically, crews in 2008 noted the insect damage was leaf-miner damage, which they frequently found on *Scaevola taccada* and occasionally found on *Guettarda speciosa* and *Intsia bijuga*. It is not clear what species caused the insect damage or what led to the dramatic decline in insect damage, but lowland rainforest and agroforest both had no observations of insect damage in 2018 after substantial disturbance from insects in 2008.

Pig damage—

Crews recorded pig damage by subplot and estimated the percentage of subplot area damaged. We estimated about 0.4 percent (SE = 0.3) of total forest area in the RMI to be damaged by pigs.

Table 5—Forest area by disturbance type in the Republic of the Marshall Islands, 2018

Disturbance type	Mean	SE
	PERCENT OF FOREST AREA	
Tree disease	–	–
Fire	–	–
Animal damage	–	–
Unknown	–	–
Geological	–	–
Insect damage	0.6	0.6
Human caused	1.9	2.0
Vegeation	2.6	2.6
Weather	4.3	3.3
Any disturbance	8.1	4.5
Undisturbed	91.9	4.5

– = not observed, SE = sample error.

Table 6—Forest community area by disturbance type in the Republic of the Marshall Islands, 2018

	Strand forest		Mangrove		Lowland rainforest		Agroforest		Total	
Disturbance type	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
	PERCENT OF FOREST COMMUNITY AREA									
Insect damage	0.6	0.6	–	–	–	–	–	–	0.6	0.6
Human caused	–	–	–	–	–	–	1.9	2.0	1.9	2.0
Vegetation	2.6	2.6	–	–	–	–	–	–	2.6	2.6
Weather	4.3	3.3	–	–	–	–	–	–	4.3	3.3
Any disturbance	6.2	4.1	–	–	–	–	1.9	2.0	8.1	4.5
Undisturbed	21.3	7.0	1.5	1.5	39.3	9.3	29.8	8.0	91.9	4.5
Total	27.5	7.6	1.5	1.5	39.3	9.3	31.7	7.9	100	

– = not observed, SE = sample error.

Treatments

We recorded silviculture treatments if they were at least 1 acre in size and if they occurred since the previous inventory (or in the 5 years before an initial plot installation). In 2018, almost one-third of forest area had been subjected to treatments, which was almost the same as reported for 2008 (Donnegan et al. 2011). For most of this area (28.7 percent [SE = 7.9]), crews recorded "other silviculture treatment," which in all cases in the RMI refers to understory burning, and to a lesser extent manual clearing of vegetation, to open the understory and facilitate copra harvest (fig. 8). About 85 percent of "other silviculture treatment" area was in agroforest, with the rest in lowland rainforest, and all treated plots had dominant *Cocos nucifera* trees present. Tree cutting affected almost 1 percent of forest area (SE = 0.9).

Trees

Tree Abundance, Dominance, and Species Composition

We report tree species by their scientific names. See appendix 1 for the associated common names. In 2018, we estimated that there were 17,426,587 (SE = 3,347,255) live trees ≥1 inch in diameter at breast height (DBH) in the RMI. *Scaevola taccada* was by far the most abundant tree species in the RMI, with about three times the number of the next two most common species, *Guettarda speciosa* and *Cocos nucifera* (table 7). *Scaevola taccada* was the fifth most dominant tree species by relative dominance (proportion of total forest basal area) and the third most dominant species by total forest area (tables 8 and 9). For every forested plot or condition, crews recorded up to three dominant tree species with the greatest percentage of non-overtopped, live canopy cover. For the 71 total

Figure 8—Relatively clear understory and pile of husks from copra (dried coconut flesh) harvest. USDA Forest Service photo by Seth Ayotte.

Table 7—Relative abundance and status of live tree species (≥1 inch in diameter at breast height) in the Republic of the Marshall Islands, 2018

Tree species	Common name	Mean	SE	Status
		Percent of trees		
Scaevola taccada	kōņņat	39.8	9.0	N
Guettarda speciosa	utilomar	13.2	3.7	N
Cocos nucifera	ni, coconut palm	11.1	3.0	I
Pandanus tectorius	bōb	7.4	2.7	N
Pisonia grandis	kañal	6.4	4.1	N
Morinda citrifolia	nen	5.0	3.4	U
Neisosperma oppositifolia	kōjbar	4.6	2.6	N
Bruguiera gymnorhiza	joñ	3.1	3.2	N
Allophylus timorensis	kūtaak	2.6	1.9	N
Pemphis acidula	kōñe	1.9	1.1	N
Terminalia samoensis	ekkōñ	1.4	0.7	N
Cordia subcordata	kōņo	1.0	1.2	N
Premna serratifolia	kaar	0.9	0.6	N
Tournefortia argentea	kiden	0.7	0.4	N
Artocarpus altilis	mā	0.3	0.4	I
Hibiscus tiliaceus	ļo	0.2	0.2	U
Pipturus argenteus	arṃwe	0.2	0.2	N
Intsia bijuga	kubuk	0.2	0.2	U
Artocarpus mariannensis	Marianas breadfruit	0.03	0.03	E
Terminalia catappa	kotōl	0.02	0.02	I

E = endemic to Micronesia, I = introduced, N = native, SE = sample error, U = unknown.
Common names and status source: Merlin et al. (2018); endemic status source: Costion and Lorence (2012).

forest plots and 76 conditions measured in the RMI, crews recorded 12 dominant tree species, of which 5 tree species had reliable cover estimates (table 9). *Cocos nucifera* was the most dominant tree species in the RMI, dominating nearly two-thirds of total forest area with more than half of the total forest basal area.

We were able to reliably estimate tree abundance by diameter classes for 12 of the 20 tree species that we inventoried (table 10). About 25 percent of species that we inventoried were only represented by trees <10 inches in DBH, and about 20 percent of species inventoried had no saplings recorded. Crews recorded only one tree species endemic to Micronesia (on Mili atoll) and no invasive tree species. There were 3.7 tree species per plot (SE = 0.4) among all forest communities, and tree species richness per plot was higher in lowland rainforest (4.5 [SE = 0.3]) than in agroforest (2.6 [SE = 0.2]) and strand forest (3.8 [SE = 0.3]).

Diameter and Height

In 2018, the mean DBH of all live trees ≥1 inch in DBH in the RMI was 4.0 inches (SE = 0.5), and the average height was 23.1 feet (SE = 2.0). More than 8 of 10 trees were <7 inches in DBH (table 11). The size distribution figure for DBH was heavily weighted toward the smallest size class of 1.0–2.9 inches (fig. 9), and the height distribution figure was weighted toward the two classes spanning 5–24 feet (fig. 10). The tallest tree was a *Cocos nucifera* on Aur atoll that was 103 feet tall and 14.8 inches in DBH. A *Pisonia grandis* tree on Arno atoll had the largest DBH, 35.8 inches, and was 94 feet tall.

The percentage of total trees that were >10 inches in DBH was 10.8 percent (SE = 7.6) higher in the southern atolls than in the northern atolls, which is likely due to more *Cocos nucifera* trees and agroforest area in the south

Table 8—Dominant tree species by relative dominance of live trees ≥1 inch in diameter at breast height in the Republic of the Marshall Islands, 2018

Tree species	Common name	Mean	SE	Status
		PERCENT OF BASAL AREA		
Cocos nucifera	ni, coconut palm	53.6	6.6	I
Pandanus tectorius	bōb	8.8	2.5	N
Guettarda speciosa	utilomar	8.5	2.3	N
Pisonia grandis	kañal	7.2	3.1	N
Scaevola taccada	kōņņat	4.8	1.9	N
Bruguiera gymnorhiza	joñ	3.6	3.5	N
Cordia subcordata	kōņo	2.7	3.2	N
Neisosperma oppositifolia	kōjbar	2.4	1.4	N
Tournefortia argentea	kiden	2.0	1.1	N
Pemphis acidula	kōñe	1.7	1.1	N
Morinda citrifolia	nen	1.2	0.8	U
Artocarpus altilis	mā	1.1	1.0	I
Terminalia samoensis	ekkōñ	0.7	0.4	N
Premna serratifolia	kaar	0.6	0.3	N
Allophylus timorensis	kūtaak	0.4	0.2	N
Intsia bijuga	kubuk	0.3	0.4	N
Artocarpus mariannensis	Marianas breadfruit	0.3	0.3	E
Hibiscus tiliaceus	ļo	0.1	0.1	N
Terminalia catappa	kotōl	0.1	0.1	I
Pipturus argenteus	arṃwe	0.03	0.03	N

E = endemic to Micronesia, I = introduced, N = native, SE = sample error, U = unknown.
Common names and status source: Merlin et al. (2018); endemic status source: Costion and Lorence (2012).

Table 9—Forest area by dominant tree species and region in the Republic of the Marshall Islands (RMI), 2018

	Northern atolls		Southern atolls		RMI	
Dominant tree species	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
	PERCENT OF FOREST AREA					
Cocos nucifera	53.0	11.7	76.6	11.9	63.5	8.6
Pandanus tectorius	9.7	6.6	6.5	6.6	8.2	4.7
Scaevola taccada	11.9	6.7	1.6	1.6	7.4	4.0
Pisonia grandis	9.7	7.2	–	–	5.5	4.2
Neisosperma oppositifolia	3.1	3.1	6.3	6.3	4.3	4.3
Guettarda speciosa	5.6	4.7	–	–	3.2	2.7
Artocarpus altilis	–	–	4.3	4.3	1.8	1.8
Bruguiera gymnorhiza	–	–	3.7	3.7	1.5	1.5
Tournefortia argentea	1.8	1.8	–	–	1.0	1.0
Pemphis acidula	0.9	0.9	–	–	0.5	0.5
Intsia bijuga	–	–	1.1	1.1	0.4	0.4

– = not observed, SE = sample error.

Table 10—Number of live trees on forest land by species and diameter at breast height (DBH) class in the Republic of the Marshall Islands, 2018

		DBH class (inches)							
		1.0–4.9		5.0–9.9		≥10.0		All classes	
Tree species	Common name	Mean	SE	Mean	SE	Mean	SE	Mean	SE
		NUMBER OF TREES							
Scaevola taccada	kōņņat	6,920,993	2,505,239	16,560	13,880	–	–	6,937,554	2,508,868
Guettarda speciosa	utilomar	1,738,404	823,209	474,387	138,843	84,148	35,803	2,296,939	856,489
Cocos nucifera	ni, coconut palm	–	–	246,079	71,470	1,683,768	302,332	1,929,847	340,825
Pandanus tectorius	bōb	457,240	318,292	833,999	261,358	5,187	5,052	1,296,427	416,514
Pisonia grandis	kañal	822,993	680,055	173,956	100,281	110,731	49,353	1,107,680	806,432
Morinda citrifolia	nen	844,075	570,112	29,402	23,162	–	–	873,477	583,974
Neisosperma oppositifolia	kōjbar	669,409	385,185	115,269	85,637	18,593	17,183	803,271	454,121
Bruguiera gymnorhiza	joñ	463,205	493,759	22,311	24,550	55,778	53,407	541,293	556,651
Allophylus timorensis	kūtaak	435,182	314,804	17,426	12,187	–	–	452,607	318,601
Pemphis acidula	kōñe	219,570	148,516	91,309	68,414	20,061	14,132	330,940	178,157
Terminalia samoensis	ekkōñ	184,129	110,520	62,862	35,886	1,469	1,418	248,460	134,765
Cordia subcordata	kōņo	46,320	60,406	79,473	83,566	40,904	53,342	166,697	196,350
Premna serratifolia	kaar	128,083	86,293	27,623	16,280	5,489	4,919	161,195	96,749
Tournefortia argentea	kiden	46,320	60,406	45,687	24,144	29,536	20,473	121,543	68,023
Artocarpus altilis	mā	31,784	50,061	10,592	9,075	13,925	12,176	56,301	63,839
Hibiscus tiliaceus	ļo	31,784	50,061	2,552	4,019	–	–	34,335	54,079
Pipturus argenteus	arņwe	31,784	50,061	–	–	–	–	31,784	50,061
Intsia bijuga	kubuk	–	–	21,144	24,577	6,270	6,298	27,414	30,185
Artocarpus mariannensis	Marianas breadfruit	–	–	–	–	5,103	8,038	5,103	8,038
Terminalia catappa	kotōl	–	–	–	–	3,719	4,849	3,719	4,849

– = not observed, SE = sample error.

Table 11—Live trees by diameter at breast height (DBH) class and region in the Republic of the Marshall Islands (RMI), 2018

	Northern atolls		Southern atolls		RMI	
DBH class	Mean	SE	Mean	SE	Mean	SE
INCHES	PERCENT OF TREES					
1.0–2.9	65.4	5.4	59.8	12.6	63.2	5.5
3.0–4.9	14.4	3.3	7.3	4.1	11.9	2.9
5.0–6.9	6.1	1.6	7.4	3.1	6.6	1.5
7.0–8.9	4.4	1.4	4.6	1.6	4.6	1.1
9.0–10.9	3.5	1.1	4.8	1.9	4.0	1.0
11.0–12.9	3.8	1.3	7.0	2.9	5.0	1.3
13.0–14.9	1.6	0.7	5.4	2.4	2.9	0.9
15.0–16.9	0.5	0.3	2.4	1.2	1.2	0.4
≥17.0	0.2	0.1	1.2	0.6	0.6	0.3

SE = sample error.

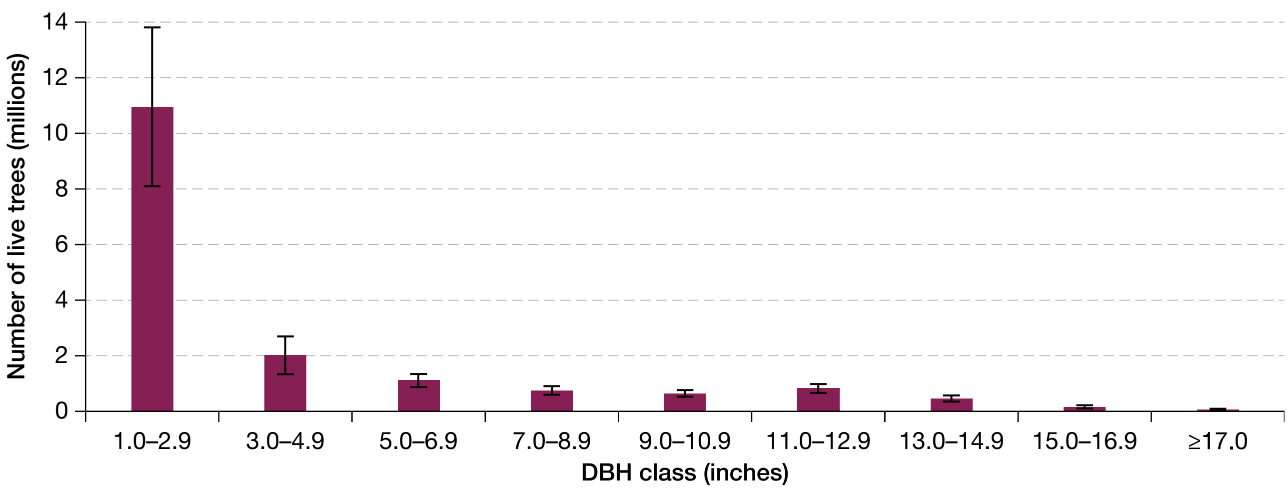

Figure 9—Number of live trees by diameter at breast height (DBH) class in the Republic of the Marshall Islands, 2018. Error bars represent 68-percent confidence level.

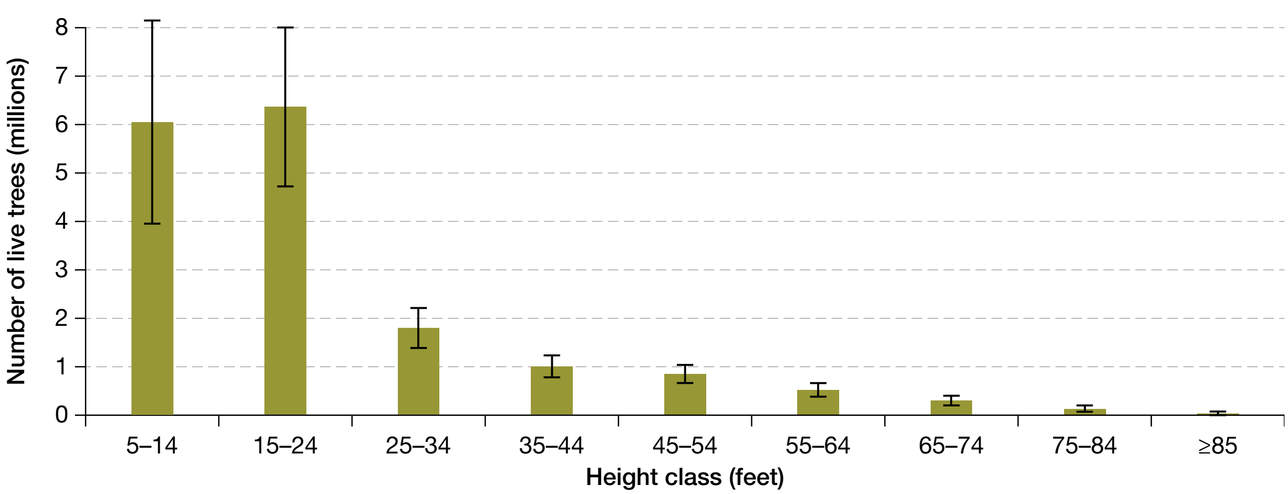

Figure 10—Number of live trees by height class in the Republic of the Marshall Islands, 2018. Error bars represent 68-percent confidence level.

(fig. 11). Mean tree height of trees ≥5 inches in DBH was 9.3 feet (SE = 3.9) higher in southern atolls. In the southern atolls, there were 9.7 percent (SE = 5.4) more trees taller than 55 feet and 14.9 percent (SE = 11.4) fewer trees in the 15–24-foot height class compared to northern atolls. There were essentially no trees >75 feet tall in northern atolls (fig. 12). In the comparison of FIA plots over time, mean tree diameter and height did not change significantly in the RMI between the 2008 and 2018 inventories. There were some significant changes by region in mean sapling diameter and height, and by percentage of trees in the 13–14.9-inch and the 3–4.9-inch DBH classes (SE values are conservative), but all changes in broader DBH classes were insignificant (fig. 13).

Tree Damages

Assessing tree damages can provide insights into the status of many forest health issues and successional patterns. Insects, disease, weather, vegetation suppression, humans, and animals, can affect individual tree health. Field crews assessed damages on trees from bottom to top, prioritizing those that lead to mortality, then those that reduce near-term growth, and finally those that hinder the tree from becoming a marketable product. Crews recorded up to three damage agents per tree and documented root and butt defects, cankers, and stem decay when any evidence was detected. This is a change from the previous inventory in which disease was only recorded if it affected a minimum threshold of 20 percent of surface area. Crews coded other damage agents if they met a threshold that

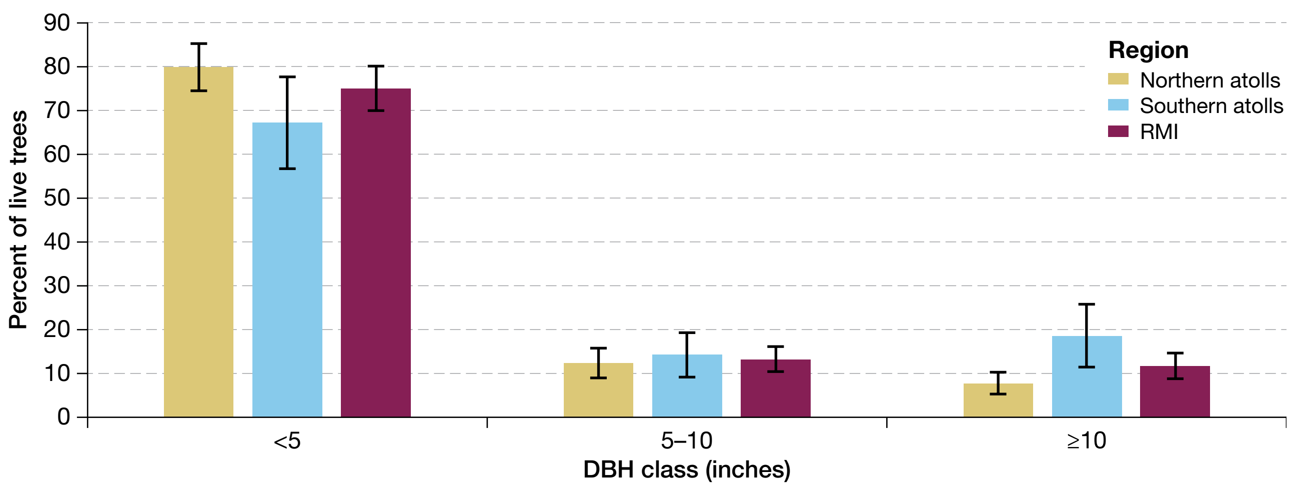

Figure 11—Percentage of live trees by diameter at breast height (DBH) class and region in the Republic of the Marshall Islands (RMI), 2018. Error bars represent 68-percent confidence level.

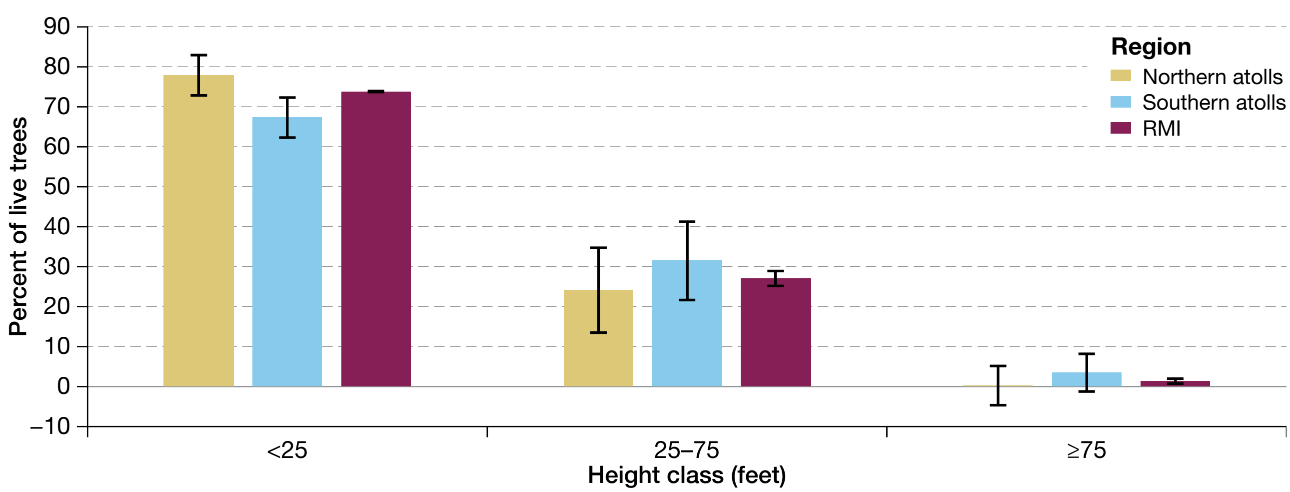

Figure 12—Percentage of live trees by height class and region in the Republic of the Marshall Islands (RMI), 2018. Error bars represent 68-percent confidence level.

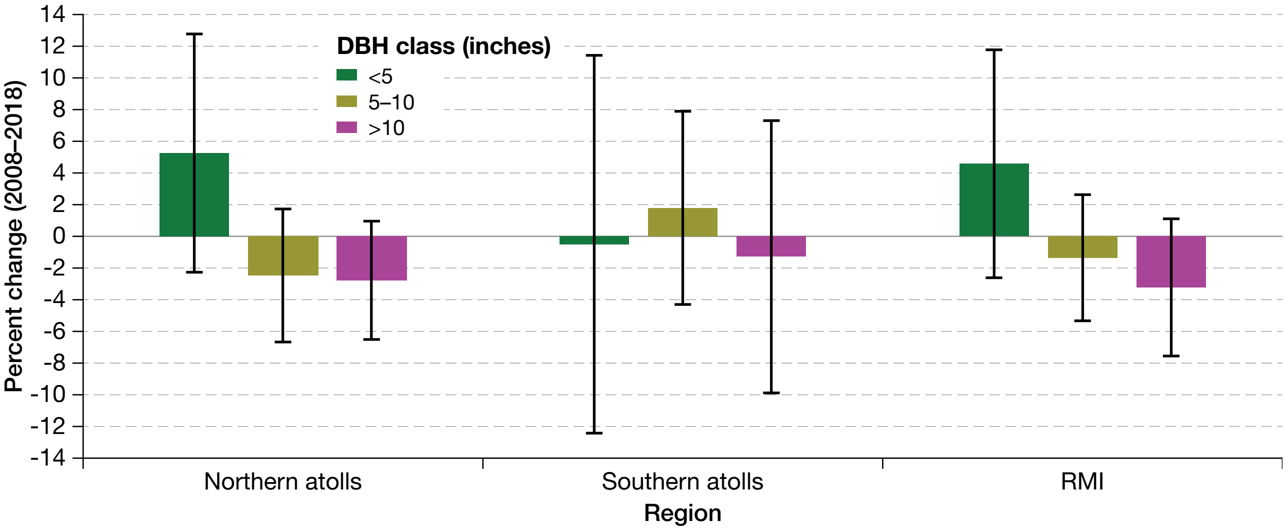

Figure 13—Change in percentage of trees by diameter at breast height (DBH) class between 2008 and 2018 in USDA Forest Service, Forest Inventory and Analysis inventories in the Republic of the Marshall Islands (RMI). Error bars represent 68-percent confidence level. Sample error is conservative.

would lead to death or reduced growth. Details on this field protocol and the thresholds by damage agent can be found in the field manual (USDA FS 2018).

In 2018, crews coded a damage on 35.8 percent (SE = 4.9) of all live trees ≥1 inch in DBH in the RMI. This is roughly the same percentage of trees with any damage observed in the 2008 inventory at 38 percent (SE = 5.3) (Donnegan et al. 2011). The most prevalent damage was stem decay, which affected 19.8 percent (SE = 13.7) of all trees (table 12). There was a large increase in tree

Table 12—Relative abundance of live trees (≥1 inch in diameter at breast height) by damage type and region in the Republic of the Marshall Islands (RMI), 2018

	Northern atolls		Southern atolls		RMI	
Damage type	Mean	SE	Mean	SE	Mean	SE
	Percent of trees					
No damage	41.9	8.2	22.4	10.5	64.2	4.9
Any damage	23.8	4.9	12.0	4.4	35.8	4.9
Stem decay	12.2	3.4	7.6	3.0	19.8	3.7
Root/butt diseases	5.8	1.6	3.1	1.1	8.9	1.5
Vine damage	6.0	2.5	1.4	2.0	7.4	3.1
Human activities	2.1	0.9	2.1	1.1	4.2	1.5
Dead top	2.5	0.8	1.4	1.0	3.9	1.2
Broken top	1.6	0.9	0.9	0.7	2.5	1.1
Open wound	1.7	0.9	0.6	0.3	2.4	0.9
Fire	1.0	0.4	0.9	0.4	1.9	0.6
Other damages and symptoms	1.0	0.6	0.9	0.8	1.9	0.9
Competition	1.4	1.1	–	–	1.4	1.1
Parasitic plants	0.0	0.0	1.2	1.2	1.2	1.2
Defoliators	0.8	0.8	0.0	0.0	0.8	1.0
Abiotic damage	0.1	0.0	0.2	0.2	0.2	0.2

– = not observed, SE = sample error.

disease, including root disease and especially stem decay, which may be due to the above-mentioned change in the measurement protocol. The total damage estimate was similar because the increase in disease was largely offset by a large decrease in insect damage, which affected <1 percent of trees in 2018. Weather damage also decreased, and physical damages like broken and dead tops increased, but there was no change in vegetation competition/vine suppression. There was an increase in human activity because both human and fire damages to trees increased. Of trees damaged by fire or human activity, 59 percent were in treated areas. There were essentially no significant differences in rates of tree damages between regions.

There were seven species of trees with any damage estimated to more than half of the individuals of the species, but results for damage types other than root disease and stem decay had high sample errors. One exception was *Cocos nucifera*, which also had significant damages from fire and human activities (table 13).

Pacific Islands-Specific Damages

A priority damage is a parameter specific to the Pacific Islands inventory that describes a damage that does not meet the national minimum thresholds for recording damage but is of special interest to this region (Cannon et al. 2022, USDA FS 2018). Of the eight priority damages on the FIA list, crews recorded only two in the RMI—brown root rot (a disease caused by the fungus *Phellinus noxius*) and tinangaja (a disease caused by the coconut cadang-cadang viroid). Brown root rot was observed on both *Cocos nucifera* and *Pandanus tectorius* trees, and tinangaja was observed on one *Cocos nucifera* tree. The percentage of *Cocos nucifera* trees estimated with brown root rot was 0.13 percent, and for trees of all species was 0.05 percent.

Table 13—Live trees (≥1 inch in diameter at breast height) by species and damage type in the Republic of the Marshall Islands, 2018

	Root/butt diseases		Stem decay		Fire		Shade		Human activities		Dead top		Open wound		Vine damage		Any damage		No damage	
Tree species	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
	PERCENT OF TREES																			
Morinda citrifolia	1	1	73	14	2	2	21	17	0	0	–	–	0	0	47	16	81	14	19	14
Cordia subcordata	37	4	54	7	–	–	–	–	–	–	2	2	7	7	2	2	59	7	41	41
Tournefortia argentea	23	17	53	29	–	–	–	–	2	2	5	5	–	–	4	5	58	31	42	31
Cocos nucifera	19	4	40	5	13	4	–	–	22	5	–	–	11	3	1	1	53	5	47	5
Terminalia samoensis	6	4	43	22	1	1	7	7	1	1	4	4	–	–	1	1	52	20	48	20
Guettarda speciosa	8	3	20	6	0	0	–	–	4	4	6	4	5	4	12	8	46	9	54	9
Pisonia grandis	8	6	33	8	–	–	–	–	3	3	1	0	–	–	1	1	45	12	55	12
Pemphis acidula	10	9	16	10	–	–	–	–	–	–	19	11	0	0	–	–	40	16	60	16
Neisosperma oppositifolia	2	2	17	7	–	–	–	–	8	10	0	0	2	2	6	5	29	10	71	10
Pandanus tectorius	14	4	6	2	4	2	–	–	2	1	1	1	0	0	5	4	28	9	72	9
Scaevola taccada	7	3	8	3	–	–	1	1	1	1	5	2	1	1	5	3	23	7	77	7
All tree species	9	1	20	4	2	1	1	1	4	1	4	1	2	1	7	3	36	5	64	5

– = not observed, SE = sample error.

Epiphyte Loading

Epiphytes are vascular plants that grow on trees or other plants, and include native orchids, forbs, and vines. Epiphytes are common in tropical forests and often make up a substantial component of total species diversity in lowland tropical rainforests (fig. 14). However, when epiphyte load becomes excessive, it can cause tree damage, mortality, and lack of growth. Epiphyte load was estimated for trees that were ≥1 inch in DBH using a composite score of none (0), light (1), or heavy (2) in three sections of each tree—the bottom, middle, and top—for a total epiphyte load composite score that ranges from 0 to 6. In the RMI, about 1 percent of all trees were heavily covered in epiphytes (epiphyte load composite score of 6), 5 percent were moderately covered (4–5), 25 percent were lightly covered (1–3), and 70 percent had no epiphytes (0) (fig. 15). The percentage of trees overall with heavy or moderate epiphyte loads did not change significantly between 2008 and 2018 (Donnegan et al. 2011). However, there was a 12.3 percent (SE = 6.9) increase in trees lightly covered in epiphytes which could be because there were more plots sampled in northern atolls in 2018.

The agroforest tree *Morinda citrifolia* was the only species, of the 12 tree species with sample sizes >30, with a mean epiphyte load composite score of 2 (fig. 16). All other species had scores <1. Although some species with small sample sizes had tentatively higher scores, it appears that RMI forests overall are characterized by low levels of epiphyte cover. This is unsurprising considering the small island size, flat terrain, and strand-like environment (influenced by salt spray) overall.

Figure 14—Epiphytes on *Pandanus tectorius* (bōb) trees. USDA Forest Service photo by Seth Ayotte.

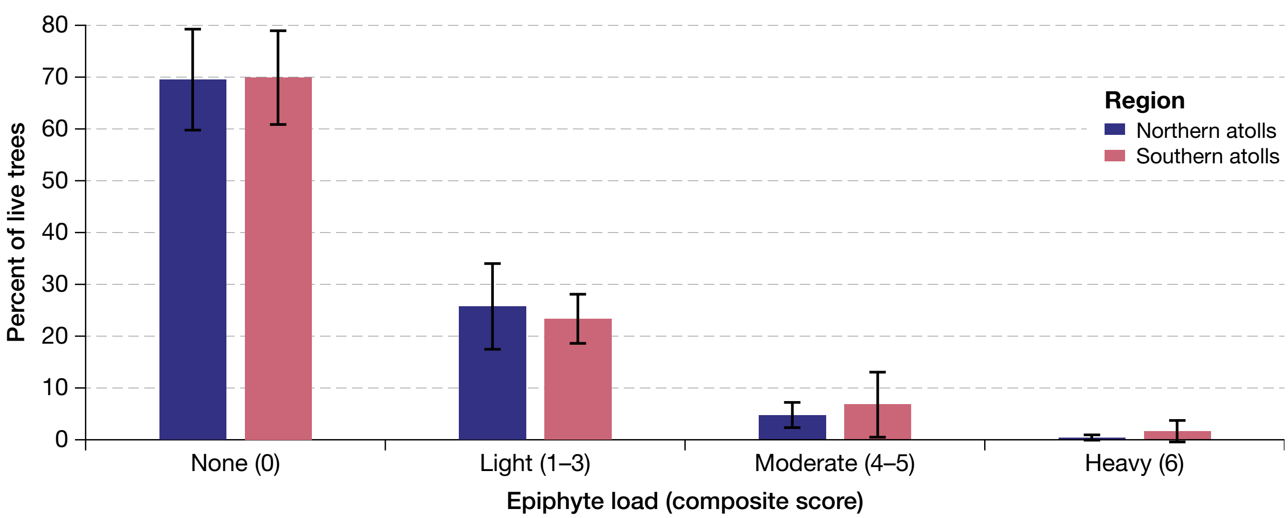

Figure 15—Live trees (≥1 inch in diameter at breast height) by epiphyte load composite score and region in the Republic of the Marshall Islands, 2018. Error bars represent 68-percent confidence level.

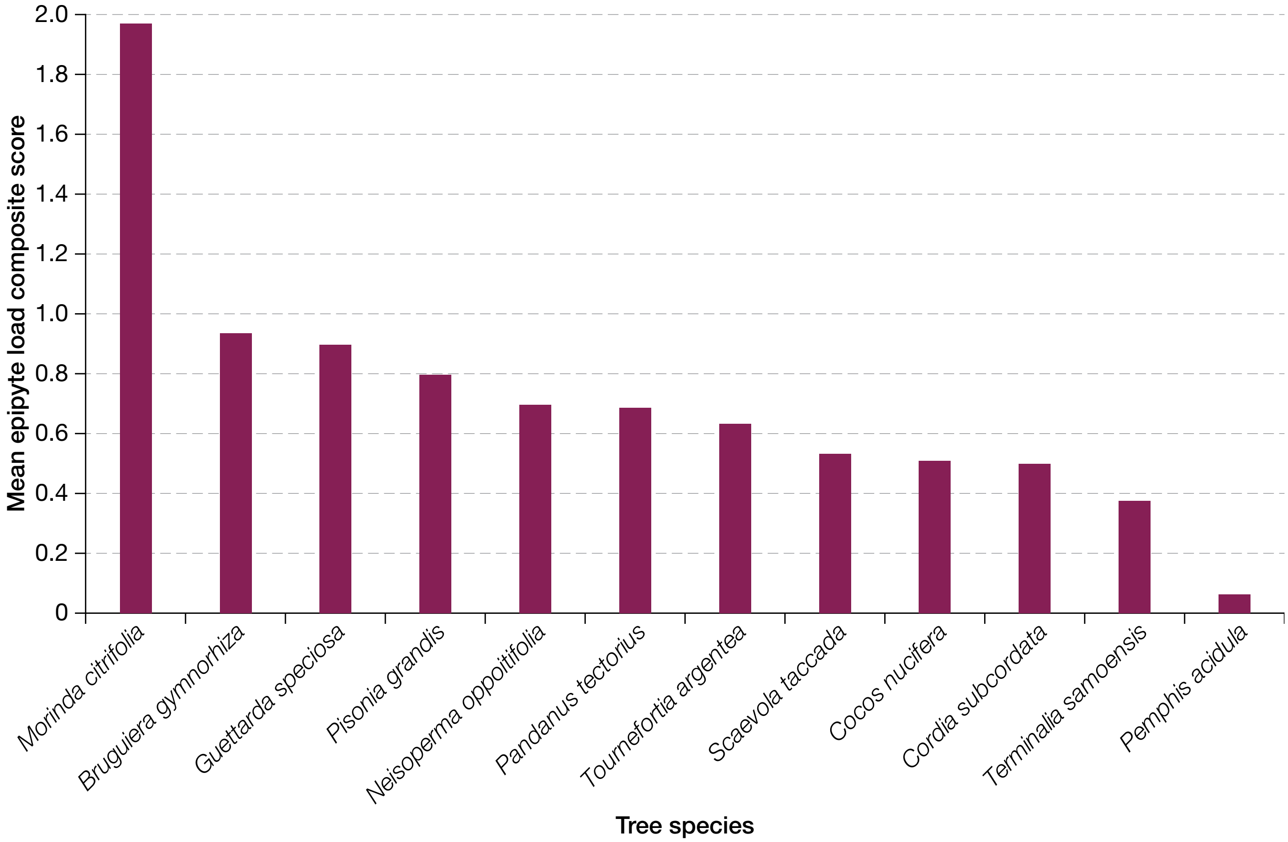

Figure 16—Mean epiphyte load composite score by tree species (n ≥ 30) in the Republic of the Marshall Islands, 2018.

Growth, Mortality, and Removals

We estimated that there were 7,013,220 (SE = 1,947,638) new trees ≥1 inch in DBH in the RMI from 2008 to 2018; 5,994,406 (SE = 1,448,227) trees lost to mortality; and 279,464 (SE = 138,853) trees removed (table 14). The sum of these categories resulted in a total net gain of 739,349 (SE = 1,420,442) trees overall, but the SE is nearly twice the estimate so we cannot know for sure if the number of total trees increased, decreased, or did not change. Removals were only observed in southern atolls. Trees ≥5 inches in DBH appeared to grow faster than those <5 inches in DBH (fig. 17).

Six inventoried tree species had significant net changes in abundance between inventories. The tree

Table 14—Growth, mortality, removals (GMR), and net change in abundance of trees ≥1 inch in diameter at breast height in the Republic of the Marshall Islands (RMI) from 2008 to 2018

	North		South		RMI	
GMR category	Mean	SE	Mean	SE	Mean	SE
	NUMBER OF TREES					
2008	6,650,162	2,268,560	5,556,121	1,240,356	12,206,283	2,218,025
2018	7,232,720	2,250,098	5,712,913	1,756,259	12,945,632	2,452,679
Growth	3,676,166	1,447,782	3,337,054	1,570,817	7,013,220	1,947,638
Mortality	–3,093,609	1,361,961	–2,900,797	860,995	–5,994,406	1,448,227
Removals	—	—	–279,464	138,853	-279,464	138,853
Net change	582,557	1,021,114	156,792	998,957	739,349	1,420,442

— = not observed, SE = sample error.

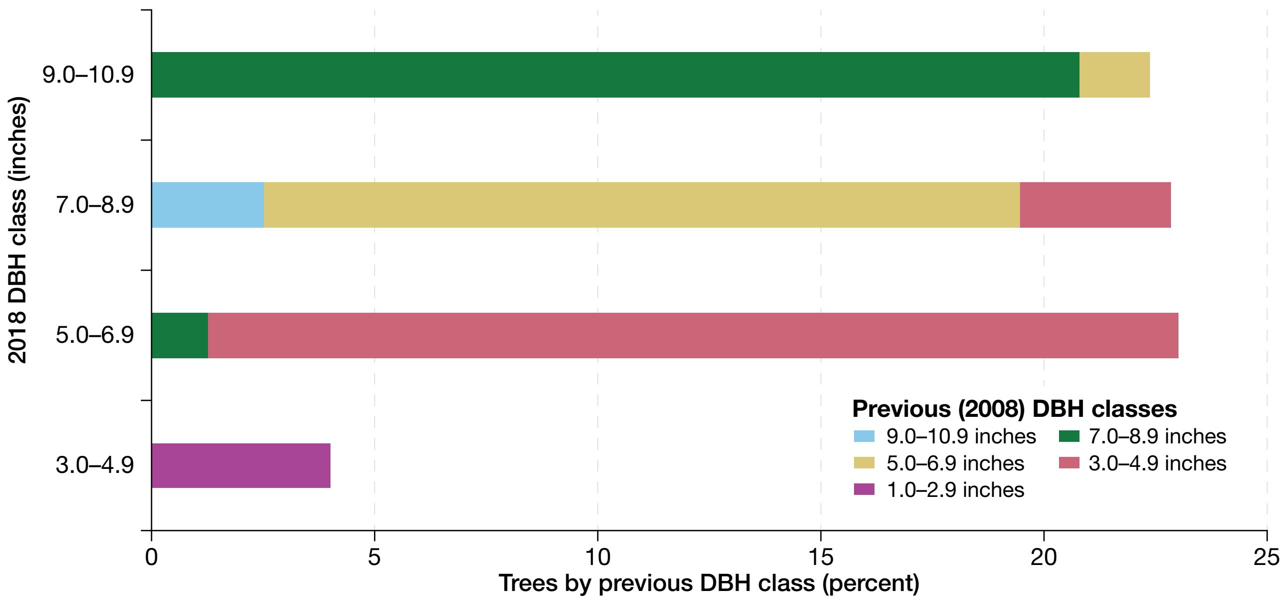

Figure 17—Percentage of trees that transitioned between diameter at breast height (DBH) classes between the 2008 and 2018 USDA Forest Service, Forest Inventory and Analysis inventories in the Republic of the Marshall Islands. Potential reasons for trees moving to smaller DBH classes include crew errors, damage at the point of measurement, and naturally occurring variation in trees near class boundaries.

species with the most reliable increase in abundance was *Terminalia samoensis*, followed by *Allophylus timorensis* and *Guettarda speciosa* (table 15). The tree species with the most reliable net loss of trees was *Cocos nucifera*, followed by *Morinda citrifolia* and *Premna serratifolia*. *Cocos nucifera* had the most reliable loss of trees to mortality and removals. The only other species with marginally statistically significant values for tree removals was *Tournefortia argentea*.

We estimated a 226,282-ton (SE = 28,196) increase in tree biomass (live, aboveground, and dry weight) from 2008 to 2018, a 179,995-ton (SE = 29,002) loss from tree mortality, and a 21,143-ton (SE = 13,983) loss from tree removals. This resulted in a total gain of 25,144 (SE = 31,960) tons of live tree biomass from 2008 to 2018 (table 16). The weight of aboveground forest carbon (total, gained, or lost) is about half the weight of the respective biomass. Five of the six tree species with significant net changes in biomass had positive changes (table 17). The species with the largest positive net change in biomass was *Guettarda speciosa*, followed by *Pemphis acidula* and *Pandanus tectorius*. *Cocos nucifera* had the largest net change and the only significant net loss.

In 2018, 4.3 (SE = 0.9) percent of trees ≥5 inches DBH were standing dead trees, or snags, which was about the same as in 2008 (4.0 percent, SE = 0.8). Northern and southern atolls had almost equal mortality rates, 4.2 (SE = 1.2) and 4.4 (SE = 1.3), respectively, for trees ≥5 inches in DBH.

Crews recorded a total of 15 species of snags. The most common species of snag was *Scaevola taccada*, accounting for 21.7 percent of standing dead trees inventoried. *Cocos nucifera* accounted for 21.4 percent and *Guettarda speciosa* 14.1 percent of snags (fig. 18). For trees that died between the 2008 and 2018 inventories, the cause of death was unknown for 54 percent, 16 percent were killed by weather, 11 percent by vegetation suppression or competition, 8 percent by fire, 7 percent by disease, and 4 percent by silviculture or land clearing activity. There was a steadily decreasing rate of mortality by increasing DBH class (fig. 19).

Table 15—Growth, mortality, removals, and net change in number of trees ≥1 inch in diameter at breast height by tree species in the Republic of the Marshall Islands from 2008 to 2018

Tree species	2008		2018		Growth		Mortality		Removals		Net change	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
	NUMBER OF TREES											
Cocos nucifera	1,712,372	245,478	1,536,196	223,629	3,565	3,565	-140,523	32,430	-39,218	32,481	-176,176	44,620
Morinda citrifolia	1,612,108	634,941	980,528	476,798	418,514	270,747	-1,005,682	470,522	-44,412	44,412	-631,579	387,854
Premna serratifolia	402,268	249,601	59,176	48,282	–	–	-292,410	182,085	-50,682	50,682	-343,092	226,131
Terminalia samoensis	31,551	21,166	125,280	85,341	101,363	69,947	-4,069	4,069	-3,565	3,565	93,729	70,436
Allophylus timorensis	222,063	161,820	459,700	261,041	354,771	224,758	-117,134	78,947	–	–	237,637	234,956
Guettarda speciosa	1,970,031	633,428	2,277,692	675,053	906,520	350,633	-595,294	229,995	-3,565	3,565	307,661	304,881
Bruguiera gymnorhiza	440,212	324,107	592,257	465,590	354,771	354,771	-202,726	202,726	–	–	152,045	152,045
Hibiscus tiliaceus	–	–	44,412	44,412	44,412	44,412	–	–	–	–	44,412	44,412
Pipturus argenteus	–	–	44,412	44,412	44,412	44,412	–	–	–	–	44,412	44,412
Pisonia grandis	665,208	429,217	898,768	632,574	449,864	319,033	-216,305	128,389	–	–	233,560	263,842
Cordia subcordata	128,182	102,860	171,733	152,471	50,682	50,682	-7,131	7,131	–	–	43,551	51,181
Artocarpus altilis	29,025	16,239	66,306	49,454	44,412	44,412	-7,131	7,131	–	–	37,281	45,370
Neisosperma oppositifolia	457,746	296,830	535,201	312,794	253,408	178,674	-175,953	172,425	–	–	77,455	104,391
Scaevola taccada	3,553,718	1,360,083	4,164,709	1,680,214	3,739,388	1,583,525	-3,027,033	1,189,348	-101,363	101,363	610,992	1,136,561
Pandanus tectorius	763,480	237,873	777,809	251,378	196,456	94,575	-173,990	73,472	-8,137	8,137	14,329	91,080
Tournefortia argentea	97,772	60,811	90,906	53,357	50,682	50,682	-29,025	21,872	-28,522	25,013	-6,866	68,850
Artocarpus mariannensis	7,131	7,131	7,131	7,131	–	–	–	–	–	–	–	–
Intsia bijuga	23,908	20,653	23,908	20,653	–	–	–	–	–	–	–	–
Pemphis acidula	89,509	56,488	89,509	56,488	–	–	–	–	–	–	–	–

– = not observed, SE = sample error.

Note: Tree species sorted by confidence (greatest to least) in the SE/estimate ratio.

Table 16—Growth, mortality, removals (GMR), and net change in biomass in the Republic of the Marshall Islands (RMI) from 2008 to 2018

	North		South		RMI	
GMR category	**Total**	**SE**	**Total**	**SE**	**Total**	**SE**
	LIVE, ABOVEGROUND DRY WEIGHT (TONS)					
2008	496,036	118,566	906,308	199,920	1,402,343	182,761
2018	517,126	123,641	910,361	200,256	1,427,487	183,987
Growth	89,589	22,593	136,694	27,547	226,282	28,196
Mortality	-68,498	20,506	-111,497	27,675	-179,995	29,002
Removals	–	–	-21,143	13,983	-21,143	13,983
Net change	21,091	19,999	4,053	25,170	25,144	31,960

– = not observed, SE = sample error.

Table 17—Growth, mortality, removals, and net change in biomass by tree species in the Republic of the Marshall Islands from 2008 to 2018

	2008		2018		Growth		Mortality		Removals		Net change	
Tree species	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
	LIVE, ABOVEGROUND DRY WEIGHT (TONS)											
Guettarda speciosa	116,699	28,419	144,777	38,101	50,112	14,040	-22,166	7,161	-432	432	27,513	13,829
Pemphis acidula	17,712	11,049	27,337	15,750	9,626	5,312	–	–	–	–	9,626	5,312
Pandanus tectorius	44,158	12,420	50,818	15,185	12,531	4,284	-5,645	1,877	-226	226	6,660	3,791
Cocos nucifera	922,537	149,835	887,528	146,145	75,110	16,099	-95,073	23,690	-15,045	10,452	-35,008	22,977
Neisosperma oppositifolia	24,040	13,768	29,750	17,170	9,085	5,304	-3,375	3,003	–	–	5,710	4,023
Bruguiera gymnorrhiza	96,498	77,984	108,440	86,669	12,830	9,628	-888	888	–	–	11,942	8,818
Hibiscus tiliaceus	–	–	1,106	1,106	1,106	1,106	–	–	–	–	1,106	1,106
Pipturus argenteus	–	–	129	129	129	129	–	–	–	–	129	129
Artocarpus mariannensis	6,428	6,428	11,374	11,374	4,946	4,946	–	–	–	–	4,946	4,946
Premna serratifolia	8,931	4,948	5,945	3,874	2,345	1,193	-4,971	3,196	-361	361	-2,986	3,037
Cordia subcordata	24,859	22,902	32,494	30,743	8,483	7,882	-848	848	–	–	7,635	7,903
Intsia bijuga	6,608	5,524	7,013	5,603	405	444	–	–	–	–	405	444
Pisonia grandis	53,682	22,379	46,524	19,651	8,140	4,530	-15,298	11,512	–	–	-7,158	10,243
Morinda citrifolia	9,010	3,402	7,222	3,876	3,048	2,002	-4,621	2,129	-215	215	-1,787	2,761
Allophylus timorensis	4,732	2,934	2,792	1,501	1,629	1,012	-3,570	2,792	–	–	-1,941	3,081
Scaevola taccada	13,174	6,722	12,367	4,100	11,258	3,830	-11,562	6,120	-503	503	-806	5,579
Tournefortia argentea	21,503	15,143	20,797	12,100	6,916	3,912	-3,465	2,969	-4,157	4,009	-706	5,082
Terminalia samoensis	2,325	1,344	2,511	2,031	1,301	1,040	-912	912	-203	203	186	1,442
Artocarpus altilis	29,448	17,405	29,128	19,095	7,281	4,182	-7,602	7,602	–	–	-321	8,308

– = not observed, SE = sample error.

Note: Tree species sorted by confidence (greatest to least) in the SE/estimate ratio.

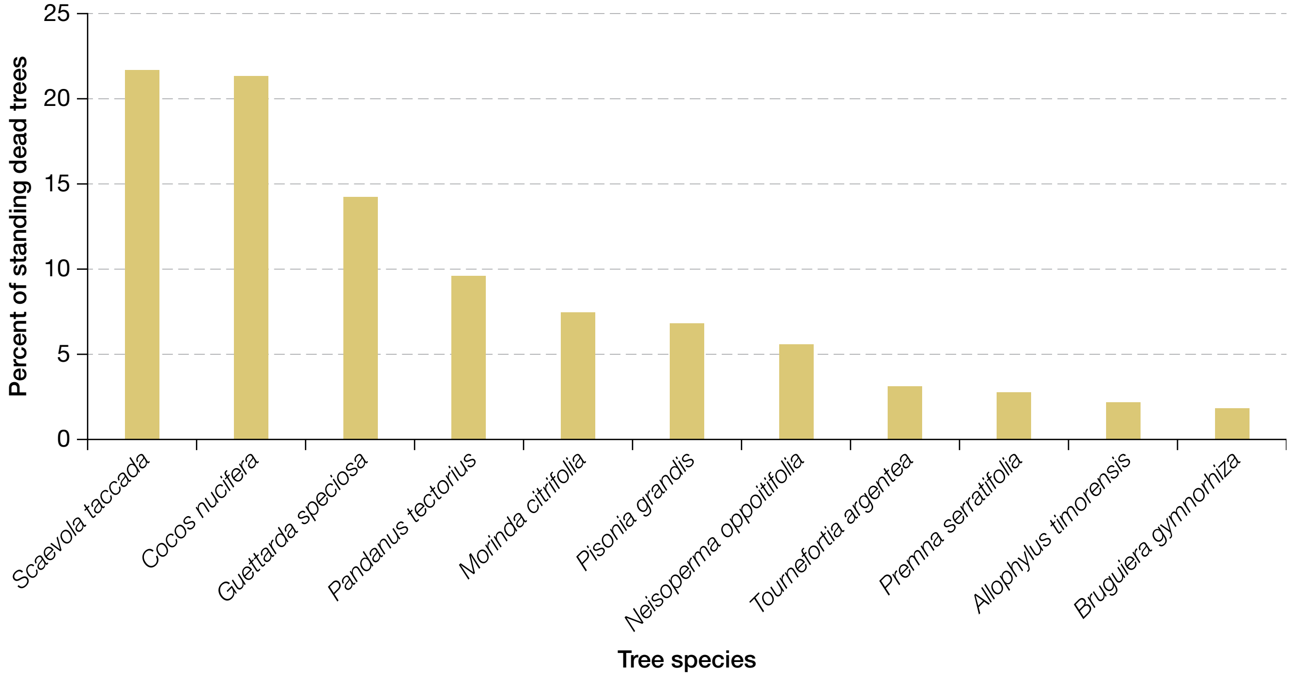

Figure 18—Percentage of standing dead trees (snags) that were inventoried in the Republic of the Marshall Islands by species that composed ≥2 percent of standing dead trees inventoried, 2018.

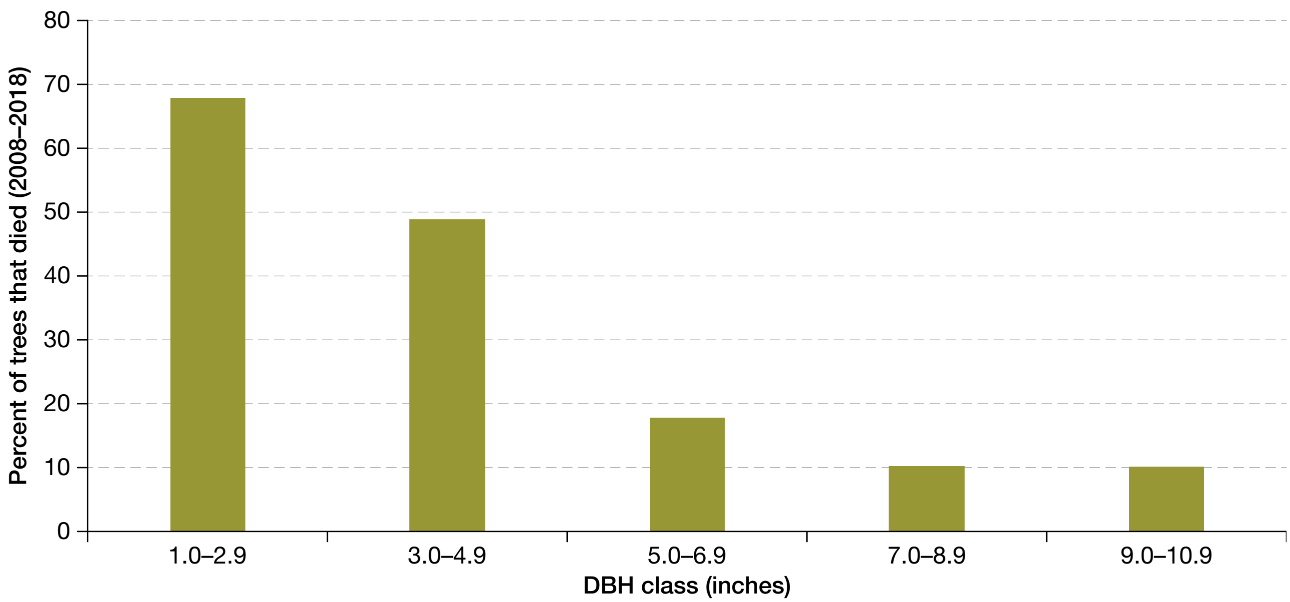

Figure 19– Percentage of trees that died between the 2008 and 2018 USDA Forest Service, Forest Inventory and Analysis inventories by diameter at breast height (DBH) class in the Republic of the Marshall Islands.

Forest Structure

Stand Size Class

The Forest Service FIA program uses six stand size classes for forests based on the predominant size of all live trees and saplings—nonstocked, class 1 (1.0–4.9 inches DBH), class 2 (5.0–10.9 inches), class 3 (11.0–19.9 inches), class 4 (20.0–39.9 inches) and class 5 (≥40 inches). Most of the forest area in the RMI was defined as stand size class 3 (table 18). In northern atolls a fifth of forest area was defined as class 1 (seedlings and saplings). We did not record any nonstocked, class 4, or class 5 forest plots in the RMI. Forests inventoried in the RMI were all considered hardwood forests.

Volume, Biomass, Carbon, Stem Density, Basal Area

In 2018, we estimated 54,782,523 cubic feet (SE = 8,633,100) of live tree stem volume and 1,537,717 tons (SE = 246,643) of live, aboveground biomass (768,859 tons of carbon, SE = 123,322) in RMI forests (Chave et al 2014). Of the forest communities that we inventoried in 2018 in the RMI, agroforest had the lowest estimated stem density (live trees ≥1 inch in DBH per acre), and strand forest had the lowest basal area (square feet per acre) and volume (cubic feet per acre) (table 19). Low tree density and high volume in agroforest is the result of forest management of *Cocos nucifera* groves for copra production. Strand forest was significantly denser but had significantly less volume per acre than both lowland rainforest and agroforest. There were also significant differences in forest structure between RMI regions; southern atolls had 45 more square feet per acre (SE = 18) and 1,605 more cubic feet per acre (SE = 499) than northern atolls. We only measured one plot in a mangrove community, which was in the south, and do not include it in comparisons of forest structure.

There were no significant changes in mean stem density between the 2008 and 2018 inventories by forest community, region, or overall (table 20). However, there were some significant increases in basal area—10 square feet per acre (SE = 7) for strand forest, 9 square feet per acre (SE = 5) for the northern atolls, and 7 square feet per acre (SE = 4) for the RMI overall.

Table 18—Forest area by stand size class and region in the Republic of the Marshall Islands (RMI), 2018

	Northern atolls		Southern atolls		RMI	
Stand size class (DBH)	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
	Percent forest area					
1 (1.0–4.9 inches)	19.3	8.7	–	–	11.4	5.3
2 (5.0–10.9 inches)	17.1	7.9	18.0	11.0	17.5	6.5
3 (11.0–19.9 inches)	63.6	11.1	82.0	11.0	71.1	8.1

– = not observed, DBH = diameter at breast height, SE = sample error.

Note: There were no nonstocked, class 4 (20.0–39.9 inches), or class 5 (≥40 inches) plots in the RMI in 2018.

Table 19—Stem density, basal area, and volume by forest community in the Republic of the Marshall Islands, 2018

	Stem density		Basal area		Volume	
Forest community	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
	Stems per acre		*Square feet per acre*		*Cubic feet per acre*	
Strand forest	1,192	369	102	16	1,222	287
Lowland rainforest	741	151	132	11	2,543	325
Agroforest	284	72	128	19	2,733	539
Total	726	131	124	9	2,283	274

SE = sample error.

Note: We only measured one plot in the mangrove community and so have not included it in comparisons of forest structure.

Table 20—Stem density and basal area and their changes by forest community based on remeasured plots in the Republic of the Marshall Islands, 2008 and 2018

Forest community	2008 Mean	2008 SE	2018 Mean	2018 SE	Change Mean	Change SE
	Stem density					
	STEMS PER ACRE					
Strand forest	980	470	1,198	510	219	265
Lowland rainforest	651	101	679	132	28	158
Agroforest	283	77	294	95	11	79
All forest communities	622	142	702	165	79	100
	Basal area					
	SQUARE FEET PER ACRE					
Strand forest	100	19	111	17	10	7
Lowland rainforest	131	13	136	13	5	6
Agroforest	142	25	149	23	8	9
All forest communities	128	11	135	11	7	4

SE = sample error.

Note: We only measured one plot in the mangrove community and so have not included it in comparisons of forest structure. Volume estimation methodology changed between inventories, so we do not show volume values here.

Vegetation Profile

Vegetation profile data collected on each subplot include two different datasets: (1) dominant vascular species composition and (2) growth habit by vegetation height layer. Dominant vascular species composition is collected for the four most abundant plant species in each growth habit (graminoids, shrubs, forbs, and trees) that meet a 3-percent cover threshold. The height layer is listed where the most species cover occurs. The coverage of each growth habit is also described by height layer along with an overall aerial estimate for each growth habit for the subplot.

Dominant Vascular Plant Species Composition

We recorded 45 dominant vascular plant species in RMI forests in 2018 (53 were recorded in 2008). About 40 percent of the dominant plant species inventoried in the RMI were tree saplings/seedlings, 6 percent were shrubs, 40 percent were forbs, and 15 percent were graminoids.

Seedlings/saplings of *Cocos nucifera* covered the most forest area of any dominant plant species in the RMI followed by *Scaevola taccada* (table 21). This

Table 21—Forest area by the 15 most widespread species of tree seedlings/saplings in the Republic of the Marshall Islands, 2018

Tree species	Mean	SE	Status
	PERCENT OF FOREST AREA		
Cocos nucifera	11.1	2.6	I
Scaevola taccada	9.8	2.6	N
Guettarda speciosa	5.0	1.0	N
Pandanus tectorius	3.8	1.1	N
Bruguiera gymnorhiza	1.8	1.9	N
Neisosperma oppositifolia	1.7	0.9	N
Morinda citrifolia	1.6	0.4	U
Pisonia grandis	1.5	0.9	N
Allophylus timorensis	1.0	0.6	N
Cordia subcordata	0.6	0.5	N
Soulamea amara	0.6	0.5	N
Terminalia samoensis	0.5	0.2	N
Premna serratifolia	0.4	0.3	N
Pemphis acidula	0.4	0.3	N
Tournefortia argentea	0.3	0.2	N

E = endemic to Micronesia, I = introduced, N = native, SE = sample error, U = unknown.

Status source: Merlin et al. (2018).

is unsurprising because *Cocos nucifera* was the most dominant tree species and covered the most forest area as a dominant tree species, and *Scaevola taccada* was the most abundant tree species. Both species had about double the cover of the next two most widespread tree seedlings/saplings (*Guettarda speciosa* and *Pandanus tectorius*), and almost three times the cover of the most widespread nontree dominant plant species (*Cassytha filiformis*, *Asplenium nidus*, and *Wollastonia biflora*) (table 22). *Cassytha filiformis* is a native pantropical vine that is common in coastal regions and is an obligate stem parasite that can cover shrubs and trees. *Asplenium nidus* is an epiphytic fern that is common in forests across the Pacific region. *Wollastonia biflora* is a sprawling vine-like herb that is common in coastal areas across the Pacific and is often an indicator of disturbance.

Table 22—Forest area by the 15 most widespread nontree plant species in the Republic of the Marshall Islands, 2018

Plant species	Mean	SE	Growth habit
	Percent of forest area		
Cassytha filiformis	3.3	1.4	Forb (vine)
Asplenium nidus	3.2	1.5	Forb (fern)
Wollastonia biflora	2.9	1.3	Forb
Lepturus repens	1.9	1.0	Graminoid
Ipomoea violacea	1.6	0.8	Forb (vine)
Vigna marina	1.4	1.1	Forb (vine)
Eleusine indica	1.2	0.7	Graminoid
Bidens pilosa	1.0	1.0	Forb
Canavalia rosea	0.6	0.4	Forb (vine)
Eustachys petraea	0.6	0.5	Graminoid
Clerodendrum inerme	0.5	0.4	Shrub
Phymatosorus grossus	0.5	0.3	Forb (fern)
Fimbristylis cymosa	0.5	0.2	Graminoid
Nephrolepis acutifolia	0.4	0.2	Forb (fern)
Nephrolepis hirsutula	0.4	0.4	Forb (fern)

SE = sample error.

Growth Habit and Vegetation Height Layer

Trees composed the most vegetation cover in RMI forests, with the highest percentage of cover in vegetation height layer 4 (>16.0 feet above ground) (table 23). Among the vegetation height layers, the highest percentage of vegetation cover overall in the southern atolls was in layer 4, but in northern atolls, there was an equal percentage of cover in layer 3 (6.1–16.0 feet) and layer 4 (table 24). Southern atolls had about 14 percent (SE = 8.6) more forest covered with forbs than northern atolls, and northern atolls had 2.1 percent (SE = 1.3) more shrub cover than southern atolls.

There were some significant differences in growth habit and height layer among forest communities in the RMI. Strand forest had the lowest percentage of forest area covered by vegetation in layer 1 (<2.0 feet) and the highest cover in layers 2 and 3 (2.1–16.0 feet) but otherwise was similar to lowland rainforest (figs. 20 and 21). Agroforest had the highest percentage of forest area covered by vegetation in layer 1, the lowest percentage of cover in layer 2 (2.1–6.0 feet), the lowest percentage of cover from trees, and the highest percentage of cover from graminoids. We do not report mangrove values here because of the small sample size (n = 1).

Table 23—Forest area by vegetation growth habit and height layer in the Republic of the Marshall Islands, 2018

	Layer 1 (0.0–2.0 feet)		Layer 2 (2.1–6.0 feet)		Layer 3 (6.1–16.0 feet)		Layer 4 (>16.0 feet)		Overall aerial	
Growth habit	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
	Percent forest area									
Tree	8	1	20	3	45	3	61	4	81	3
Shrub	1	0	1	0	0	0	0	0	1	1
Graminoid	5	1	0	0	0	0	0	0	5	1
Forb	10	2	7	2	4	1	3	1	17	3

SE = sample error.

Table 24—Forest area covered by all growth habits by vegetation height layer and region in the Republic of the Marshall Islands (RMI), 2018

	Northern atolls		Southern atolls		RMI	
Vegetation height layer	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
	PERCENT OF FOREST AREA					
1 (0.0–2.0 feet)	21	3	30	4	24	3
2 (2.1–6.0 feet)	30	4	26	5	28	3
3 (6.1–16.0 feet)	55	5	44	5	50	4
4 (>16.0 feet)	57	6	72	5	63	4

SE = sample error.

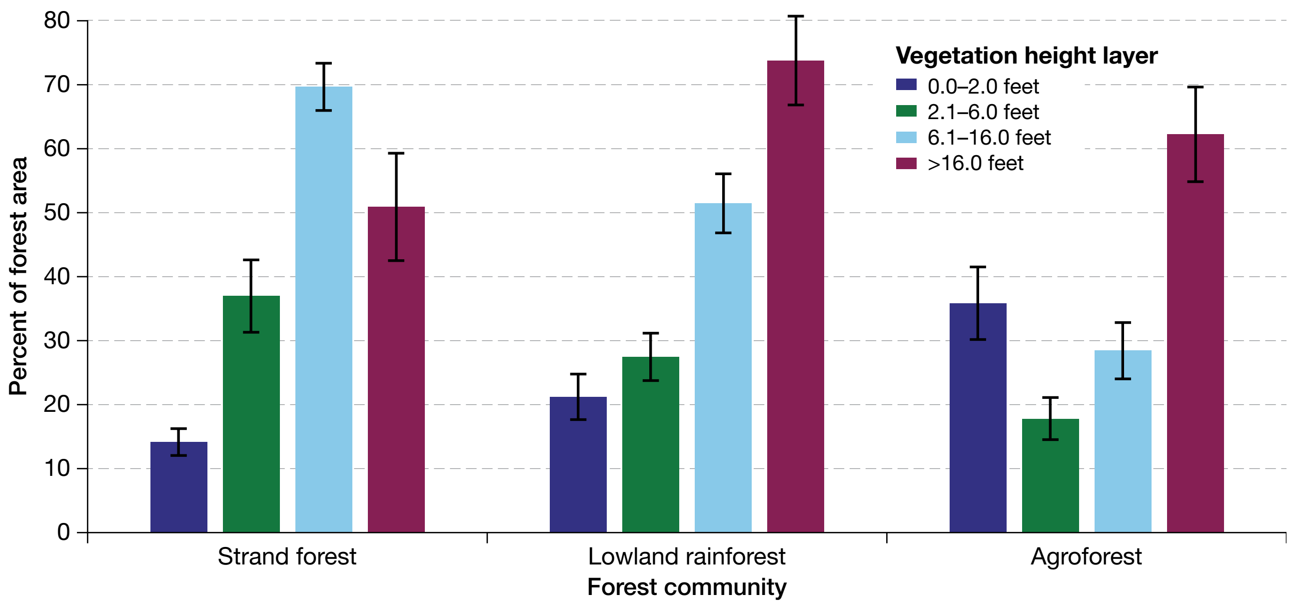

Figure 20—Forest area by vegetation height layer and forest community in the Republic of the Marshall Islands, 2018. Error bars represent 68-percent confidence level.

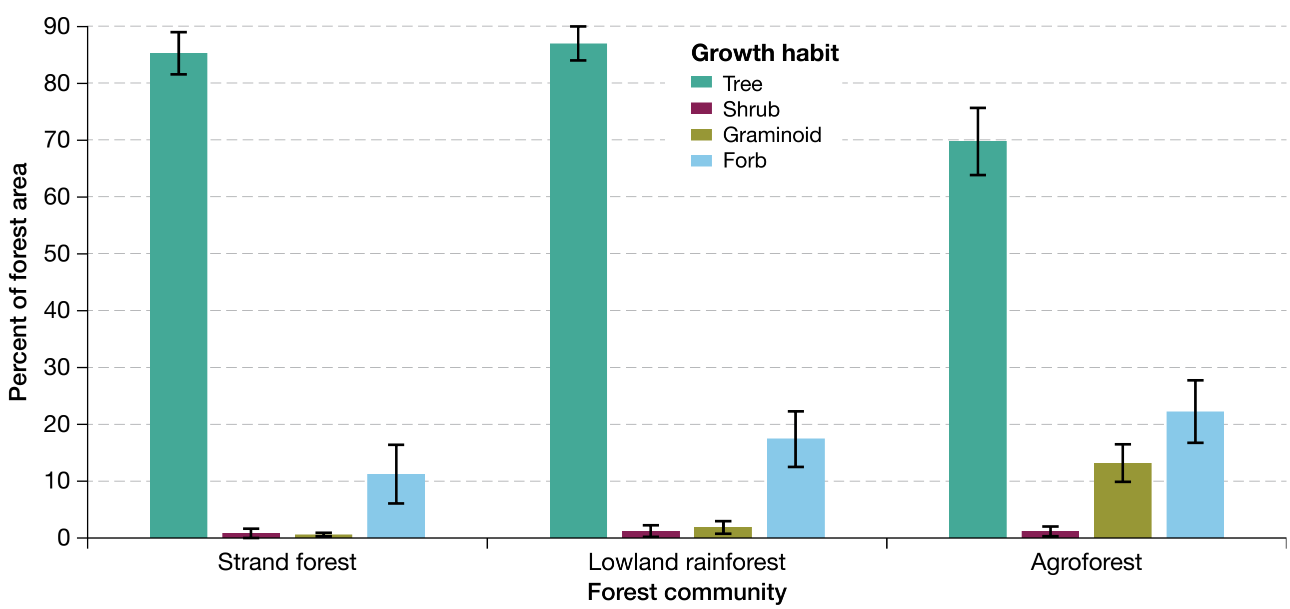

Figure 21—Forest area by growth habit and forest community in the Republic of the Marshall Islands, 2018. Error bars represent 68-percent confidence level.

Invasive Species

Invasive species are a threat to native biodiversity and forest health, especially in the Pacific, which is why the FIA program incorporated an invasive plant species protocol in the most recent measurement cycle. State forestry offices provided lists of invasive plants and trees, and field crews recorded any invasive plant species that they observed from those lists. Overall, percentage of forest area covered by invasive species was low in the RMI compared to other Pacific Islands (Dendy et al. 2020). This is likely due to the geographic isolation of the islands, relatively low visitation rates to remote atolls, lack of conventional agriculture and grazing livestock, partial sampling of atolls, and saline growing conditions throughout the study area. We only recorded three species of invasive plants in the 2018 inventory, covering about 1.3 percent (SE = 1.1) of total forest area in the RMI. There were small differences in invasive species coverage between regions; invasive species covered more forest area in northern atolls, and more forest area in southern atolls had invasive species present (tables 25 and 26). We recorded no invasive tree species in the RMI.

Cocos nucifera **(Ni, Coconut Palm) and** ***Pandanus tectorius*** **(Bōb)**

In the RMI, the boundary between strand forest and other forest communities is less distinct than elsewhere in Micronesia. Strand forest elements permeate RMI forests because of the small size of atoll islets and a general lack of an elevation gradient. Historical forest management was associated with extensive transformation of native forests to *Cocos nucifera* (ni, coconut palm) plantations, and because of the continued dominance of the useful and economically important *Cocos nucifera* palm in the forests of the RMI today, we include some highlights here. In addition, we summarize a pilot measurement of *Pandanus tectorius* (bōb) varieties as a trial to assess the predominant uses of this locally and culturally important tree species.

Cocos nucifera (Ni, Coconut Palm) Resources

The 2018 inventory included three pilot measurements of *Cocos nucifera*: tree variety, tree age, and annual tree fertility. We classified *Cocos nucifera* palms into two varieties: tall or dwarf. We calculated palm age with

Table 25—Forest area by invasive plant species and region in the Republic of the Marshall Islands (RMI), 2018

	Northern atolls		Southern atolls		RMI	
Invasive species	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
	PERCENT FOREST AREA					
Sphagneticola trilobata	–	–	0.2	0.2	0.1	0.1
Bidens pilosa	1.8	1.7	0.2	0.1	1.1	1.0
Turnera ulmifolia	0.2	0.2	0.0	0.0	0.1	0.1
Total	1.9	1.8	0.5	0.3	1.3	1.1

– = not observed, SE = sample error.

Table 26—Forest area by region and invasive plant presence/absence in the Republic of the Marshall Islands (RMI), 2018

	Northern atolls		Southern atolls		RMI	
Invasive plants	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
	PERCENT FOREST AREA					
Present	11.2	7.3	17.0	8.2	13.6	5.4
Absent	88.8	7.3	83.0	8.2	86.4	5.4

SE = sample error.

Note: Invasive species presence is recorded if any trace or more is observed within forested, 24-foot radius subplots. Only one plot per 500 acres of forest is sampled, with the percent of total forest area estimates generated at the state/island level from this sample.

an equation developed by the South Pacific community that uses the total length of the tree stem (height) and the distance from 4.5 feet on the stem to the 11^{th} leaf scar above 4.5 feet (proxy for rate of growth) (Forstreuter 2018). We calculated annual tree fertility by taking the average number of coconuts of the lowest three bunches and multiplying that by 12.

In the RMI, 99.4 percent (SE = 0.7) of *Cocos nucifera* palms, 1,917,307 (SE = 341,149) trees, were the tall variety. The dwarf variety is generally planted in residential areas that do not qualify as forest and therefore were not part of the forest inventory. In 2018, we estimated 4.7 percent (SE = 1.6) of *Cocos nucifera* palms were standing dead.

Based on the age equation, most *Cocos nucifera* palms in the RMI (63.1 percent, SE = 3.8) were between 20 and 40 years of age. However, height growth stops after a certain age, making an age equation based on the leaf scars and length of the bole inaccurate for older trees. Because older trees predominate in the RMI (Merlin et al. 2018), we do not include an age table here.

Most *Cocos nucifera* palms were in the height classes of 35–54 feet and 55–74 feet. We recorded more of the tallest palms in southern atolls and more of the shortest palms in northern atolls, and we found the volume per acre of palms in southern atolls to be more than twice that of northern atolls (figs. 22 and 23). This is likely due to differences in precipitation and management. By forest community, agroforest had the highest proportion of its *Cocos nucifera* palms in the two taller height classes, and strand forest had the highest proportion in the two shorter height classes (fig. 24). In strand forest, palms (fig. 25) are more exposed to salt spray and wind and have less access to fresh water and good soil. This leads to a more natural stand development than in agroforests.

Based on the fertility equation described above, the largest category (46.5 percent, SE = 4.4) included palms that produced 0 to 20 coconuts per year. The next largest category included palms that produced 24 to 44 coconuts per year (table 27). This is much lower than the annual mean fertility of 70–100 coconuts per palm (CFC 2002) so most *Cocos nucifera* palm stands in the RMI are of low productivity. *Cocos nucifera* was the tree species most affected by human damage. They were most damaged in agroforest and least damaged in strand forests. The damage from human activities is mostly the cutting of steps to facilitate harvest. This does not appear to have a major impact on tree health; healthy trees were often observed with very old steps cut into them.

Pandanus tectorius (Bōb) Resources

Pandanus tectorius was the second most dominant tree species in the RMI after *Cocos nucifera*, and the fourth most abundant tree species after *Scaevola taccada*,

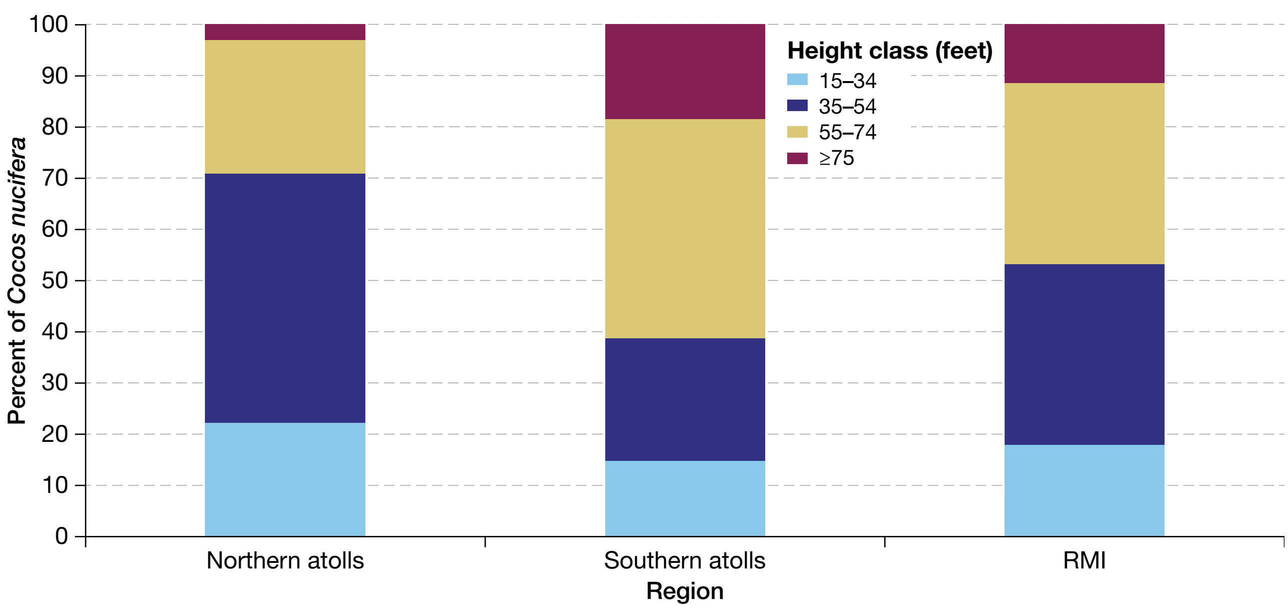

Figure 22—Percentage of *Cocos nucifera* (ni, coconut palm) by height class and region in the Republic of the Marshall Islands (RMI), 2018.

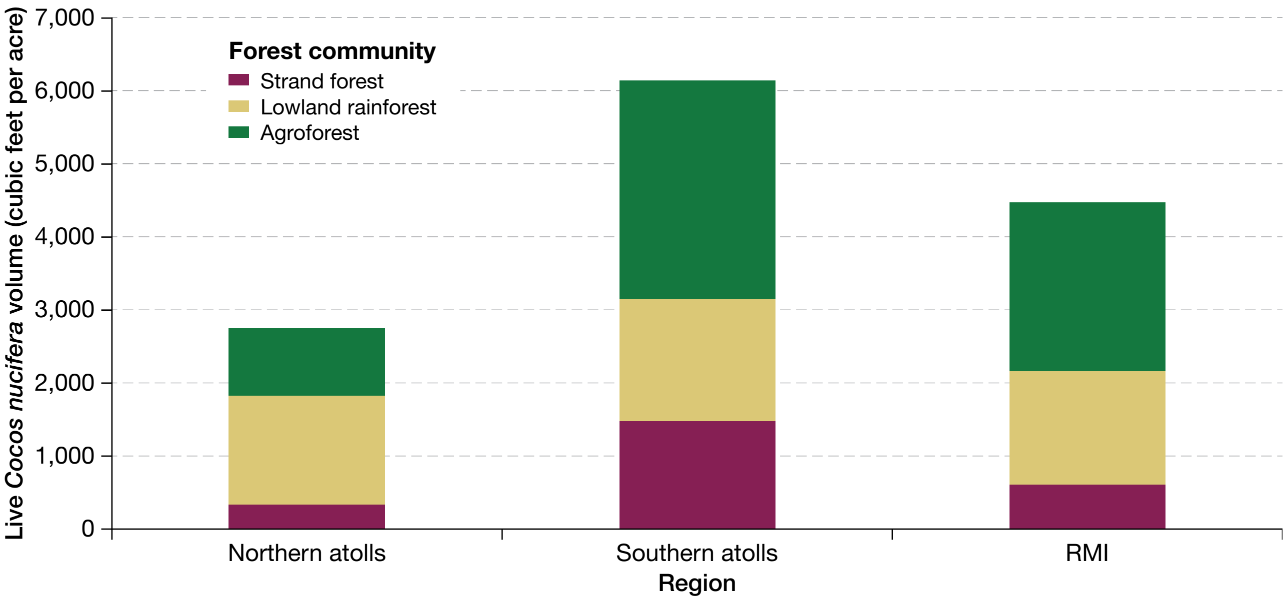

Figure 23—*Cocos nucifera* (ni, coconut palm) volume by forest community and region in the Republic of the Marshall Islands (RMI), 2018.

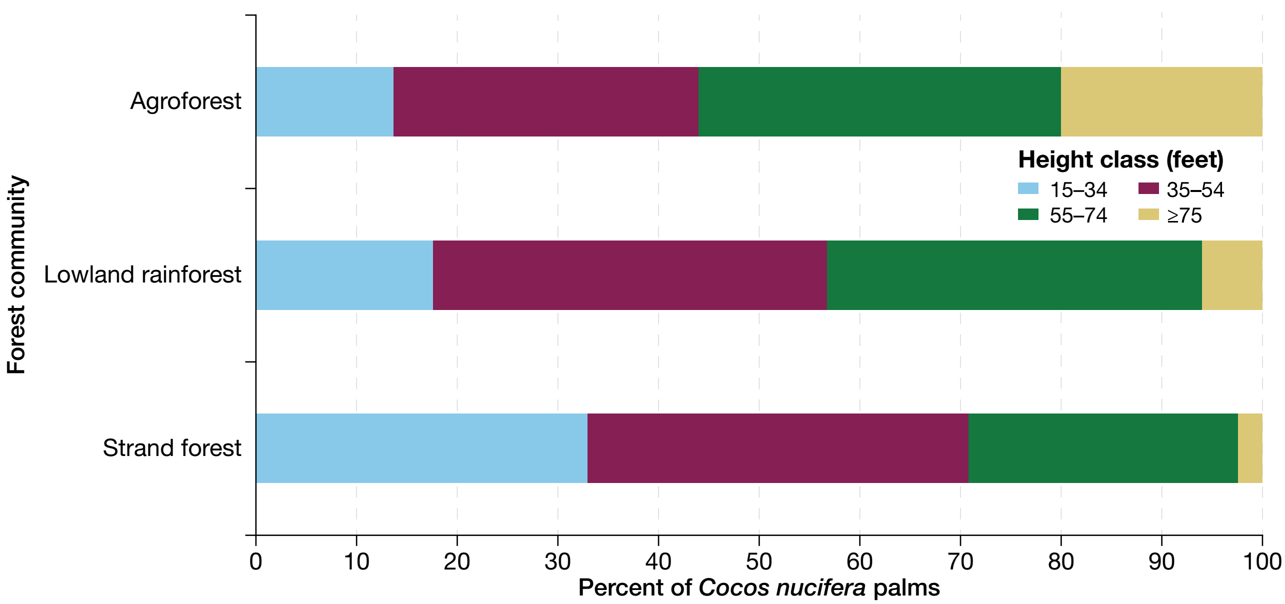

Figure 24—Percentage of live *Cocos nucifera* (ni, coconut palm) by height class and forest community in the Republic of the Marshall Islands, 2018.

Guettarda speciosa, and *Cocos nucifera*. *Pandanus tectorius* is highly salt tolerant and one of the few plants that thrives in the sandy soils found throughout the RMI (fig. 26). It serves an important role in stabilizing soil on the exposed ocean side of atolls and is a highly useful plant for people in the RMI. It is a source of the primary materials used in the traditional weaving of products such as sleeping mats and baskets. In most parts of the RMI, traditional Micronesian staple foods such as breadfruit, taro, and yams are difficult to grow so the Marshallese rely more heavily on *Pandanus tectorius* for food than other parts of the region. These uses have led to extensive selection and cultivation of the species in the RMI where more than 200 cultivar names exist (Kusto et al. 2011). Unfortunately, these cultivars have been developed at a small scale on each atoll, and there is no comprehensive method or guide for identifying the varieties.

Figure 25—Republic of Marshall Islands, Ministry of Natural Resources and Commerce agroforestry officer Joel Bujen measuring a *Cocos nucifera* (ni, coconut palm) at the edge of the strand forest. USDA Forest Service photo by Seth Ayotte.

Table 27—*Cocos nucifera* (ni, coconut palm) by estimated annual production of coconut fruits per tree in the Republic of the Marshall Islands, 2018

Coconut fertility	Mean	SE	Mean	SE
FRUITS PER TREE PER YEAR	NUMBER OF TREES		PERCENT	
0 to 20	896,897	177,390	46.5	4.4
24 to 44	618,559	131,709	32.1	2.9
48 to 68	295,670	70,751	15.3	2.5
72 to 92	72,413	26,687	3.8	1.3
96 to 116	30,050	25,178	1.6	1.3
120 to 140	16,259	9,824	0.8	0.5
Total	1,929,847	340,825	100	

SE = sample error.

Note: Gaps in the number ranges of fruits per tree per year are an artifact of multiplying the data ranges by 4.

Figure 26—Field crew measuring *Pandanus tectorius* (bōb). USDA Forest Service photo by Seth Ayotte.

In 2018, the FIA inventory attempted to capture the various uses of *Pandanus tectorius* (≥5 inches in DBH) in the RMI by using broad functional groups: food, weaving, soil stabilization, and "not sure/other." We used the last group to describe *Pandanus tectorius* trees for which no human use was apparent, including wild-type trees that were growing in the forest with no evidence of human cultivation. Because of the abundance of naturally reproducing trees in forest areas away from human settlement, "not sure/other" was the most observed functional group of *Pandanus tectorius* (table 28). The food functional group was the least common because the varieties used for food propagate vegetatively close to human habitation; these areas do not qualify as forest land and are not part of the FIA inventory.

Table 28—Abundance of *Pandanus tectorius* (bōb) trees (≥5 inches in DBH) by functional group in the Republic of the Marshall Islands, 2018

Functional group	Mean	SE	Mean	SE
	NUMBER OF TREES		PERCENT	
Not sure/other	481,935	192,284	57.4	17.3
Weaving	167,890	180,568	20.0	18.2
Soil stablilzation	152,152	83,230	18.1	10.3
Food	37,209	23,873	4.4	3.1
Total	839,187	260,980	100	

SE = sample error.

Forest Community Highlights

Strand Forest

Strand forest comprises vegetation near the shore with species adapted to high rates of evaporation by wind and to high salt concentrations from windblown ocean spray or inundation by saltwater. *Cocos nucifera* was the dominant tree species in strand forest in both northern and southern atolls, but its basal area in southern atolls was more than twice as high as that in northern atolls. There was a higher stem density of *Cocos nucifera* in southern atolls, and five more species of dominant trees in northern atolls. This suggests that strand forests in the less-populated northern atolls were historically less altered for *Cocos nucifera* plantations. In strand forest, *Cocos nucifera* had far less damage from almost all damage agents than it did in agroforest or lowland rainforest. Many of the damages observed on *Cocos nucifera* were associated with human activity (e.g., fire, cutting steps). Therefore, less damage of *Cocos nucifera* in strand forests may be because they are managed less in strand forests, which are less productive for copra than other forest communities.

Agroforest

Agroforest comprises tree species in agricultural ecosystems used in crop or animal production. As expected from the rainfall gradient, southern atolls had more developed agroforest than northern atolls, with about twice the total forest area dedicated to it. *Cocos nucifera* was the most dominant tree species in agroforest in both regions, making up about three-quarters of estimated basal area and covering more agroforest understory area than any other species. Crews recorded more plant species in agroforest understory than strand forest or lowland rainforest including three invasive species which together covered about 4 percent (SE = 3.2) of agroforest area. Agroforest tree species (*Cocos nucifera, Pandanus tectorius*, *Morinda citrifolia*, *Artocarpus altilis*) occurred in all forest communities; there were more *Cocos nucifera* in the south, but more *Pandanus tectorius* and *Morinda citrifolia* in the north (fig. 27). There seem to be more *Artocarpus altilis* in southern atolls, but the sample size was small. It was the consensus among local people that *Artocarpus altilis* grows better in the wetter southern atolls.

Lowland Rainforest

Lowland rainforest is a multistoried forest with many canopy-dwelling epiphytes, open ground, and shrub layers. More lowland rainforest has survived in the northern atolls, where it composed almost half of forest area. In the southern atolls, lowland rainforest composed about one-third of forest area. *Cocos nucifera* was dominant in two-thirds of lowland rainforest area and composed about half of the basal area.

Conclusion

In 2018, the forests of the RMI were mostly undisturbed, with no disturbance estimated for more than 90 percent of forest area. Weather was the largest category of disturbance to forest but affected <5 percent of forest area, and insect disturbance appears to have declined substantially since 2008. The RMI had high percentage of live canopy

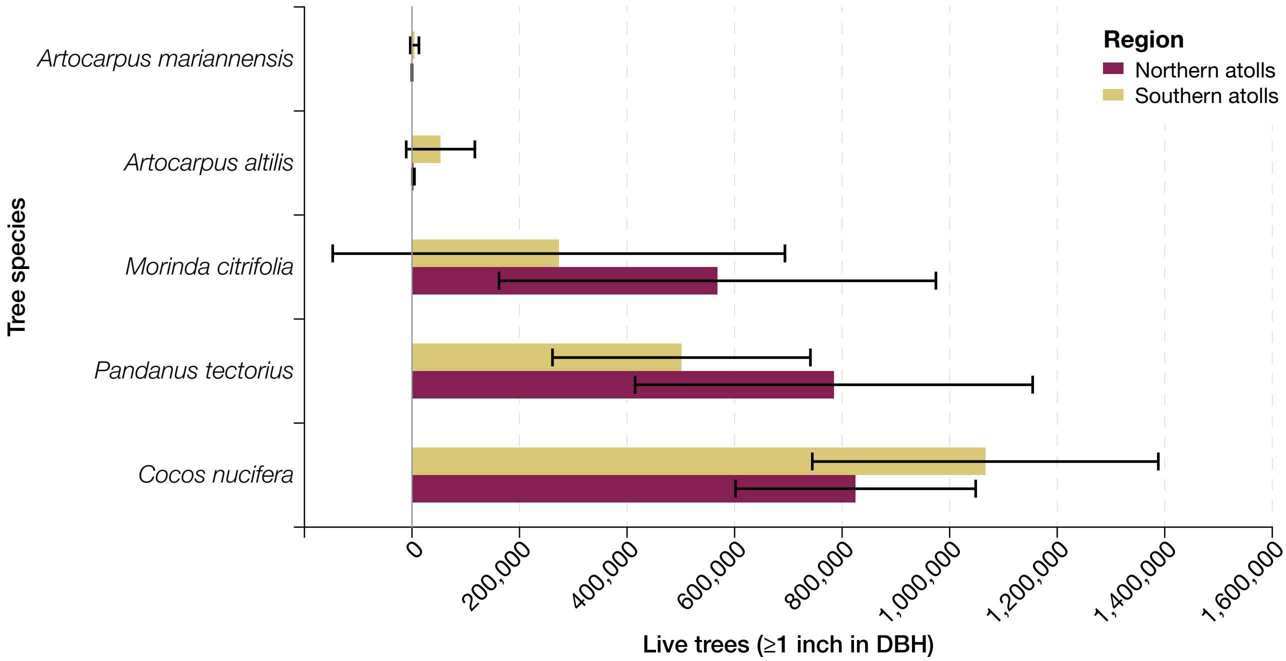

Figure 27—Agroforest tree species by region in the Republic of the Marshall Islands, 2018. Error bars represent 68-percent confidence level.

coverage, with <10 percent of total forest area having ≤50 percent cover and <5 percent of forest area missing canopy. Forests in southern atolls had higher mean canopy cover (more than 70 percent) than forests of the northern atolls. Among forest communities, lowland rainforests had the highest mean canopy cover (more than 80 percent). Agroforest had the lowest mean percentage of canopy cover, which is likely related to understory vegetation management associated with copra production. The area of forest with silviculture treatment was about the same as the area of agroforest, or about one-third of total forest in the RMI.

As in the 2008 FIA inventory (Donnegan et al. 2011), we found smaller trees were predominant in RMI forests in 2018; most trees were <3 inches in DBH and <25 feet tall. *Cocos nucifera* was not the most abundant tree species in RMI forests, composing 11.1 percent (SE = 3.0) of all trees, but it was dominant in most forest area in the RMI. *Cocos nucifera* accounted for more than half of total basal area of all trees in the RMI (three-quarters in agroforest) and was the dominant species by canopy cover in two-thirds of the overall forest area. It was also dominant in the understory as the most common tree seedling/sapling, covering the most forest area (11.1 percent, SE = 2.6). Less forest area in northern atolls was dominated by *Cocos nucifera*, and trees were shorter there, resulting in much lower mean volume per acre than in southern atolls. There were also fewer *Cocos nucifera* trees and less agroforest area in northern atolls, which resulted in significantly fewer trees ≥10 inches in DBH than in southern atolls.

The number of *Cocos nucifera* trees decreased significantly between the 2008 and 2018 inventories, which appears to be because of natural mortality and senescence of old trees. This may be related to the increase in forest area covered by seedlings/saplings of other tree species in the RMI between 2008 and 2018, particularly *Guettarda speciosa*, *Scaevola taccada*, *Pandanus tectorius*, *Pemphis acidula*, *Pisonia grandis*, and *Allophylus timorensis*. This is a sign of recovery of native forests in the RMI; however, some of this change may be related to the increased number of forest plots sampled in northern atolls.

Mueller-Dombois and Fosberg (1998), and Thomas et al. (1988) reported that forests dominated by *Neisosperma oppositifolia* were likely to have been much more common in the recent past and mentioned not seeing it at all in southern atolls. In the 2018 inventory, *Neisosperma oppositifolia* was more common in the south than in the north and was the second most common dominant tree in southern lowland rainforests. Perhaps this is another sign that some of the native species are gradually coming back as planted *Cocos nucifera* senesce. In other recovering atoll forests, Wolf et al. (2018) showed that the presence of invasive rats prevented recruitment of seedlings of *Pisonia grandis* and other species including *Cocos nucifera*. Rat eradication efforts could be necessary to assist the full return of native forest; if rats are removed, *Cocos nucifera* seedlings may need to be thinned manually to continue recovery (Wolf et al. 2018).

There were also significant decreases in numbers of the agroforest species *Morinda citrifolia* and the native lowland rainforest tree *Premna serratifolia*, and a significant increase in the number of the strand forest tree *Terminalia samoensis*. *Guettarda speciosa* had the most significant increase in biomass by species, and there were no species with a significant loss of biomass. Each of these species have important uses to the rural communities in the Marshall Islands. The fruit and leaves of *Morinda citrifolia* are used in traditional medicine. The juice is most widely known to help people who have diabetes. The Marshallese use *Premna serratifolia* for baby medicine, mixed with other species to enhance medicinal recipes, and to help find love and luck (Merlin et al. 2018). They use *Terminalia samoensis* for firewood and for medicine used in skin remedies (Merlin et al. 2018). They commonly harvest *Guettarda speciosa* for firewood and for timbers in house construction, and they use its flowers in medicinal recipes and floral decorations (including leis) and for their fragrant scent (Merlin et al. 2018).

Total forest biomass increased by about 25,000 tons. There was an annual increase of about 1.6 percent from growth, and annual losses of 1.3 percent to mortality and 0.2 percent to removals, for a net annual increase of 0.2 percent. We found that tree harvesting was relatively minimal between the 2008 and 2018 inventories with <2 percent of all trees harvested. All removals occurred in southern atolls where about 4 percent of trees were removed. We found RMI forests to be highly dynamic during this period, with roughly similar ingrowth and trees that died between inventories (about 700,000 new trees and 600,000 dead trees per year, or about 5 percent of all trees each). Total forest area did not change significantly in the RMI between the 2008 and 2018 inventories.

The *Cocos nucifera* and *Pandanus tectorius* pilot measurements generated mixed results. The *Cocos nucifera* fertility estimates indicate mostly low productivity stands in the RMI. The coconut age pilot was unreliable because of the predominance of older trees in the country and associated flaws in the age calculation method. More than half of *Pandanus tectorius* trees observed could not accurately be assigned to a functional group, leading to mostly wild varieties being recorded as "not sure/other."

There are two main types of agroforests in the RMI: agroforest used for copra production and agroforest used for food crops. Food crop agroforests across Micronesia, especially in the RMI, are frequently located close to houses for convenience, efficiency, security, and shade. These patches of agroforest often do not meet minimum size or canopy cover thresholds to be considered forest and so are not sampled by the FIA inventory. This is probably why we recorded relatively few *Artocarpus altilis* trees and no common understory agroforest species like banana, papaya, citrus, or arrowroot.

Invasive plant abundance was very low in the RMI compared to the rest of Micronesia; we recorded only three invasive species covering about 1 percent of forest area. We recorded no invasive tree species in the inventory. As mentioned earlier, this is likely due to the geographic isolation of the islands, relatively low visitation rates to remote atolls, lack of traditional agriculture and grazing livestock, partial sampling of atolls, and saline growing conditions throughout the study area. We did not observe the coconut rhinoceros beetle (*Oryctes rhinoceros*) in this inventory, and it was not known in the RMI at the time of writing. We found brown root rot (*Phellinus noxius*) on both *Cocos nucifera* and *Pandanus tectorius*, although the percentage of live trees estimated with root rot was very low (0.05 percent). We estimated that pig damage affected about 0.4 percent of total forest area.

In the most recent inventory, RMI forests had the lowest levels of disturbance and invasive species coverage in Micronesia (Dendy et al. 2020). They also provide a wide range of ecosystem services beneficial to humans and other organisms, such as protection and creation of soil; shoreline protection; regulation of temperature; and production of food, medicine, and building materials (RMI 2020). As such, ongoing monitoring of forests in the RMI through programs like FIA is important for detecting and responding to changes in forest health.

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We recognize the partnership between the FIA program and the Micronesia Conservation Trust (MCT) in developing meaningful local partnerships. MCT provided funding from a U.S. Department of Agriculture, Forest Service, Landscape Scale Restoration Program grant for the work and staff to survey additional inventory plots to meet the forest monitoring priorities of the RMI government. They supported analysis of this dataset and local workshops on data access and use. We offer special thanks to Tamara Greenstone-Alefaio for her local knowledge and communication with local partners and help with logistics.

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We thank Pierre and Antonella Morisco, the captain and first mate of the live-aboard vessel, for their careful navigation and attention to the safety of the crew and project. Their warm hospitality and delicious food kept the field crew in good spirits living on a 50-foot boat for 53 days.

Thank you to the Marshallese communities on so many atolls for your generous hospitality and your support for continual monitoring of your forest resources. Koṃṃooltata.

Metric Equivalents

When you know:	Multiply by:	To find:
Inches	2.54	Centimeters
Feet	0.3048	Meters
Miles	1.609	Kilometers
Acres	0.405	Hectares
Square miles	2.59	Square kilometers
Cubic feet	0.0283	Cubic meters
Tons	0.907	Tonnes or megagrams
Square feet per acre	0.229	Square meters per hectare
Cubic feet per acre	0.07	Cubic meters per hectare
Trees per acre	2.47	Trees per hectare
Degrees Fahrenheit (°F)	0.56(°F – 32)	Degrees Celsius

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Appendix 1: Scientific and Common Names of Plants Found During Inventory

Life form	Scientific name	Authority	Common name
Trees:	*Allophylus timorensis*	(DC.) Blume	kūtaak
	Artocarpus altilis	(Parkinson) Fosberg	mā, breadfruit
	Artocarpus mariannensis	Trécul	mā, Marianas breadfruit
	Bruguiera gymnorhiza	(L.) Lam. ex Savigny	joñ
	Calophyllum inophyllum	L.	lukwej
	Cocos nucifera	L.	ni, coconut palm
	Cordia subcordata	Lam.	kōṇo
	Dodonaea viscosa	(L.) Jacq.	Florida hopbush
	Guettarda speciosa	L.	utilomar
	Hibiscus tiliaceus	L.	ḷo
	Intsia bijuga	(Colebr.) Kuntze	kubuk
	Morinda citrifolia	L.	nen
	Neisosperma oppositifolia	(Lam.) Fosberg & Sachet	kōjbar
	Pandanus tectorius	Parkinson ex Zucc.	bōb
	Pemphis acidula	J.R. Forst. & G. Forst.	kōñe
	Pipturus argenteus	(G. Forst.) Wedd.	arṃwe
	Pisonia grandis	R. Br.	kañal
	Premna obtusifolia	R. Br.	premna
	Premna serratifolia	L.	kaar
	Scaevola taccada	(Gaertn.) Roxb.	kōṇṇat
	Soulamea amara	Lam.	bitter tree
	Terminalia catappa	L.	kotōl
	Terminalia samoensis	Rech.	ekkōñ
	Tournefortia argentea	L. f.	kiden
Forbs:	*Asplenium nidus*	L.	kartōp
	Bidens pilosa	L.	hairy beggarticks
	Boerhavia tetrandra	G. Forst.	dāpijdekā
	Canavalia cathartica	Thouars	marḷap
	Canavalia rosea	(Sw.) DC.	marḷap
	Cassytha filiformis	L.	kaōnōn
	Centella asiatica	(L.) Urb.	mariko
	Conyza bonariensis	(L.) Cronquist	asthmaweed
	Cucurbita pepo	L.	baañke
	Epipremnum pinnatum	(L.) Engl.	pothos
	Hemigraphis reptans	(G. Forst.) T. Anderson ex Hemsl.	redflame
	Ipomoea violacea	L.	beach moonflower
	Nephrolepis acutifolia	(Desv.) Christ	anṃōkadede
	Nephrolepis hirsutula	(J.R. Forst.) C. Presl	anṃōkadede
	Phymatosorus grossus	(Langsd. & Fisch.) Brownlie	kino

Life form	Scientific name	Authority	Common name
	Phymatosorus scolopendria	(Burm. f.) Pic. Serm.	monarch fern
	Sphagneticola trilobata	(L.) Pruski	Bay Biscayne creeping-oxeye
	Triumfetta procumbens	G. Forst.	atat
	Vigna marina	(Burm. f.) Merr.	markinenjojo
	Wedelia biflora	(L.) DC.	
	Wollastonia biflora	(L.) DC.	marjāj
Graminoids:	*Bothriochloa bladhii*	(Retz.) S.T. Blake	Caucasian bluestem
	Cynodon dactylon	(L.) Pers.	Bermudagrass
	Eleusine indica	(L.) Gaertn.	katejukjuk
	Eustachys petraea	(Sw.) Desv.	pinewoods fingergrass
	Fimbristylis cymosa	R. Br.	pādālijmaan
	Lepturus repens	(G. Forst.) R. Br.	wūjooj
	Paspalum vaginatum	Sw.	wūjooj katejukjuk
	Thuarea involuta	(G. Forst.) R. Br. ex Roem. & Schult.	wūjooj kakkūmkūm
	Clerodendrum inerme	(L.) Gaertn.	wūlej
	Soulamea amara	Lam.	bitter tree
	Triumfetta procumbens	G. Forst.	atat
	Turnera ulmifolia	L.	ramgoat dashalong

Source: Common names are primarily Marshallese names from Merlin et al. (2018). When no Marshallese name is available or there is a broadly known English common name (e.g., coconut palm), then names are from USDA (n.d.).

Scientific Name Changes and Considerations

Tree species are listed here as they occurred in the field guide (USDA FS 2018) except for *Bruguiera gymnorhiza*, which was recorded as *Bruguiera sexangula*. *Bruguiera sexangula* occurs across Southeast Asia and is invasive in Hawaiʻi. It is almost indistinguishable from *Bruguiera gymnorhiza*, which has a broader distribution from eastern Africa through Asia and across Micronesia (Allen and Duke 2006).

The FIA tree species list can be different from or lag behind the most up-to-date nomenclatural publications. *Tournefortia argentea* is a synonym of *Heliotropium foertherianum* Diane & Hilger, *Scaevola taccada* is a synonym of *Scaevola sericea* Vahl var. *taccada* (Gaertn.) Thieret & B. Lipscomb, and *Allophylus timorensis* is a spelling variation of *Allophylus timoriensis* (USDA, n.d.). *Wedelia biflora* and *Wollastonia biflora* are both synonyms of *Melanthera biflora* (L.) Wild. The FIA program does not have an official nontree species list and uses the USDA PLANTS database for plant species names and vegetation codes (USDA, n.d.). Some species names have been updated since the fieldwork was completed in 2018.

Appendix 2: Sample Error and How to Interpret It

We report sample error (SE) of the mean for every estimate in this report, and it is crucial for assessing reliability of the estimate. The smaller the SE value is compared to the estimate, the more reliable the estimate is.

The value of SE added to and subtracted from the estimate creates a range (low value to high value) of confidence in which the true value of the population is likely to occur. If we repeatedly sampled the population and constructed a confidence interval in such a way, the true value would be within these confidence intervals about 68 percent of repeats. Throughout this report, when addressing values, the term "significant" refers to this 68-percent confidence interval. A 95-percent confidence level interval can be created by multiplying the SE by two (and adding to and subtracting from the estimate). SE can be used to create intervals with any confidence level, as needed, using a statistical reference table (t table).

We organized the growth, mortality, and removal estimates in this report in ascending order of the ratio of SE to the estimate (SE/estimate), so the values at the top of the table are more reliable compared to values at the bottom of the table.

The U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis program follows a strict protocol to ensure the high quality of data collected, including quality assurance and control procedures for measurements, data entry, and processing. However, measurement errors; species misidentifications; and mistakes in data entry, processing, and analysis still occur, although the program makes considerable effort to minimize them. We presented data with the precision of one decimal point, which in some cases results in values not summing exactly to totals.

Glossary

biodiversity—Variety and variability among living organisms and the ecological complexes in which they occur. Biodiversity can include genetic, species, and ecosystem diversity, including the number of different items and their relative frequencies (Glowka et al. 1994).

biomass—The aboveground weight of wood and bark in live trees that are ≥1 inch in diameter at breast height, from the ground to the tip of the tree, excluding all foliage. The weight of wood and bark in lateral limbs, secondary limbs, and twigs under 0.5 inch in diameter at the point of occurrence on sapling-size trees is included.

condition class—The combination of discrete landscape and forest attributes that identify, define, and stratify the area associated with a plot. Such attributes include reserved status, owner group, forest type, stand size class, stand origin, and tree density.

damage—Damage to trees caused by biotic agents such as insects, diseases, and animals or abiotic agents such as weather, fire, or mechanical equipment.

diameter at breast height (DBH)—The diameter of a tree stem, located 4.5 feet (1.37 meters) above the ground ("breast height") on the uphill side of a tree. The point of diameter measurement may vary on abnormally formed trees (USDA FS 2018).

disturbance—Any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment (Helms 1998).

ecosystem—A spatially explicit, relatively homogeneous unit of the Earth that includes all interacting organisms and components of the abiotic environment within its boundaries. An ecosystem can be of any size: a log, a pond, a field, a forest, or the Earth's biosphere (Helms 1998).

endemic—Plant species that are unique to a defined geographical location, e.g., species only found in Micronesia.

forb—A broad-leaved herbaceous plant, as distinguished from graminoids, shrubs, and trees (USDA FS 2018).

forest community— A classification of forest land based on and named for the tree species that forms the plurality of live-tree cover that is not overtopped, delineated by the classification guide outlined by Mueller-Dombois and Fosberg (1998).

forest land—The U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis program defines forest land as an area currently or formerly (within 30 years) exhibiting at least 10 percent crown cover of trees of any size and which is not currently developed for nonforest use (USDA FS 2018). Forest land must occupy at least 1 acre and have a minimum continuous width of 120 feet.

introduced (species)—Species that are nonnative or naturalized and are introduced by humans and have established or expanded their populations (Balick and Kitalong 2020).

invasive species—Species that are nonnative to the ecosystem under consideration and that cause or are likely to cause economic or environmental harm or harm to human, animal, or plant health.

live trees—All living trees, including all size classes, all tree classes, and both commercial and noncommercial species listed in the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis field manual (USDA FS 2018).

mortality—The death of trees from natural causes or following incidents such as storms, wildfire, or insect and disease epidemics (Helms 1998).

native species—Plant species that were native to a region prior to Euro-American settlement.

pathogen—An organism or virus directly capable of causing disease or mortality.

sample error—Difference between a population value and a sample estimate that is attributable to the sample, as distinct from errors due to bias in estimation, errors in observation, etc. Sample error is measured as the standard error of the sample estimate (Helms 1998).

sapling—A live tree 1.0–4.9 inches in diameter at breast height (USDA FS 2018).

seedling—A live tree <1 inch in diameter at breast height and ≥12 inches in height (USDA FS 2018).

shrub—Woody, multiple-stemmed plants of any size, and vines. Most cacti are included in this category (USDA FS 2018).

snag—A standing dead tree. To qualify as a snag, dead trees must be ≥1 inch in diameter at breast height, have a bole that has an unbroken actual length ≥4.5 feet, and have a lean angle that is <45 degrees from vertical.

stand size class—A classification of stands based on tree size. Most trees in large-diameter stands are ≥11 inches in diameter at breast height (DBH). Most trees in medium-diameter stands are ≥5 inches in DBH but not as large as large-diameter trees. Most trees in small-diameter stands are <5 inches in DBH.

succession—The gradual supplanting of one community of plants by another (Helms 1998).

tree—The U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) program defines a tree as a woody perennial plant, usually with a single, well-defined stem supporting a crown of leaves, with a minimum diameter at breast height of 3 inches (7.6 cm) and a minimum height of 12 feet (4.6 meters) at maturity. Tally trees are defined as all live and standing dead trees (i.e., snags) in accessible forest land or measurable nonforest land condition classes (USDA FS 2018). Any plant species on the FIA tree list in the current field manual is measured as a tree.

understory—Lowermost canopy layer, including shrubs, vines, and herbaceous vegetation such as forbs and graminoids.

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