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Forest Status Across Micronesia from an Assessment of Micronesia Challenge Terrestrial Measures and Forest Inventory and Analysis Data[1]

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Abstract— The Micronesia Challenge (MC) is an agreement initiated in 2006 by the region's political jurisdictions to conserve both marine and terrestrial natural resources. To assess the success of the terrestrial goals of the challenge, the Micronesia Conservation Trust (MCT) coordinated the compilation of a list of terrestrial measures and utilized them to summarize data from the United States Department of Agriculture (USDA) Forest Service Forest Inventory and Analysis (FIA) program. The MCT and FIA programs added and measured additional forest plots within conservation and special management areas on Guam, within conservation, special management areas or previously unsampled islands in the Federated States of Micronesia (FSM), and on previously unsampled islands in the Republic of Marshall Islands (RMI). Data from these forested plots show that the special management areas (MC areas) generally exhibited preferred forest conditions compared to unmanaged areas (Non-MC areas) across Micronesia. In Guam and FSM, MC areas had less forest area disturbed by people, less forest area with invasive plant species, higher ratios of endemic to invasive tree species, and taller trees than Non-MC areas. In RMI, MC areas had higher basal area and canopy cover than Non-MC areas. Among all jurisdictions, the Republic of Palau had the highest species diversity and endemism and the highest average canopy cover; the Mariana Islands (Commonwealth of Northern Mariana Islands and Guam) had the smallest trees, the lowest basal area, the highest stem density, the lowest average canopy cover, and the highest levels of disturbance and invasive species coverage; FSM had the highest diversity of forest communities, the largest trees, the lowest stem density, and the highest average basal area; RMI had the lowest levels of disturbance and invasive species coverage. Results from this analysis can be used to understand the role of management based on indicators of forested areas across the region.

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Introduction

Micronesia covers about 2.9 million square miles of the earth's surface, of which less than one half of one percent (about 26,000 square kilometers) is land. It is located almost entirely within the tropics of the northwestern Pacific Ocean and stretches over 27 degrees of latitude and 44 degrees of longitude (Fig. 1). For such a large area, Micronesia unsurprisingly contains a great deal of variation in island geography and topography, terrestrial and marine habitats, and human cultural traditions. The region is home to four main island groups (Caroline, Mariana, Marshall, and Gilbert Islands), five independent nations (Republic of Palau, Federated States of Micronesia (FSM), Republic of Marshall Islands (RMI), Republic of Kiribati, and Republic of Nauru), and two US territories (Guam and Commonwealth of Northern Mariana Islands (CNMI)).

The four main island groups of Micronesia are part of the Polynesia-Micronesia global biodiversity hotspot, defined by having at least 1500 endemic vascular plant species and less than thirty percent of native forest remaining (Conservation International, 2007). Because of the relatively small size of oceanic islands and the limited range of many species, plant endemism richness is almost ten times higher on islands than mainland regions, but the relative human impact as a measure of current threat is also significantly higher (Kier et al, 2009). The Polynesia-Micronesia hotspot has been shown to be one of the most vulnerable in the world to extinctions (Baillie et al, 2004), and recent evidence indicates Micronesia having the highest rate (per area) of plant species endemism of any of the world's island biodiversity hotspots (Costion & Lorence, 2012). Therefore, terrestrial habitat conservation is critical in the region (Kier et al, 2009).

The Micronesia Challenge (MC) is a multijurisdictional commitment to effectively manage twenty percent of terrestrial resources and thirty percent of near shore marine resources by 2020, which was signed by leaders from Palau, Guam, FSM, CNMI and Republic of Marshall Islands (RMI) in 2006. Participating jurisdictions chose management areas for inclusion in the MC based on a wide variety of factors. Regional scientists, resource managers, communities and government agency personnel among the jurisdictions compiled a list of measures in 2016 to indicate progress towards the MC goals in the terrestrial realm. A monitoring protocol for the terrestrial environment was developed which includes streams, groundwater in atolls, trees (including mangrove species), and birds. While several terrestrial measures have yet to be monitored, data from USDA Forest Service Forest Inventory Analysis (FIA) program has been used to describe terrestrial measures of trees and mangroves.

The FIA program has existed throughout the contiguous U.S. states since the 1930's and was primarily focused on quantifying timber resources. In 1998, the FIA program merged with the nation's forest health program and developed an enhanced inventory program focused on monitoring the status and trends of the health of the forests over time. This program also expanded to include all US states, territories, and affiliated island nations. The data collected by the program has been used for many purposes, including tree species range and distribution maps, wildfire management plans, models of carbon storage and forest change after disturbance cycles, and baselines for research of ecosystem change over time. The FIA program expanded into the Pacific region in the 2000's, and remeasured forest plots approximately eleven years later in Palau (2003-2014), CNMI (2004-2015), Guam (2002-2013), FSM (2005-2016), and RMI (2008-2018).

The Micronesia Challenge Regional Office (MCRO), and representatives from the jurisdictions determined that further expanding the FIA forest plot framework and dataset in the region would help support the terrestrial monitoring requirements of the MC program. In coordination with the FIA program and partnership with MCRO, the MCT measured additional forest plots within conservation and special management areas on Guam (2014), within conservation, special management areas and previously unsampled islands in FSM (2016) and on previously unsampled islands in the Marshall Islands (2018).

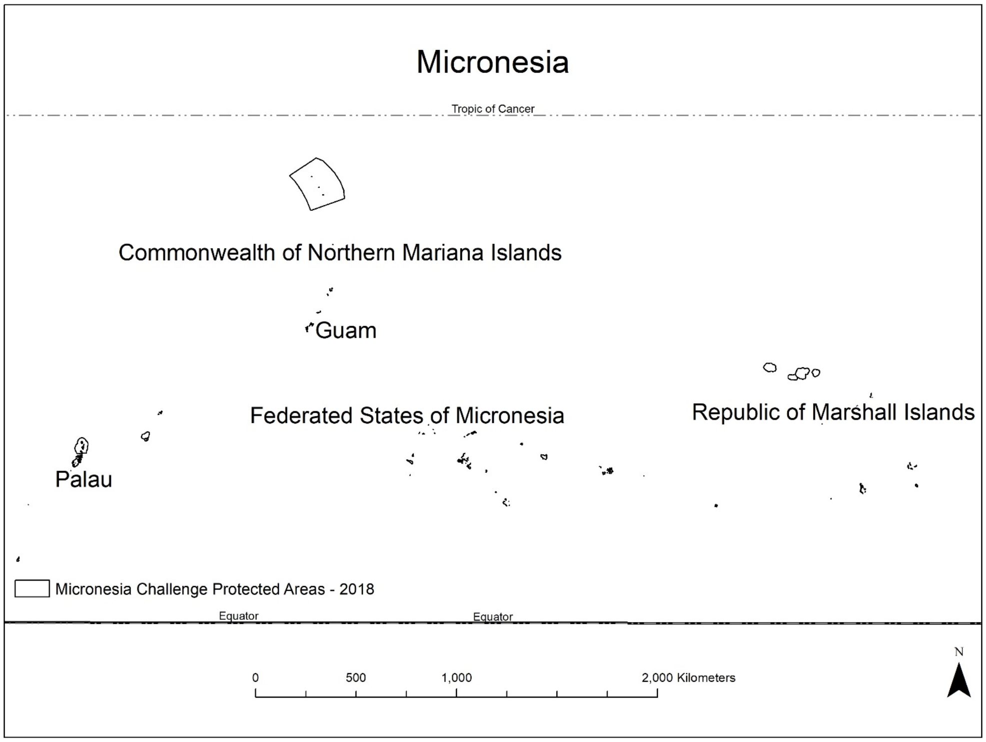

Figure 1. Map of Micronesia showing jurisdictions included in the FIA program and locations of Micronesia Challenge protected areas as of 2018.

The objective of this study was to describe and summarize the MC terrestrial measures for trees and mangroves across the region using FIA plot data and compare them in managed and unmanaged areas in Guam, FSM and RMI.

The foundational source for general comparative observations and predictions of forest vegetation and forest communities across the region is Muller-Dombois & Fosberg's Vegetation of the Tropical Pacific Islands book from 1998. As with any comparative study of islands, most patterns of natural differences in terrestrial species diversity can be expected to conform to the predictions of MacArthur & Wilson in the book Theory of Island Biogeography from 1967.

Methods

The FIA uses a grid laid over each island to sample locations randomly for potential forest plots to measure. Only those locations which can be ruled out as non-forest in recent satellite imagery are not visited on the ground. Any location that could at least overlap with a minimum of one acre of forest is visited. If the minimum one-acre size, ten percent canopy cover, and 120-foot width requirements are met, the forest on that plot is measured according to field manual methodology protocol. Definitions and parameters of plot measurements can be found in the field manuals at https://www.fia.fs.fed.us/library/field-guides-methods-proc/.

On most of the US mainland, the sampling intensity results in one plot measured for every 6000 acres of forest. Because of the drastic difference in land area in the Pacific, the base sampling intensity was increased three-fold, resulting in a sampling intensity of one plot for every 2000 acres of forest. In RMI, where most of the islands are small atoll islets, the sampling intensity was increased by four times again (twelve times total), resulting in a sampling intensity of one plot for every 500 acres of forest. Sampling and estimation procedures for the FIA are based on Bechtold and Patterson (2005).

Given the relatively small size of terrestrial special management areas in Micronesia, many of these areas went unsampled within the base intensity FIA sampling design. In order to measure these forests in the region, the MCT and FIA programs increased the overall sampling intensity by another nine times (twenty-seven times total) and selected only those forest plots falling within terrestrial protected areas (including mangroves), so that in those areas the sampling intensity resulted in one plot for every 222 acres of forest.

In the FSM and Guam, two groups of FIA forest plots were created called "MC areas" and "Non-MC areas", defined by whether or not the plots were located inside the boundary of a protected or special management area. The mean values of all terrestrial measures within MC areas and Non-MC areas were compared using two-tailed two-sample T-tests. Given the small sample sizes per jurisdiction, the high natural diversity and variation of forests across the region, and the intention of using the data to inform management, the results are reported in confidence intervals generated at an 80% confidence level.

The category of protected or special management terrestrial area was defined and identified by a group of selected representatives in both jurisdictions. In the FSM this included "Areas of Biological Significance" in places where there were no formal protected area boundaries for key terrestrial ecosystems, and in Guam this included prioritized watersheds (SPREP, 2003).

On Pohnpei, in FSM, the Watershed Forest Reserve containing montane rainforest was not intensified for plot sampling because the resulting number of additional plots was too large for the difficult terrain, and FSM representatives decided to sample other areas with few to no already existing plots. In Ulithi, an outer island of Yap state in FSM, the sampling intensity was insufficient to locate forest plots in Areas of Biological Significance (ABS) on the small atoll islets, so any plot locations on land with forest were considered MC plots there.

In the RMI, additional FIA plots were added in previously unsampled atolls, but not specifically in protected or special management areas. Two-tailed two-sample T-tests were performed on mean values of all terrestrial measures to make comparisons between base plots located within protected area boundaries (MC areas) and all other plots (Non-MC areas) there, and results are reported in confidence intervals generated at an 80% confidence level.

The FIA data was compiled to describe and summarize the compiled terrestrial measures for trees and mangroves. The list of terrestrial forest measures, the corresponding FIA data used to describe each measure, and the summary analyses performed are shown in Table 1. Forest community is a term used to describe forest type, which is not a terrestrial measure of the MC, but was included to improve the clarity of interpretation of observed differences between managed and unmanaged areas of forest.

Table 1. List of Micronesia Challenge terrestrial measures, FIA data used, and analyses performed to describe each measure. BA is basal area. N/A = indicator uses different units.

MC Terrestrial Measure	FIA Data Used	Area or # of Trees	% of Forest or % of Trees
Human disturbance	Disturbance (human and fire)	Acreage	% of Forest area
Species diversity	Tree species per plot	N/A	N/A
	Dominant vascular plant species per plot	N/A	N/A
	Tree species: relative dominance	Square feet per acre	BA/BA of All Trees
	% Cover of understory species	Acreage	% of Forest Area
Forest structure	Tree DBH (diameter at breast height)	# of Trees	% by DBH class
	Tree height	# of Trees	% by Height class
	Basal area	Square feet per acre	N/A
	Stem density (per plot and per acre)	# of Trees per plot/acre	N/A
Invasive species	Tree species	# of Trees	% of All trees
	Invasive vegetation subplot cover	Acreage	% of Forest area
Forest cover	% Live canopy cover	Acreage	% of Forest area
Tree abundance	Tree species	# of Trees	% of All trees
	Tree rank order: endemics and invasives	# of Trees	% of All trees
Mangrove stem density	Stem density (per acre)	# of Trees per acre	N/A
Mangrove basal area	Basal area	Square feet per acre	Relative dominance
Forest community	Forest community	Acreage	% of Forest area

Results

HUMAN DISTURBANCE

Human disturbance is classified by FIA as any significant threshold of human-caused damage which is not otherwise described by other disturbance categories. In Micronesia, fires are primarily caused by humans, so the total human disturbance is the sum of these two categories.

In Palau, fire disturbed 6.8% [80% CI:3-10.6%] of forest area. In Guam 5.6% [80% CI:1.9-9.3%] of the total forest area was disturbed by fire. In CNMI, human disturbance affected 6.6% [80% CI:1.1-12.2%] of forest area. In the FSM, human disturbance was 14.7% [80%CI:3.5-25.9%] lower in MC areas than in Non-MC areas. No fire disturbances were recorded in MC areas in the FSM, but overall, 3.4% [80% CI:1.2-4.6%] of forest area was disturbed by fire. In RMI, 8.1% [80% CI:2.3-13.9%] of forest area was disturbed, which was the lowest across Micronesia (Table 2), although 24.9% [80% CI:14.8 – 35%] of total forest area including 65.1% [80%CI: 46.6 – 83.6%] of agroforest area was managed with fire as a silviculture treatment. No differences in RMI were observed in disturbance between MC areas and Non-MC areas, and human disturbance estimates were unreliable because of high sample error values.

Table 2. Source of largest forest disturbance by percent of forest area disturbed, and total percent of forest area affected by all disturbance types across Micronesia. CI: confidence interval, FSM: Federated States of Micronesia, RMI: Republic of Marshall Islands, CNMI: Commonwealth of Northern Mariana Islands.

Jurisdiction	Largest disturbance type	% of Forest area [80% CI]	All disturbances [80% CI]
RMI	Weather	4.3% [0-8.6%]	8.1% [2.3-13.9%]
FSM	Human	21.2% [16.2-26.2%]	39.2% [33.5-45.7%]
Palau	Weather	10.9% [5.6-16.2%]	25.1% [18.2-32%]
Guam	Animals	29.8% [22.2-37.4%]	49.1% [40.8-57.4%]
CNMI	Tree Disease	40.1% [33.1-47.1%]	67.7% [58.7-76.7%]

SPECIES DIVERSITY

Palau had the highest mean number of tree species per plot and the highest number of dominant vascular plant species per plot in Micronesia (Table 3), with two endemic and no invasive tree species in the top ten most dominant tree species. 20.6% [80% CI:17.9-23.3%] of forest area overall was covered by endemic understory species, which was also the highest in Micronesia (Table 4).

In Guam, there were three endemic tree species and two invasive tree species in the top ten most dominant tree species in MC areas, no endemics with three invasive tree species in Non-MC areas, and one endemic and three invasive tree species overall. There were 1.5 [80% CI:0.8-2.3] more tree species per plot in MC areas than Non-MC areas, but 2.2 [80% CI:1.1-3.3] fewer dominant plant species per plot. In CNMI, one endemic tree species and one invasive tree species were in the top ten most dominant tree species.

FSM had three endemic tree species and no invasive tree species in the top ten most dominant tree species in MC areas, one endemic and one invasive tree species in Non-MC areas, and three endemics and one invasive tree species overall. There were 1.8 [80% CI:1.1-2.5] more tree species per plot and 7.4 [80% CI:6.1-8.7] more dominant plant species per plot in Non-MC areas than MC areas.

In RMI, there was one endemic tree species inventoried, and no differences were observed in tree species or dominant plant species richness per plot between MC and Non-MC areas. RMI had the lowest number of tree and vascular plant species per plot in Micronesia.

Table 3. Mean species diversity values per plot for trees and vascular plants across Micronesia. CI: confidence interval, FSM: Federated States of Micronesia, RMI: Republic of Marshall Islands, CNMI: Commonwealth of Northern Mariana Islands.

Jurisdiction	# of Plots (MC area plots)	Tree species/plot [80%CI]	Dominant vascular plant species/plot [80%CI]
RMI	71 (12)	3.6 [3.4-3.8]	6.1 [5.7-6.5]
FSM	149 (83)	5.9 [5.5-6.3]	10.3 [9.6-11]
Palau	56 (0)	12.6 [11.6-13.6]	14.3 [13.4-15.2]
Guam	109 (71)	5.2 [4.8-5.6]	9.9 [9.4-10.4]
CNMI	37 (0)	5 [4.1-5.9]	13.4 [12.5-14.3]

Table 4. Percent of forest area covered by endemic understory plant species (including tree seedlings), most common understory species and percent of forest area covered by it. CI: confidence interval, FSM: Federated States of Micronesia, RMI: Republic of Marshall Islands, CNMI: Commonwealth of Northern Mariana Islands.

Jurisdiction	Endemics [80%CI]	Most common understory species	% Forest area [80%CI]
RMI	0%	*Cocos nucifera*	11.1% [7.7-14.5%]
FSM	8.3% [6.9-9.7%]	*Hibiscus tiliaceus*	8.1% [6.3-9.9%]
Palau	20.6% [17.9-23.3%]	*Pinanga insignis*	16.5% [13-20%]
Guam	6.9% [5-8.8%]	*Hibiscus tiliaceus*	9.9% [7.8-12%]
CNMI	9.3% [5.8-12.8%]	*Leucaena leucocephala*	23.5% [17.9-29.1%]

FOREST STRUCTURE

In Palau, 52.2% [80% CI:48.3-56.1%] of trees were in the smallest diameter class (1 to 2.9-inches), and less than 10% of trees were 9 inches or larger in diameter at breast height (DBH) (Fig. 2).

In Guam, 61.9% [80% CI:57.3-66.5%] of trees were in the smallest diameter class, and less than 5% of trees were 9 inches or larger in diameter. Mean tree height was 2.4 [80% CI:0.6-4.2] feet higher in Non-MC areas compared to MC areas, but there were no significant differences in mean tree diameter, mean stem density or basal area between MC and Non-MC areas in Guam. In CNMI, 65.1% [80% CI:59.1-71.1%] of trees were in the smallest diameter class, and about 1% of trees were >9 inches in diameter.

FSM forests had the highest mean tree height and diameter, as well as the lowest stem density and highest basal area across Micronesia (Table 5). 56.8% [80% CI:53.2-60.4%] of trees were in the smallest diameter class, and more than 10% of trees were greater than 9 inches in diameter. The mean diameter for all estimated trees over one-inch DBH was 1.3 [80% CI:0.6-2] inches larger and 4.8 [80% CI:1.6-8] feet taller in FSM MC areas than in Non-MC areas. There were 4.9 [80% CI:1.6-8.2] more stems per plot in Non-MC areas than MC areas, but no significant difference was observed in stem density per acre. Non-MC areas had 28.2% [80% CI:17.1-39.3%] more 1 to 2.9-inch diameter stems, and 14% [80% CI:7.8-20.2%] more 3 to 4.9-inch stems than MC areas.

In RMI, 63.2% [80% CI:56.1-70.3%] of trees were in the smallest diameter class, and more than 10% of trees were greater than 9 inches in diameter. No significant differences were observed in average tree diameter, height, or stem density per acre between MC areas and Non-MC areas, but there were 54 [80% CI:31-77] more square feet per acre of basal area in RMI MC areas than Non-MC areas.

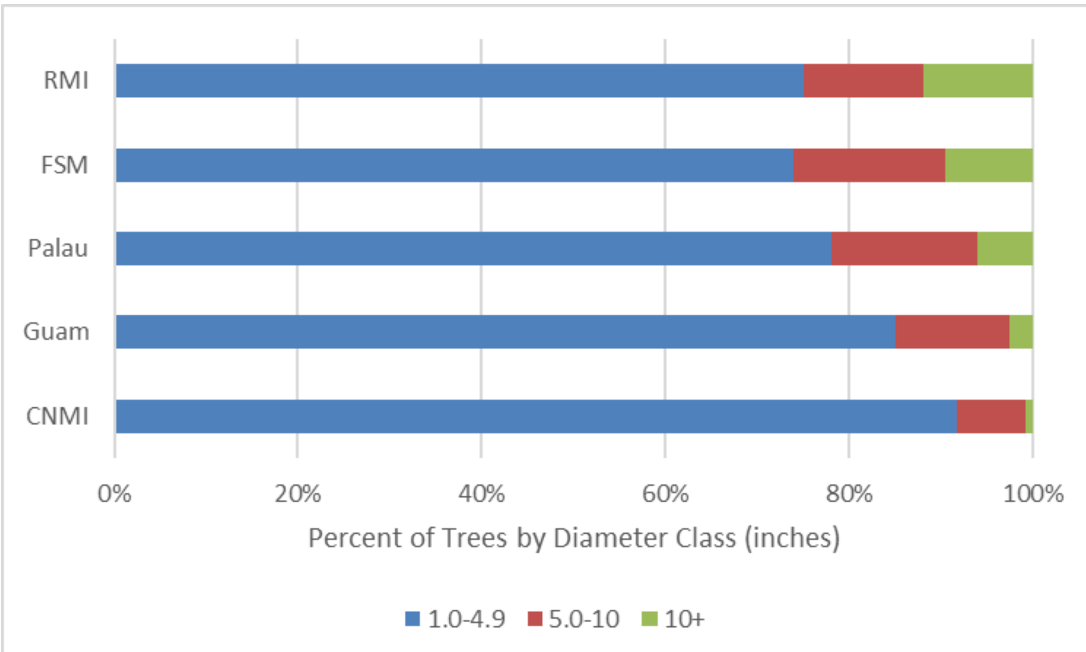

Figure 2. Estimated percentage of all trees by diameter class (in inches) by jurisdiction across Micronesia. FSM: Federated States of Micronesia, RMI: Republic of Marshall Islands, CNMI: Commonwealth of Northern Mariana Islands.

INVASIVE SPECIES

In Guam, there was 15.2% [80% CI:3.4-27.2%] more forest area with invasive plant species present in Non-MC areas than in MC areas, a higher but nonsignificant percentage of forest area covered in invasive plants, and a higher but nonsignificant percentage of invasive trees. CNMI had the highest proportion of forest covered with invasive plant species and the highest percentage of invasive trees in Micronesia (Table 4). In FSM, 8.1% CI:3.7-12.5%] more forest area was covered in invasive species in Non-MC areas compared to MC areas. In RMI, 11.4% [80% CI:4.9-17.9%] of RMI's forest had invasive plants present, which was the lowest estimate across Micronesia (Table 6), but there was no difference in presence or coverage of invasive plants between MC and Non-MC areas.

FOREST COVER

Palau had the highest average canopy cover in Micronesia (Table 7). In the FSM, Non-MC areas had 56.7% [80% CI:49.7-63.7%] more forest area ≥50% canopy cover than MC areas. In RMI, there was 10.7% [80% CI:4.1-17.3%] more forest with ≥50% canopy cover in MC areas than in Non-MC areas.

Table 5. Mean tree DBH, height, stem density, and basal area for forest across Micronesia. CI: confidence interval, FSM: Federated States of Micronesia, RMI: Republic of Marshall Islands, CNMI: Commonwealth of Northern Mariana Islands.

Jurisdiction	DBH in inches [80%CI]	Height in feet [80%CI]	Stems/acre [80%CI]	Square Feet/acre [80%CI]
RMI	4 [3.3-4.7]	23.1 [20.5-25.7]	726 [556-896]	124 [112-136]
FSM	4.4 [4.1-4.7]	27.3 [26.3-28.3]	611 [558-664]	145 [132-158]
Palau	3.9 [3.8-4]	26.9 [25.7-28.1]	937 [866-1008]	143 [131-155]
Guam	3.1 [3-3.2]	22.7 [22.2-23.6]	1014 [885-1143]	84 [78-90]
CNMI	2.8 [2.5-3.1]	20.8 [19.9-21.7]	1392 [1148-1636]	84 [72-96]

Table 6. Percent of forest area with invasive plant species present or covered with invasive plant species, and percent of all trees that are invasive across Micronesia. CI: confidence interval, FSM: Federated States of Micronesia, RMI: Republic of Marshall Islands, CNMI: Commonwealth of Northern Mariana Islands.

Jurisdiction	Invasives present [80%CI]	Covered in invasives [80%CI]	Invasive trees [80%CI]
RMI	11.4% [4.9-17.9%]	1% [0-2%]	0
FSM	49.2% [43.9-54.5%]	11.3% [9-13.6%]	5.4% [2.1-8.7%]
Palau	13.3% [9.1-17.5%]	0.9% [0.2-1.6%]	1.2% [0-2.4%]
Guam	85.7% [81.8-89.6%]	39.9% [34.5-45.3%]	30.1% [23.9-36.3%]
CNMI	84.9% [80.4-89.4%]	54.6% [44.2-65%]	43.6% [31.8-55.4%]

Table 7. Estimated percent of forest area with live canopy cover percent of greater than or equal to 50%, 80% and 90% across Micronesia. CI: confidence interval, FSM: Federated States of Micronesia, RMI: Republic of Marshall Islands, CNMI: Commonwealth of Northern Mariana Islands.

Jurisdiction	% Forest area with canopy cover >=50% [80%CI]	Canopy cover >=80% [80%CI]	Canopy cover >=90% [80%CI]
RMI	92.3% [87.2-97.4%]	77.4% [68.3-86.5%]	50.1% [38-62.2%]
FSM	90.4% [86.4-90.8%]	52.5% [46-59%]	6.4% [3.2-9.6%]
Palau	92.7% [88.8-96.7%]	82.3% [76.6-88%]	61.6% [53.8-69.4%]
Guam	90.5% [85.3-95.7%]	62.9% [54.6-71.2%]	31.4% [23.9-38.9%]
CNMI	81.6% [72.8-90.4%]	58.9% [48.2-69.6%]	30.8% [20-41.6%]

TREE ABUNDANCE

In Palau, 36.6% [80% CI:32.2-40.9%] of trees were endemic species, and there were eight endemic and zero invasive species in the top twenty most abundant tree species, the highest in Micronesia (Table 8). *Pinanga insignis*, a palm, was the most abundant tree with 13% [80% CI:9.1-16.9%] of all trees. In Guam, the most abundant tree species was *Leucaena leucocephala*, an invasive species, with 15.2% [80% CI:10.3-20.1%] of all trees, and there were 30.8% [80% CI:17.3-44.3%] more endemic trees in MC areas than in Non-MC areas, but there was no significant difference in the percentage of invasive trees. In CNMI, *Leucaena leucocephala* was also the most abundant tree at 42.9% [80% CI:31.1-54.7%] of all trees. In the FSM, the most abundant tree species was *Hibiscus tiliaceus*, which comprised 12.6% [80% CI:9-16.2%] of all trees, and there were 12.9% [80% CI:0.6-25.2%] more endemic trees and 6.5% [80% CI:2.5-10.5%] fewer invasive trees in MC areas than in Non-MC areas. In RMI, there were zero invasive tree species and one endemic tree species inventoried, *Artocarpus mariannensis*, which comprised less than 1% of all trees. The most abundant tree in RMI was *Scaveola taccada* with 39.8% [80% CI:28.1-51.5%] of all trees.

Table 8. Estimated percent of endemic tree species, and number of endemic tree species inventoried across Micronesia. CI: confidence interval, FSM: Federated States of Micronesia, RMI: Republic of Marshall Islands, CNMI: Commonwealth of Northern Mariana Islands.

Jurisdiction	% Endemic trees [80%CI]	# of Endemic species
RMI	0%	1
FSM	23.6% [19.3-27.9%]	26
Palau	36.7% [32.4-41%]	38
Guam	18.4% [11.9-22.3%]	13
CNMI	17.1% [9.3-27.5%]	9

MANGROVES

Mangrove plots had the lowest numbers of tree species (3.4 species per plot [80%CI:2.7-4.1%]) compared with other community types (Table 9), but were not sampled in Guam and the CNMI (Table 10). In the FSM, mangrove swamps made up 17.1% [80% CI:12.2-22%] of total forest area, which was the most in Micronesia (Table 10). There was no significant difference in stem density or basal area of mangrove forests between MC areas and Non-MC areas overall in FSM.

FOREST COMMUNITY

For Micronesia overall, lowland rainforest had 3.5 [80% CI:3-4] more tree species per plot than strand forest, 4.1 [80% CI:3.3-4.8] more tree species per plot than mangrove forest, and 4 [80% CI:3.5-4.6] more species per plot than agroforest. There were vastly more plots in lowland rainforest than any other community (Table 9).

In the FSM, there was 25.2% [80% CI:12-38.4%] more relative forest area in montane rainforest and 13.1% [80% CI:2.9-23.3%] more in strand forest, but 22.3% [80% CI:5-39.6%] less relative forest area in tropical lowland rainforest and 13.2% [80% CI:2.5-23.9%] less in agroforest in MC areas than in Non-MC areas. FSM had the most different forest communities sampled and was the only jurisdiction with montane rainforest present in Micronesia (Table 10). RMI had the second most different forest communities sampled, although there was only one partial mangrove plot measured.

Table 9. Number of live tree species per plot and total number of forest plots sampled for each forest community across Micronesia. CI: confidence interval, FSM: Federated States of Micronesia, RMI: Republic of Marshall Islands, CNMI: Commonwealth of Northern Mariana Islands.

Forest community	# of Tree species per plot [80%CI]	# of Plots
Lowland Rainforest	7.5 [7.1-7.9]	253
Montane Rainforest	7.5 [6-9]	4
Strand Forest	3.8 [3.3-4.3]	32
Agroforest	3.4 [3-3.8]	44
Mangrove	3.4 [2.7-4.1]	24

Table 10. Number of forest communities, and percent of total forest area by forest community in all measured plots across Micronesia. CI: confidence interval, FSM: Federated States of Micronesia, RMI: Republic of Marshall Islands, CNMI: Commonwealth of Northern Mariana Islands. Agroforest was not sampled in Palau, mangrove was not sampled in Guam or CNMI, and Montane rainforest only occurs in FSM.

Jurisdiction	Communities	Lowland [80%CI]	Strand [80%CI]	Agroforest [80%CI]	Mangrove [80%CI]	Montane [80%CI]
RMI	4	39.3% [27.2-51.4%]	27.5% [17.6-37.4%]	31.7% [21.4-42%]	1.5% [0-3.4%]	-
FSM	5	57.5% [51.2-63.8%]	2.8% [1-4.6%]	17.9% [13.1-22.7%]	17.1% [12.2-22%]	4.6% [1.8-7.4%]
Palau	3	84.1% [78.1-90.1%]	4.2% [1-7.4%]	-	11.7% [6.6-16.8%]	-
Guam	3	94.3% [90.3-98.3%]	2.6% [0-5.2%]	3.1% [0-7.1%]	-	-
CNMI	3	93% [87.8-98.2%]	6.3% [1.5-10.8%]	0.7% [0-1.6%]	-	-

Discussion

The MC terrestrial measures for trees and mangroves present a broad spectrum of potential forest characteristics with which to gauge the status, value, and performance of forest resources and management. The data collected by the FIA offer a level of detail and breadth of scale that adequately describe the MC terrestrial measures. However, because of their small size and high variability, many of the MC area terrestrial measure estimates and individual island or FSM state estimates were exceeded by their sample errors. Differences from comparisons of measures with proportionally many zero values observed may also fail to meet the assumption for the T distribution.

Nevertheless, there were significant differences between MC areas and Non-MC areas in RMI, FSM and Guam, as well as meaningful differences and suggestive trends overall among jurisdictions and forest communities. Overall, islands with larger areas of forest with invasive species present were associated with more disturbed forest area and less forest area with high canopy cover. Higher species diversity was associated with larger, less remote islands with less forest area disturbed. Lowland rainforest was the most widespread forest community in the region and contained the most plant species, including endemics.

The following discussion examines how each metric varied among the five jurisdictions.

Human Disturbance

FSM, Guam, and CNMI were all highly disturbed overall. Human disturbance was relatively high in CNMI, but not specifically recorded in Guam or Palau. Human-caused disturbance was highest in FSM, with more than half in agroforest area, indicating ongoing management. *Hibiscus tiliaceus* was the most abundant tree species, with the highest mean understory cover in FSM. *H. tiliaceus* has many uses across FSM, is sometimes planted intentionally as tree cover in agroforest areas during fallow intervals and is often an indicator of recovery after disturbance (Falanruw, 1993, Raynor & Fownes, 1993).

Palau was somewhat disturbed and RMI had the lowest level of disturbance. Fire is known to be a persistent issue in CNMI, Guam, Yap, and Palau, which was confirmed with the fire disturbance data. Semi-controlled understory burning is frequently applied as a silviculture treatment in RMI to manage coconut plantations and facilitate copra harvest. No fire disturbances were observed in FSM MC areas, probably since wildfires essentially occur only on Yap proper in FSM. In addition to human disturbance, there was a high level of disturbance from tree disease in CNMI and from feral animals in Guam, and weather damage from a typhoon caused about a quarter of the disturbance in FSM.

Species Diversity

Based on the geography of the region and the theory of island biogeography, which predicts that larger and less remote islands will have more species than smaller and more remote islands, the highest terrestrial species diversity values would be expected in Palau, the lowest in RMI and intermediate diversity values elsewhere depending mostly on island size. The highest mean tree and dominant vascular plant species richness values were indeed observed in Palau forest. The FSM species richness values generally decreased from west to east at the state level, excepting Chuuk, which is composed of several small sized islands and had the lowest diversity values in FSM. RMI had the lowest mean tree and dominant plant species richness overall, as well as the lowest number of endemic species which is probably due to the small size of atoll islets.

In FSM, Non-MC areas had higher mean tree and dominant plant species richness than MC areas, but MC areas generally had higher ratios of endemic to invasive tree species in the top ten most dominant trees. The difference in mean species richness in FSM was mostly due to disproportionate area of forest communities since lowland tropical rainforest has the highest dominant plant and tree species richness of all forest communities in the region. In Guam, MC areas had higher tree species richness but lower dominant plant species richness than Non-MC areas. Many introduced and invasive plants in Guam and CNMI have become established in disturbed areas, which could partly explain the difference in dominant plant species richness on Guam and the relatively high overall dominant plant species richness in CNMI.

Forest Structure

FSM had the tallest and thickest trees, lowest stem density and highest basal area overall in the region. MC areas there had slightly larger and taller trees and lower stem densities than Non-MC areas, and Non-MC areas had a higher proportion of smaller diameter stems, which aligns with the higher disturbance in Non-MC areas and suggests that forest regeneration is occurring in those forests. RMI had surprisingly large trees, due to the high proportion of coconut trees, which also helps explain the relatively low stem density there. Palau had similar mean diameter of trees with RMI, but higher mean height of trees and mean basal area. Guam and CNMI had the lowest proportions of large trees in the region, which seems likely to be primarily attributed to the high frequency of typhoons there but could also be related to relatively high levels of urban development and high proportions of smaller tree species, like *Leucaena leucocephala*. Trees were slightly but significantly taller in Guam Non-MC areas, but otherwise there was little difference in forest structure there with Non-MC areas. CNMI had the smallest mean DBH and height of trees and highest mean stem density in Micronesia, which could be a consequence of the dominance of forests by the relatively short and densely growing *Leucaena leucocephala*.

INVASIVE SPECIES

Invasive species are an important threat to native biodiversity and forest health, especially in the Pacific, which is why the FIA incorporated an invasive plant species methodology in the last measurement cycle. Palau and RMI both had around 1% of forest area covered in invasive plants, with RMI having no invasive trees inventoried, and Palau having about 1% of invasive trees. Almost half of the forest area in FSM had invasive species present, and MC areas there had less area covered in invasive plants and proportionally fewer invasive trees than Non-MC areas. Guam and CNMI both had more than 80% of forest area having invasive plants present, more than 30% of forest area covered in invasive plants, and more than 20% of all trees being invasive. In Guam, MC areas had proportionally less forest area with invasive plants present than Non-MC areas. The entire region was subjected to varying degrees of disruption from Spanish, German, and Japanese colonial occupation for centuries and then violent conflict and destruction throughout WWII, but in Guam and CNMI the clearance of native vegetation was probably the most extensive (Mueller-Dombois & Fosberg, 1998). That, the aerial seeding of *Leucaena leucocephala* after the war by the US administration, and the use of Saipan and Guam as commercial and military hubs largely explain why invasive species have spread to such an extent in the Marianas.

FOREST COVER

Palau had the highest mean canopy cover overall in Micronesia, followed by RMI, where MC areas had more forest area with canopy cover of 50% or more than Non-MC areas. FSM had the lowest percentage of forest cover with 90% canopy cover or greater in the region, and MC areas there had less forest area with 50% of canopy cover or greater than in Non-MC areas. While this was unexpected and contrary to most of the terrestrial measure comparison trends in FSM, it seems likely to be mostly due to the lower average canopy cover in strand forest (data not shown), which was sampled disproportionately more in MC areas. CNMI was the only jurisdiction with less than 90% of forest area with 50% canopy cover or greater. By global standards, the entire region has excellent forest land cover, with all jurisdictions except for Guam in the top 25 countries by percent of forested land area (Dillinger, 2019). Relative differences of forest cover within the region could be due to numerous factors related to disturbance that vary greatly by jurisdiction, including human population relative to island size, prevalence of wildfire, occurrence of typhoons, agroforestry management and presence and impact of feral ungulates.

TREE ABUNDANCE

Remote islands are often home to endemic species due to their isolation which can easily become endangered or extinct with changes to habitat. The highest rate of endemic species is generally expected on the most remote, largest, oldest, most geographically diverse, and most climatically stable islands with the most habitat diversity (Bruchman & Hobohm,2014). Palau had the highest percentage of endemic trees, the highest number of endemic tree species, and the highest number of endemic trees in the top twenty most abundant trees. FSM also had a high rate of tree species endemism, with Pohnpei MC areas showing the highest overall rate in Micronesia at 44% [80% CI:31-57%]. The overall value for FSM is slightly lower than expected due to low sample size of plots and only two endemic tree species inventoried in Chuuk. There were more endemic trees and fewer invasive trees in MC areas than Non-MC areas, and a higher ratio of endemic to invasive tree species in the top twenty most abundant trees in FSM. In Guam, the most common tree was an invasive species, and 30% of all trees were invasive there. MC areas in Guam had more endemic trees than Non-MC areas, and a higher ratio of endemic to invasive tree species in the top twenty most abundant trees. In CNMI, more than 40% of trees were invasive, and most of these were the most abundant tree, *Leucaena leucocephala*. In RMI, only one endemic tree species was inventoried, and no invasive tree species were recorded.

Mangroves

Mangroves are present in every jurisdiction mentioned here, but were not sampled in Guam or CNMI, and in RMI only one mangrove plot was sampled, due to the small proportional area of mangroves in those countries. FSM had the largest proportional area of mangrove in the region, which, in addition to low species diversity in mangroves and especially large size of trees, explains why the most dominant tree there was a mangrove species (*Sonneratia alba,* 12.9% [80% CI:7.6-18.2%] of total basal area). Sample errors were high in general for mangroves due to small sample sizes, but there were 494 [80% CI:186-802] fewer stems in Yap MC Areas than Non-MC Areas. Palau had the most total tree species in mangroves (21 to 16) but had 632 [80% CI:252-1012] more stems per acre and 64 [80% CI:9-119] fewer square feet of wood per acre than FSM mangroves.

Forest Community

Forest community is not an official MC terrestrial measure, but we included it to demonstrate that forest habitat diversity varies considerably across Micronesia, which has consequences for comparisons of forests, particularly species diversity. Mangrove and strand forest both have naturally lower tree and plant species diversity due to the challenges of exposure to saltwater and spray. Agroforests also have limited tree species diversity, due to human control. Montane rainforest has high diversity and endemism and is only present in Pohnpei and Kosrae states in the FSM but was only sampled in Pohnpei. Lowland rainforest has the highest mean tree species richness of any of the forest communities in the region, although in RMI there were more total dominant plant species in agroforest than any other forest community there. Across the region, strand forest had the highest proportion of plots measured with partial forest (77%), and mangrove had the lowest (39%), which confirms that strand forests tend to be a narrow habitat and suggests that mangroves are the most intact forest community in Micronesia.

The relative differences in percent of forest area by forest community between MC and Non-MC areas demonstrate how much the habitat proportion in MC areas differs from the overall habitat proportion in those jurisdictions. Across the region there has been a trend towards designating strand forest as protected areas proportionally more and lowland rainforest (and agroforest) proportionally less, which resulted in the higher mean tree and dominant plant species richness in Non-MC areas compared to MC areas observed in FSM.

Species diversity is not the only factor in determining forest areas for special management or protection, which is reflected in the variety of MC terrestrial measures. Mangrove and strand forest play important roles in preventing coastal erosion and offshore reef sedimentation and are both important habitats for marine invertebrate diversity and shorebird nesting. However, the unique and dense species diversity of the region overall is what defines it as a global biodiversity hotspot; it is therefore noteworthy to recognize some of the best remaining lowland rainforest in FSM coincide or overlap with ABS that lack protected status.

Agroforest is culturally important across Micronesia and is somewhat unique within the FIA system with the focus being on food rather than wood. There is a great deal of plant diversity at the species and variety level of culturally important plants in agroforest, much of which may be missed by the FIA methodology due to area size and canopy cover limits of forest. In RMI there is much local interest in the trends of important food species like *Artocarpus altilis* (breadfruit), *Cocos nucifera* (coconut), and varieties of *Pandanus tectorius*. Since these species and varieties tend to occur near households rather than in the forest as defined in the methodology, they often went unsampled and did not have large enough sample sizes to produce meaningful summaries. Specific and focused surveys of agroforest may thus be necessary to produce locally useful information to islanders in RMI and elsewhere across Micronesia.

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