Mariana Islands Forest

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Abstract

We present a status assessment of the Mariana Islands archipelago (Marianas) forests, including the current status, stressors, and future viability. Forests in the Marianas generally receive moderate to high rainfall during distinct wet and dry seasons and are associated with limestone or volcanic substrates. Prior to the arrival of humans in the Marianas approximately four

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centuries ago, native forest was the dominant forest type. As a result of natural and anthropogenic disturbance, a proportion of native forest was converted to three additional forest sub-types: secondary, monoculture, and Leucaena forests. Forests were defined and characterized using the classification of landcover types for the Mariana archipelago developed by Amidon et al. (2017). Currently, forests occur on all islands in the archipelago, except for Farallon de Medinilla due to extensive bombing during military operations and continuing volcanic activity on Uracas. The main stressors to forests are invasive species, development, volcanic eruptions, typhoons, and fire. Ongoing conservation efforts include biosecurity measures, protected area and species management, invasive species control, and existing laws and regulations. Forest viability, defined as the likelihood of persistence over the long term, is described based on the concepts of representation, redundancy, and resiliency. We developed four plausible future scenarios, each differing in levels of natural resource management, to evaluate the status of forests into the foreseeable future. Two of the scenarios, which are based on no change in conservation actions (Scenario One; status quo) and a slight increase in conservation actions (Scenario Two) have the highest likelihood of occurring in the foreseeable future while the other two, which are based on a slight to moderate decrease in conservation actions (Scenario Three) and a moderate to large increase in conservation actions (Scenario Four) do not. Scenario One would continue to degrade and fragment native forests and result in reduced resiliency, redundancy, and representation. In Scenario Two, the slight improvements in conservation actions would result in a moderate increases in resiliency, redundancy, and representation.

Mariana Islands Forest

Introduction

The Mariana archipelago consists of 15 main islands and various small islets spanning a north-south distance of 890 kilometers (km) in the western Pacific Ocean between latitudes 21° and 13°N and longitudes 144° and 146°E. The vast majority of the archipelago's land area is concentrated in the larger, southern main islands, including Saipan, Tinian, Rota, and Guam.

We provide an overview of the forest ecoregion in the Mariana archipelago and describe the ecological factors that have influenced this biome over time and into the future. Forests occur on all islands in the archipelago, except for Farallon de Medinilla due to extensive bombing during ongoing military operations and continuing volcanic activity of Uracas. A thorough introduction of the geography, geology, climate, hydrology and descriptions of the islands in the Marianas archipelago are described in the Physical Geography of the Mariana Archipelago by Harrington et al. (2019).

Description

Here we use the definition of a forest as a plant community characterized by vegetation with >25% cover in trees (a woody perennial that usually has a single trunk) (Gagne and Cuddihy, 1999). We defined and characterized Mariana forests using the landcover types for the Mariana archipelago described by Amidon et al. (2017). The 2017 study incorporated existing classification systems by the National Oceanic and Atmospheric Administration (NOAA) and U.S. Forest Service (Liu and Fisher, 2006a,b; NOAA, 2017) with additional imagery data to delineate a total of 23 vegetation types in six major landcover types (biomes). Ten vegetation types associated with the forest biome were then grouped into the four Marianas forest sub-types: native, secondary/mixed, monoculture, and *Leucaena leucocephala* or tangantangan, hereafter referred to as "Leucaena" described in the Current Condition section.

Geology

The six southern islands are geologically older than the nine northern islands, and due to complex plate uplifting, contain large areas of limestone substrate and areas volcanic in origin. The islands are characterized by plateaus ringed by a series of steep escarpments (Young, 1989). Limestone areas have shallow, highly weathered soils with an abundance of calcium (Donnegan et al., 2011). Guam, Rota, Aguiguan, Tinian, and Saipan exhibit well-developed, deep soils where the underlying volcanic parent materials have been exposed and weathered. The abundance of calcium in the limestone and coral sand on these landscapes creates soils that are inherently more fertile than volcanic soils (Donnegan et al., 2011).

All of the northern islands, from Anatahan to Uracas, are stratovolcanoes comprised mostly of hardened lava, tephra and volcanic ash, and are characterized by steeply sloping topography, both above and below the ocean's surface (Brainard et al., 2012). Periodic, explosive volcanic eruptions occur on the islands, with the most recent major eruptions occurring at Uracas in 1967, Pagan in 1981, and Anatahan in 2003 (Global Volcanism Program, 2013). While deep, soil developed on volcanic parent materials has low fertility, most of which resides in the topsoil.

Physical/life history components

Water availability and climate

Climate in the Mariana archipelago is classified as "tropical rainforest" (according to the Koeppen climate classification) with seasonal monsoons (Ohba, 1994). Moderate temperatures, ranging between 30 °C and 22.8 °C and constant trade winds create stabile conditions. Precipitation averages 96 in (218 cm) per year, dependent in part on elevation, with a rainy season between July and October, and a drier season from November through June, with April characteristically being the driest month of the year

(Ohba, 1994; Mueller-Dombois and Fosberg, 1998). During the dry season, brisk east and northeast trade winds dominate the western Pacific Ocean (Eldredge, 1983), while slower east and southeast trade winds occur during summer months. An average of at least one tropical cyclone per year impacts the Mariana archipelago, typically during the summer months as they move from east to west.

Vegetation structure and composition

Forests in the Marianas are characterized by a closed canopy of broadleaf trees with an understory of younger trees, vines, epiphytic ferns, and orchids (Stone, 1970; Vogt and Williams, 2004). It is usually composed of tall trees (10+ meters (m)) that comprise the upper canopy, small to mid-size trees (3–10 m) as a mid-story, and shrubs and herbs that form the understory (Falanruw et al., 1989a,b). Undergrowth can be sparse in densely shaded areas but may contain ground herbs, shrubs, ferns, and small trees of varying heights in areas with more open canopy.

The Marianas are one of the highest risk areas in the world for typhoons (Marler, 2001). Many plant species evolved to avoid catastrophic damage from these storm events by having leaves which are easily removed during high wind. This is far less damaging than uprooting or the breaking of major branches. Most native woody perennial plants recover fairly rapidly following typhoon damage, provided that they remain well-rooted and the major scaffold system of the canopy remains intact (Marler, 2001).

Biodiversity/biotic components

The Marianas, situated in Micronesia, lies within the Polynesia-Micronesia bioregion recognized as a global biodiversity hotspot (Conservation International, 2019). A comprehensive study of the endemic plant species in Micronesia indicate that the region contains the highest percentage of plant endemism per kilometer out of globally recognized insular biodiversity hotspots (Costion and Lorence, 2012). The combination of old age and close proximity to continental land masses of some of the Micronesian islands has enabled them to accumulate a very high richness of distinct plant lineages compared to more remote archipelagos such as Hawaii. The Marianas possess a level of richness measured by endemic plants per square kilometer (5%; 54 endemics/1007 total species) somewhat below the average for the region (14%; 364/2628), but on par with other island groups recognized for their biodiversity (Hawaii at 4%, Fiji and Samoa at 5%, and Marquesas and Society Islands at 6%).

Forests in the Marianas provide habitat for several endemic vertebrate species including the Mariana fruit bat (*Pteropus mariannus mariannus*), Micronesian megapode (*Megapodius laperouse*), and the Mariana crow (*Corvus kubayari*). Many of these native vertebrate species are known to be important pollinators and/or dispersers of seeds for the native forest plant species. Without seed dispersing vertebrates, plants would deposit their seeds directly below themselves with little expectation of successful reproduction due to low light, competition with more established plants and high seed density.

Several endemic invertebrate species such as the fragile tree snail (*Samoana fragilis*), humped tree snail (*Partula gibba)* and Guam tree snail (*Partula radiolata*) occur in the cool, shaded forest habitat with high humidity and reduced air movement (USFWS, 2015a). These invertebrates feed primarily on dead or decaying plant material recycling nutrients near the bottom of the food chain (Cowie, 1992). This recycling creates chemical nutrients that are released back into the soil, air and water and become available for new growth.

Pre-Human Condition

Forest Sub-types

Marianas forests likely began as strand vegetation (small plants that hold the soil and are tolerant of wind, salty air, and waves) that dispersed from elsewhere to isolated shores via the sea, and inland plant species blown by air currents to the islands' slopes and mountains. These initial plant species evolved to create distinct species adapted for newly encountered niches including the limestone substrate. In addition, seed dispersers such as bats or migrating birds are likely responsible for carrying some species to the islands, and during the evolution of the plant fauna, new species were continually making their way to the island chain (Berger et al., 2005).

Before human settlement occurred on the Marianas, forests had probably reached their climax of primary succession. Forested areas were likely well distributed on the southern islands of Guam, Rota, Aguiguan, Tinian, Saipan, and Farallon de Medinilla, and likely covered the majority of the landmass (Reeves and Amidon, 2018). Conversely, the northern islands are much younger geologically, and many have large areas of barren lava or lack the kind of soils needed to support forests (Ohba, 1994). The species found in the pre-human forest in the southern islands included, but were not limited to: *Ficus*, *Elaeocarpus*, *Mammea*, *Guamia*, *Cynometra*, *Aglaia*, *Premna*, *Pisonia*, *Ochrosia*, *Neisosperma*, *Intsia*, *Melanolepis*, *Eugenia*, *Pandanas*, *Artocarpus*, *Hernandia*, and others (Engbring et al., 1986). In the native forest found on the northern islands, predominant plant genera included *Aglaia*, *Pandanus*, *Terminalia*, *Trema*, *Morinda*, and *Erythrina* (Liske-Clark, 2015). Several of the trees and shrubs within these groups, including *Artocarpus mariannensis*, *Pandanus tectorius, and Terminalia catappa* are endemic or indigenous and produce fruit that provide food for wildlife such as the Mariana fruit bat (Vogt and Williams, 2004).

Forest Viability of Pre-Human Conditions

The viability of Mariana forests depended on maintaining multiple and distributed occurrences (redundancy) of sufficient quality and size (resiliency) with species richness and genetic diversity (representation) to survive across the Mariana archipelago over time.

Native forests likely recovered quickly from storms and were widespread across many islands and appeared to be well-represented. The ecologically healthy, or viable, forests that existed throughout the Marianas prior to human contact likely maintained natural connections between system components. Native biota that was historically characteristic of Mariana forests filled environmental niches necessary to sustain the habitat. It can be assumed that in the less volcanically active southern islands, forests reached their carrying capacity and were spread across the islands with a high level of land coverage. Conversely, in the northern volcanic islands, the frequency and intensity of volcanic eruptions likely had catastrophic impacts to forest vegetation and replaced suitable soils with volcanic rocks which made it difficult for new forest plants to colonize. This delayed or prevented succession into native forest as seen on areas of all of the northern islands.

Reproductive strategies of forest species, such as fruit and seed dispersal by birds and fruit bats, encouraged representation on all islands that supported those dispersing species. In addition, the presence of fruit-eating animals such as birds and fruit bats benefited plant recruitment by increasing germination during gut passage and moving seeds away from conspecifics, thereby creating more resilient forest systems (Egerer et al., 2018). Overall, the high diversity of plant species and seed dispersers within native forests in the Marianas likely improved the ability of these forests as a whole to survive stochastic or even catastrophic events.

Table 1 summarizes the viability of Mariana forests in its pre-human condition based on what is known about these forests in their native state.

Current Condition

Forest Sub-types

Prior to the arrival of humans approximately four centuries ago, native forest was the dominant forest type in the Marianas. As a result of natural and anthropogenic disturbance, a proportion of native forest was converted to three additional forest sub-types: secondary, monoculture, and Leucaena forests. A summary of current Mariana forest sub-types, dominant canopy species, and distribution across the archipelago follows in Table 2 (Fig. 1).

Current Forest Extent/Range

Native forest

In its current condition, native forest covers approximately 38,288 ac (15,495 ha) or 15% of the land area in the Marianas (Reeves and Amidon, 2018). In the southern islands, native forest is predominantly restricted to limestone substrate (25,347 ac (10,258 ha)) with the exception of native volcanic forest on Guam (8576 ac (3471 ha)). In the northern islands, native forest is represented only by volcanic forest (3542 ac (1433 ha)) and hibiscus thicket (590 ac (239 ha)). The impacts of nonnative species and human colonization have greatly influenced the quality and quantity of native forests throughout a majority of the archipelago. Only the islands of Guguan, Asuncion, Uracas, and Maug have been left relatively undisturbed, however relatively recent volcanic eruptions has limited the amount of native forest established on these islands.

Southern Islands

Approximately 90% (13,821 ha) of native forest can be found in the southern islands with the most area on Guam (8769 ha) and Rota (4068 ha), followed by Tinian (432 ha), Aguiguan (380 ha), and Saipan (173 ha). Native forest represents a significant portion of the islands of Rota (47%) and Aguiguan (55%), but less than 17% of Guam, less than 5% of Tinian and 2% of Saipan. The decline in the quantity of native forests on Guam, Tinian, and Saipan largely occurred from clearing for agriculture, residential, commercial and military development (Liske-Clark, 2015; USFWS, 2015a,b). Nevertheless, native forest still occurs along the edges and tops of cliff sides, in steep ravines, and other rugged karst terrain.

Although Rota and Aguiguan still contain large tracts of native forest, the high number of feral ungulates on both islands impedes recruitment of native plants by browsing on new growth and seedlings. The reduction in new growth and recruitment makes the native forests on these islands less able to recover from stochastic and catastrophic events (decreased resiliency and redundancy). The introduction of the brown tree snake had a profound effect on the forests of Guam by predating on and completely wiping out a majority of the forest birds on the island, which served as important pollinators and seed dispersers for the forests. Some native forest seeds need to pass through the gut of a bird to germinate, therefore islands with healthy bird populations (Rota, Tinian, and Saipan) have more intact forests than Guam (Rogers, 2011). A decline in fruit bat populations may

Table 1 Assessment of native forest resiliency, redundancy, and representation of forests in the Mariana Islands prior to human contact.

Forest type	*Resiliency*	*Redundancy*	*Representation*
Native forest	High	High	High

Table 2 Mariana archipelago forest subtypes with associated vegetation types, dominant species, and brief descriptions (Amidon et al., 2017; Reeves and Amidon, 2018).

Forest subtype	*Vegetation Types*	*Dominant species (Common name)*	*Characteristics*	*Island*														
				Agr	*Agu*	*Ala*	*Ana*	*Asu*	*FDM*	*Gua*	*Gug*	*Mau*	*Pag*	*Rot*	*Sai*	*Sar*	*Tin*	*Ura*
Native	Native Limestone Forest	Canopy species include: *Elaeocarpus joga* (joga), *Pisonia grandis (umumu or umomo)*, *Hernandia labyrinthica* (oschal), *Hernandia sonora* (nonak or nonag)*, Ficus prolixa* (nunu), *Macaranga thompsonii* (pengua), and *Intsia bijuga* (ifit)	Forest on limestone substrate with a canopy dominated by native tree species. Includes forests of varying age classes. Dominant canopy species can vary by island and region of island.		■					■				■	■		■	
	Native Volcanic Forest	Canopy species include: *Pisonia grandis (*umumu or umomo*)*, *Hernandia sonora* (nonak or nonag)*, Barringtonia asiatica* (putting), *Pandanus tectorius* (kafu), and *Terminalia catappa* (talisai).	Forest on volcanic soil substrate with a canopy dominated by native tree species. Includes forests of varying age classes and is primarily found in the northern volcanic islands of the CNMI and volcanic soil regions of southern Guam.	■				■		■	■	■				■		
	Hibiscus Thicket	*Hibicus tiliaceus* (pago)	Found throughout the archipelago around wetlands, along streams, and in interior areas	■		■	■	■		■		■	■	■	■	■		
Secondary	Mixed Introduced Forest	Canopy species can include combinations of coconut, ironwood, tangantangan, *Spathodea campanulata* (African tulip tree), *Delonix regia* (flame tree), *Acacia confusa* (sosugi), *Albizia lebbeck* (trongkon-kalaskas), *Pithecellobium dulce* (kamachile), and *Samanea saman* (trongkon-mames or monkeypod)	All forests dominated by non-native species. May include components of other forest subtypes. Mixed in composition, not dominated by a specific non-native species.		■	■	■			■			■	■	■	■	■	
	Vitex Forest	*Vitex parviflora*	Large stands occur in northern Guam							■								

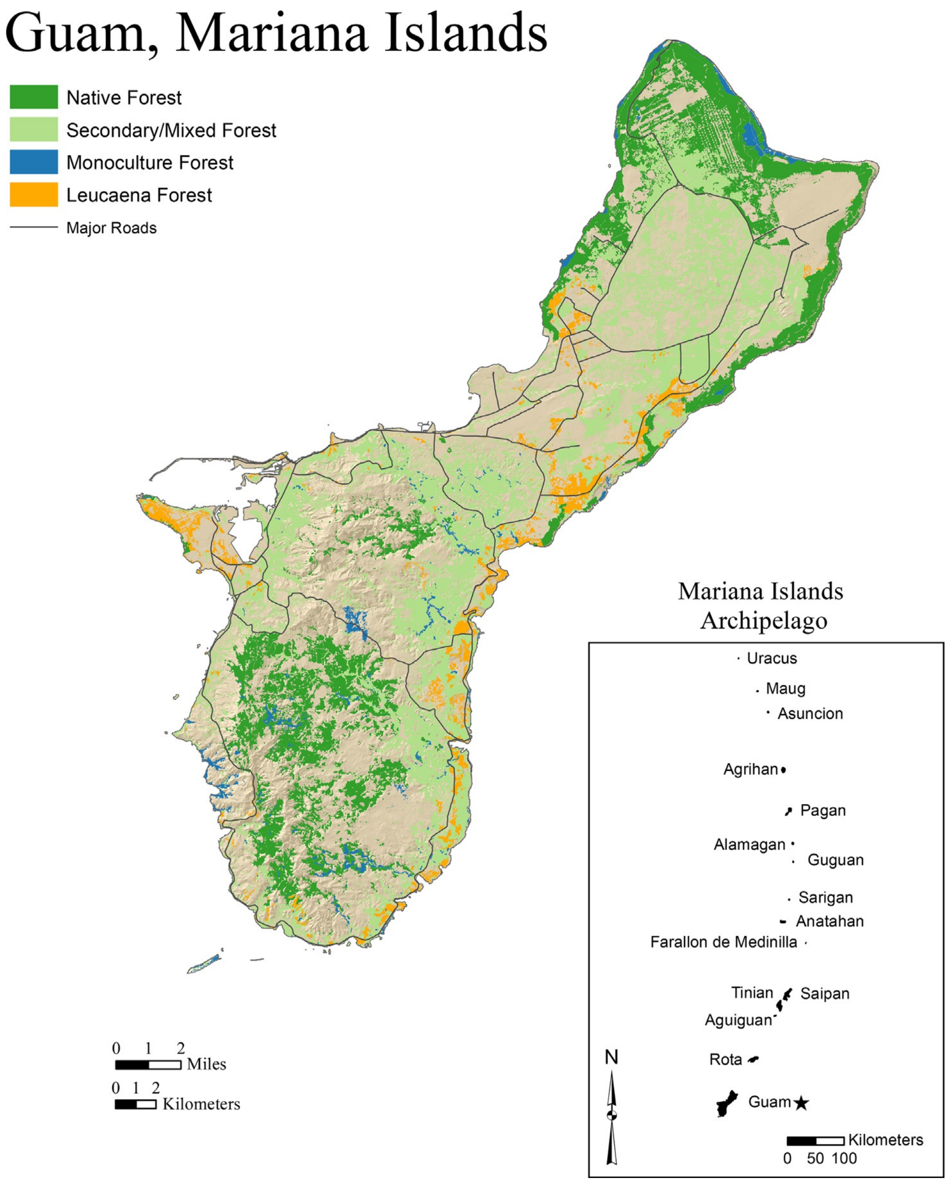
(*Continued*)

Table 2 (Continued)

Forest subtype	*Vegetation Types*	*Dominant species (Common name)*	*Characteristics*	*Island*														
				Agr	*Agu*	*Ala*	*Ana*	*Asu*	*FDM*	*Gua*	*Gug*	*Mau*	*Pag*	*Rot*	*Sai*	*Sar*	*Tin*	*Ura*
Monoculture	Coconut Forest	*Cocos nucifera* (coconut)	Former coconut plantations. Found on limestone and volcanic substrates.	■		■	■	■		■		■	■	■	■	■	■	
	Casuarina Forest	*Casuarina equisetifolia* (ironwood)	Along shorelines and throughout the interior of an island. Found on volcanic and limestone substrates.	■	■					■			■	■	■		■	
	Bamboo Thicket	*Bambusa vulgaris* (bamboo)	Along streams and near wetlands, however, can also occur throughout the interior of an island.							■					■		■	
	Acacia Forest	*Acacia auriculiformis* and *Acacia mangium*	Found on volcanic substrates in the badlands on southern Guam.							■								
Leucaena	Leucaena Thicket	*Leucaena leucocephala* (tangantangan)	Associated with previously cleared areas and often forms monotypic stands. Found on limestone and volcanic substrates.	■	■					■			■	■	■	■	■	

Shading indicates occurrence of forest.

Island abbreviations: *Agr*, Agrihan; *Agu*, Aguiguan; *Ala*, Alamagan; *Ana*, Anatahan; *Asu*, Asuncion; *FDM*, Farallon de Medenilla; *Gua*, Guam; *Gug*, Guguan; *Mau*, Maug; *Pag*, Pagan; *Rot*, Rota; *Sai*, Saipan; *Tin*, Tinian; *Ura*, Uracas.



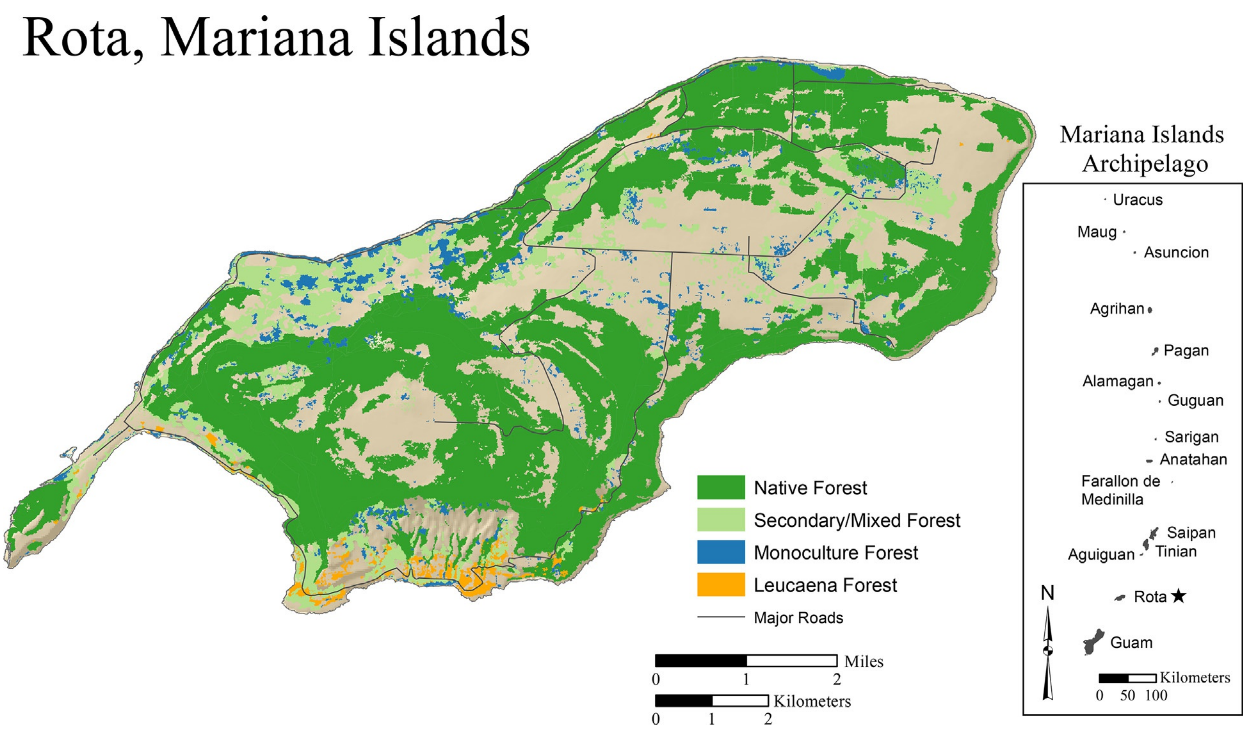


Fig. 1 (A–F) Current distribution of forests in the Mariana archipelago (Reeves and Amidon, 2018).

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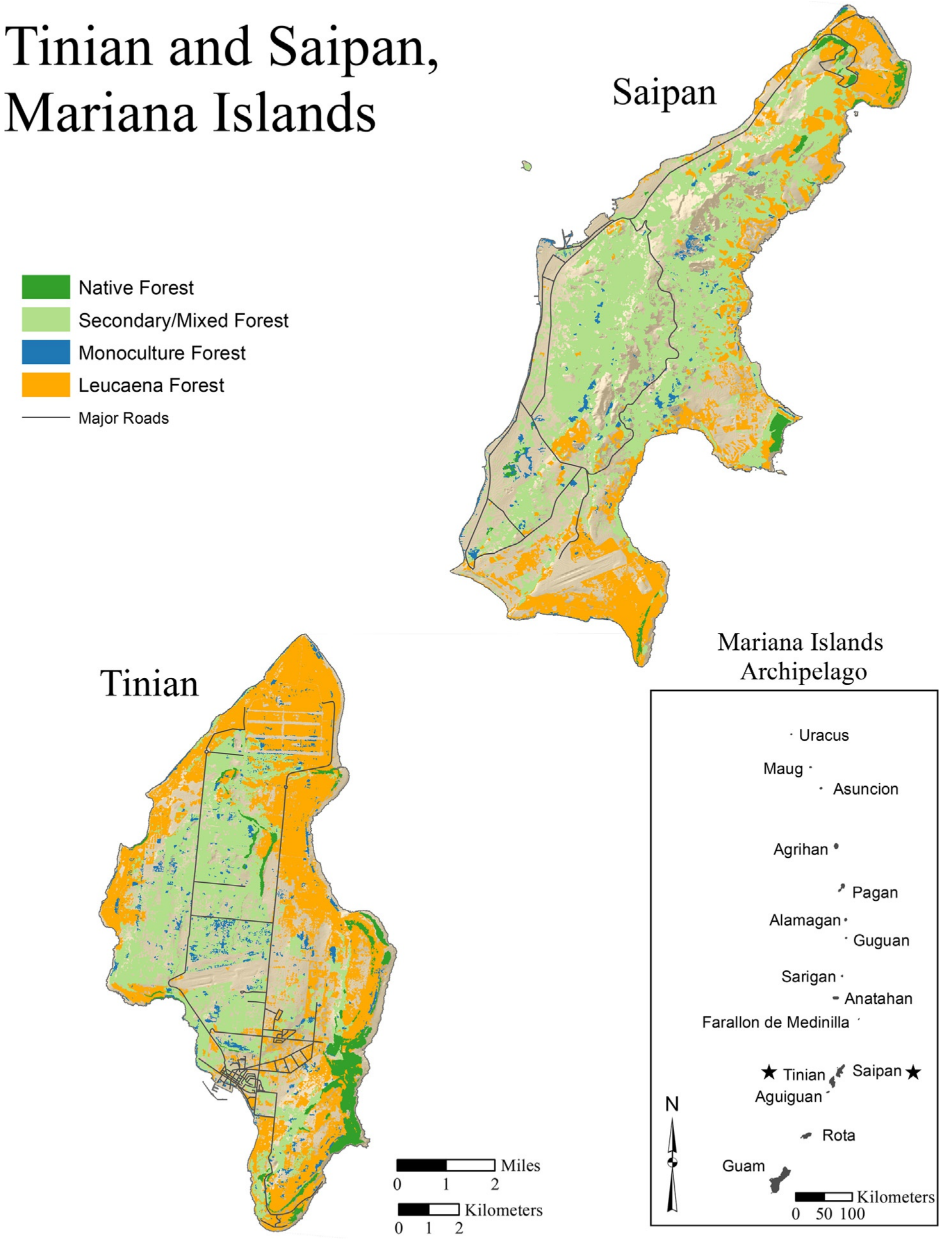
Tinian and Saipan,
Mariana Islands
Saipan
Native Forest
Secondary/Mixed Forest
Monoculture Forest
Leucaena Forest
Major Roads
Tinian
Mariana Islands
Archipelago
Uracus
Maug
Asuncion
Agrihan
Pagan
Alamagan
Guguan
Sarigan
Anatahan
Farallon de Medinilla
Tinian
Saipan
Aguiguan
N
Rota
Guam
Kilometers
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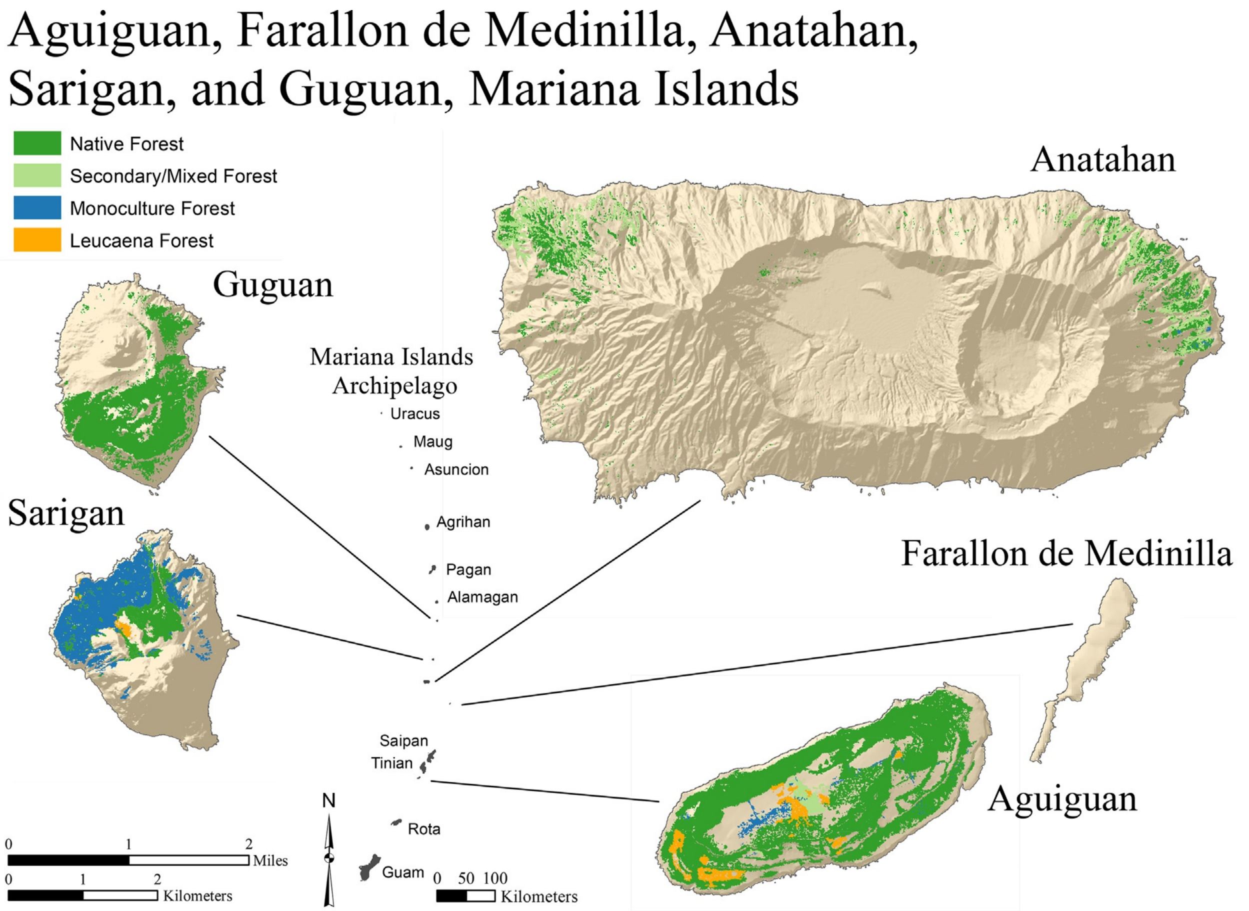
Fig. 1, Cont'd


Aguiguan, Farallon de Medinilla, Anatahan, Sarigan, and Guguan, Mariana Islands
Native Forest
Secondary/Mixed Forest
Monoculture Forest
Leucaena Forest
Anatahan
Guguan
Mariana Islands Archipelago
Uracus
Maug
Asuncion
Agrihan
Pagan
Alamagan
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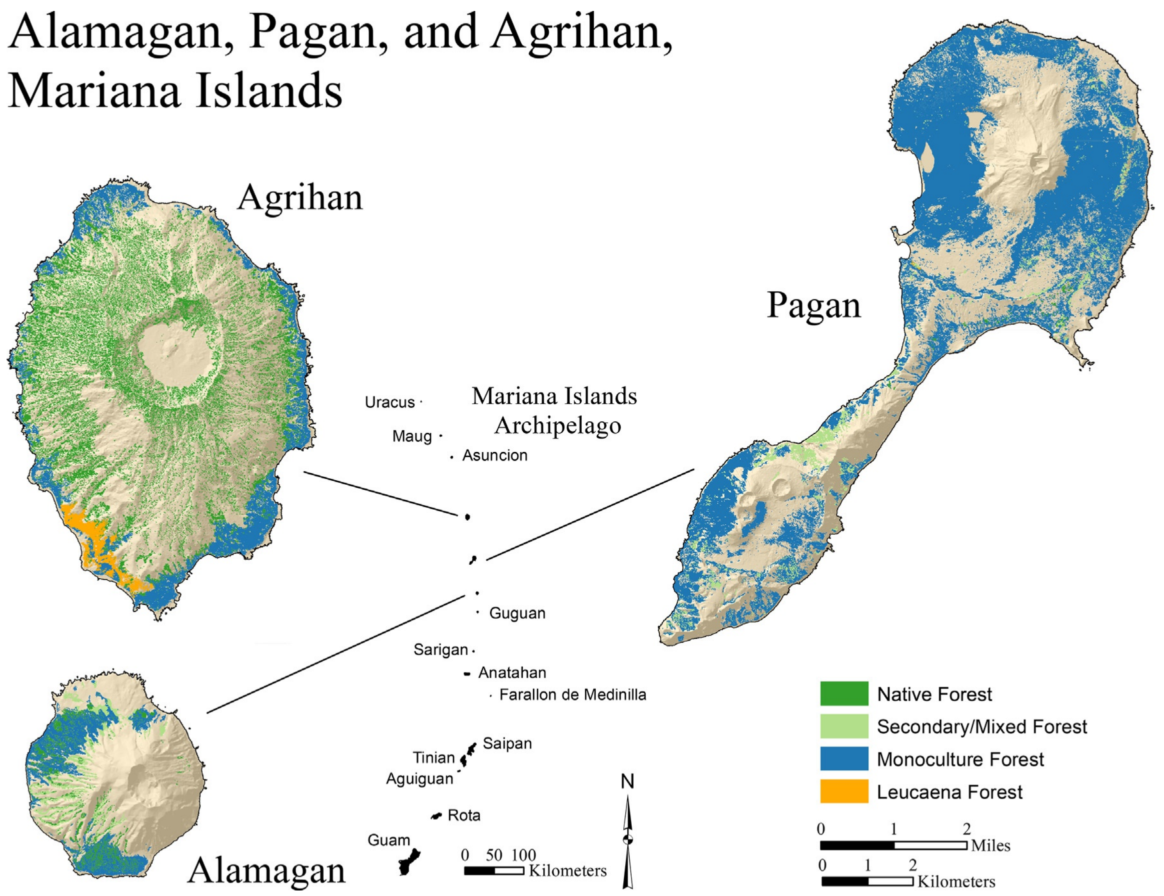
Alamagan, Pagan, and Agrihan, Mariana Islands
Agrihan
Pagan
Mariana Islands Archipelago
Uracus
Maug
Asuncion
Guguan
Sarigan
Anatahan
Farallon de Medinilla
Saipan
Tinian
Aguiguan
Rota
Guam
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Native Forest
Secondary/Mixed Forest
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Leucaena Forest
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Fig. 1, Cont'd

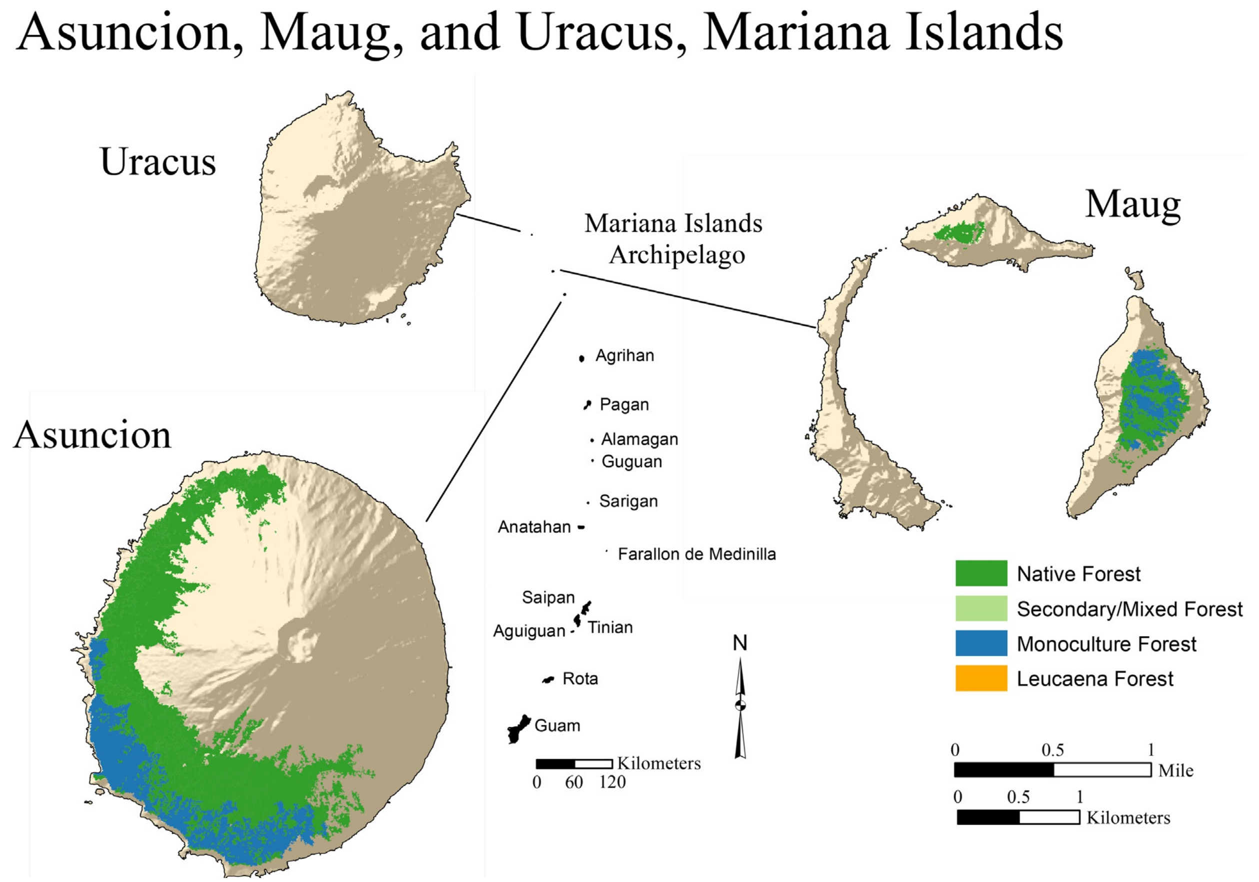

Fig. 1, Cont'd

have had an impact on the recruitment of forest trees with large seeds such as *Cycas micronesica*. Feral pigs and deer have also been found to act as seed dispersers, although feral ungulates have been found to selectively disperse native species (Gawel et al., 2018).

There are now several nonnative tree, shrub, and vine species that are found in native forests that colonize the forest edge and become established in disturbed areas. The colonization of these plants into the native forests has reduced the habitat quality and converted large swaths of the native forests in the islands most disturbed by humans further reducing resilience and redundancy of native forests (Figs. 2 and 3).

Northern Islands

Approximately 10% of native forest (1672 ha) in the Marianas can be found in the northern islands, comprised of 1433 ha of volcanic forest and 239 ha of hibiscus thicket. Native forest distribution, abundance, and quality varies among the northern islands largely based on the level of impacts from feral ungulates, copra production, and volcanic activity. Forests on islands such as Anatahan, Sarigan, Alamagan, Pagan, and Agrihan have been greatly affected by the introduction of ungulates. The recent volcanic eruptions on Anatahan and Pagan resulted in the loss of large tracts of native forest. Guguan, Asuncion and Maug did not have ungulates introduced and remain relatively unaffected by volcanism as well leaving their forests relatively intact.

Secondary forest

Secondary forest presently covers approximately 21,231 ha or 21% of the land area in the Marianas (Reeves and Amidon, 2018). Secondary forest is one of the most common forest types on the more developed southern islands such as Guam, Tinian, and Saipan due to a history of disturbance by humans. Aguiguan, Rota, and some of the northern islands (Anatahan, Alamagan, and Pagan), have smaller areas of secondary forest, while the islands that were not colonized by humans have little to none.

Secondary forest is composed of a mixture of native and nonnative species representing forests recovering from disturbance; native forests invaded by nonnative species or forests that are establishing in disturbed areas from a mix of seed sources (Liske-Clark, 2015). As such, secondary forests are generally dominated by nonnative species, but may include components of other forest types. Natural disturbances such as typhoons or drought can result in the loss of mature trees but the understory often remains intact,

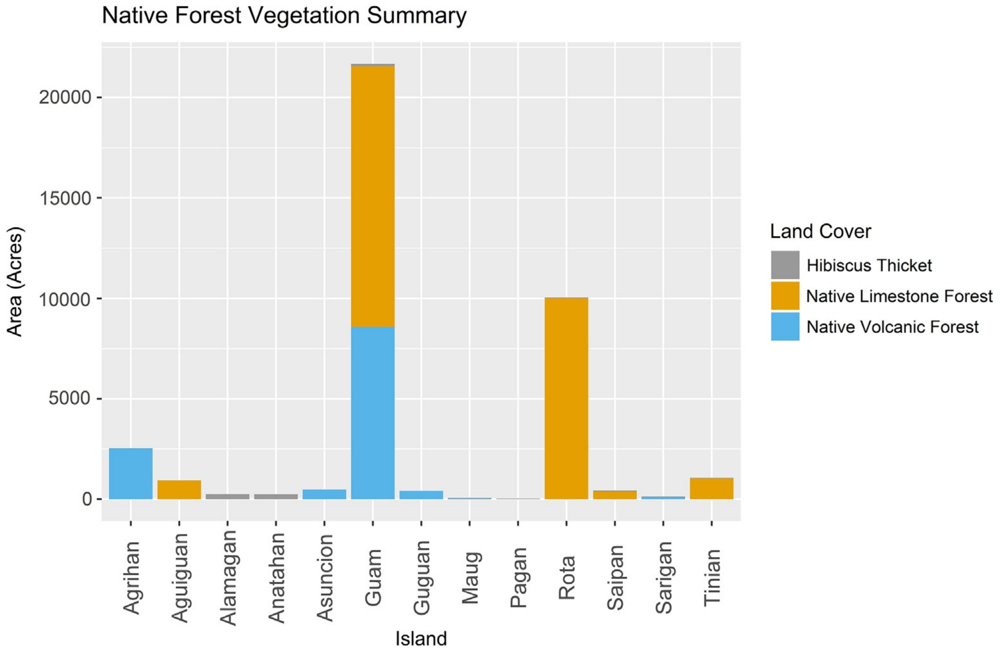

Fig. 2 Native forest vegetation summary with land cover types (Reeves and Amidon, 2018).

Fig. 3 Native forest on karst limestone terrain, Marpi, Saipan. Photo by Tyler Willsey.

while man made disturbances such as land clearing and fire usually result in conversion to bare ground. During World War II, large portions of Guam, Tinian, and Saipan were destroyed during intense bombing or cleared for the development of military infrastructure. This resulted in major losses to native forest. Following disturbance, hardy and low-growing grasses and herbs colonized this bare ground. In time, shrubs, small trees, and seedlings of tall forest trees grow and soon overtop the grasses and herbs, forming a secondary forest. Major forest loss during World War II, and the introduction of nonnative plant species which outcompete natives led to the establishment of secondary forest currently found on large portions of Guam, Tinian, and Saipan.

Secondary forest tends to have a more open canopy, generally below 10 m in height, and a dense understory. Secondary forest is often composed trees such as *Albizia lebbeck*, *Cynometra ramiflora*, *Ficus prolixa*, and a thick understory of native and introduced shrubs, vines, and grasses (Falanruw et al., 1989a,b) (Figs. 4 and 5).

Monoculture forest

Monoculture forest presently covers approximately 4688 ha or 5% of the land area in the Marianas (Reeves and Amidon, 2018). Monoculture forests are described as those planted by people for agricultural purposes or areas solely consisting of ironwood trees (*Casuarina equisetifolia*). Historically, large plantations of coconuts, for copra production (kernel of the coconut where oil is

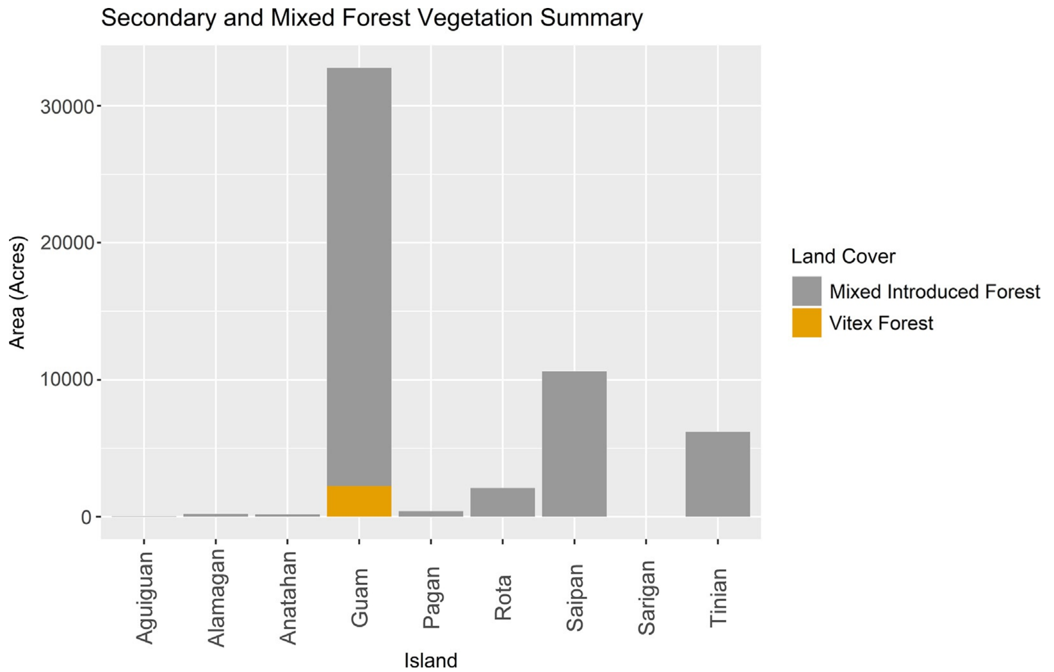

Fig. 4 Secondary forest vegetation summary with land cover types (Reeves and Amidon, 2018).

Fig. 5 Secondary forest in Navy Hill, Saipan. Photo credit: Tyler Willsey.

extracted), were planted and managed on several islands, including Anatahan, Sarigan, Alamagan, and Agrihan until the 1940s. It is likely that all areas of coconut monocultures were man-made, and not formed by coconuts being washed ashore in great numbers (Mueller-Dombois and Fosberg, 1998). In addition to coconut monoculture forests, mango (*Mangifera*), betel nut (*Areca catechu*), and citrus (*Citrus* sp.) monoculture forests are found on the islands where larger human populations exist such as Guam, Rota, Tinian, and Saipan. In these forests, the trees tend to all be the same height, as they were usually planted at the same time, and in rows. If the farm is actively being worked, the understory will typically be solely small herbaceous plants and grasses. The ground within coconut plantations is often filled with thick cordlike roots that prevent most other large woody plant species from growing (Mueller-Dombois and Fosberg, 1998).

In addition to agricultural monoculture forest, other monoculture forests in the Marianas exist because of allelopathic properties of certain species of trees such as ironwood (*Casuarina equisetifolia*). The long needle shaped leaves cover the forest floor, smothering other plants, and have been found to have allelopathic tendencies to prevent other species' seeds from germinating (Wheeler et al., 2011). An ironwood forest typically has a single tree species and very limited understory. Currently, large expanses of iron wood monoculture forest occur on the islands of Guam, Tinian, and Pagan (Figs. 6 and 7).

Leucaena forest

Leucaena or tangantangan (*Leucaena leucocephala*) forest presently covers approximately 7768 ha or 8% of the land area in the Marianas (Reeves and Amidon, 2018). The southern islands of Guam, Tinian, and Saipan have vast areas of Leucaena forest, while Rota and Aguiguan only have a few stands (Vogt and Williams, 2004). Leucaena was not introduced to the northern islands so Leucaena forests do not exist north of Saipan. Leucaena was first observed on Tinian in 1946, although it is uncertain exactly when and how Leucaena was introduced to the Marianas and Tinian or whether it was intentional or inadvertent (Fosberg, 1980, unpublished report, as quoted in Hawaiian Agronomics 1985). It is possible that the U.S. military broadcast seeds of Leucaena and other plants from planes in an attempt to reduce erosion (Guam Division of Aquatic and Wildlife Resources (DAWR), 2006, Marler and Moore, 2011). Because of its rapid growth, and possibly allelochemical attributes (the ability to inhibit surrounding, competing plant growth) once established, it quickly forms dense thickets that crowd out native vegetation (Little and Skolmen, 1989). Consequently, Leucaena is considered highly invasive in many parts of the world including in the tropical Pacific and the Hawaiian Islands. On some islands, Leucaena has formed large areas of dense forest which, due to its small leaves which allow bright sunlight to reach the forest floor, produces a xeric (containing little moisture) understory (Hopper and Smith, 1992) (Figs. 8 and 9).

Stressors

Historic Habitat Loss and Destruction

Since the arrival of humans in the Mariana archipelago, there has been ongoing degradation and impacts to native forests from hundreds of nonnative plants and animals, resulting in various rates of conversion to secondary, monoculture, and Leucaena forests

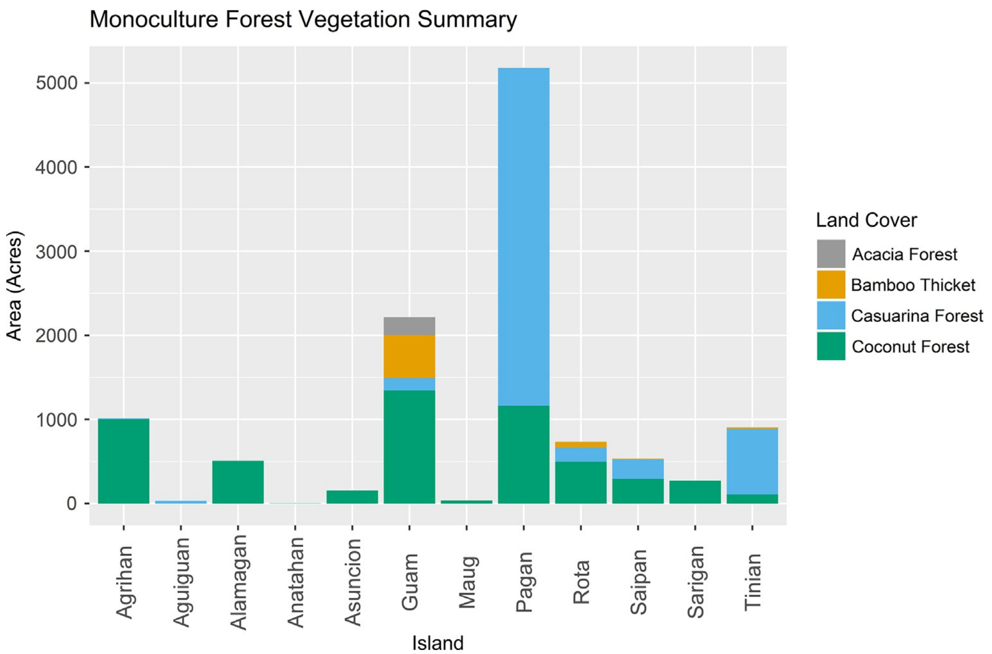

Fig. 6 Monoculture forest vegetation summary with land cover types (Reeves and Amidon, 2018).

Fig. 7 Betel nut (*Areca catechu*) monoculture forest on the island of Saipan. Photo credit Tyler Willsey.

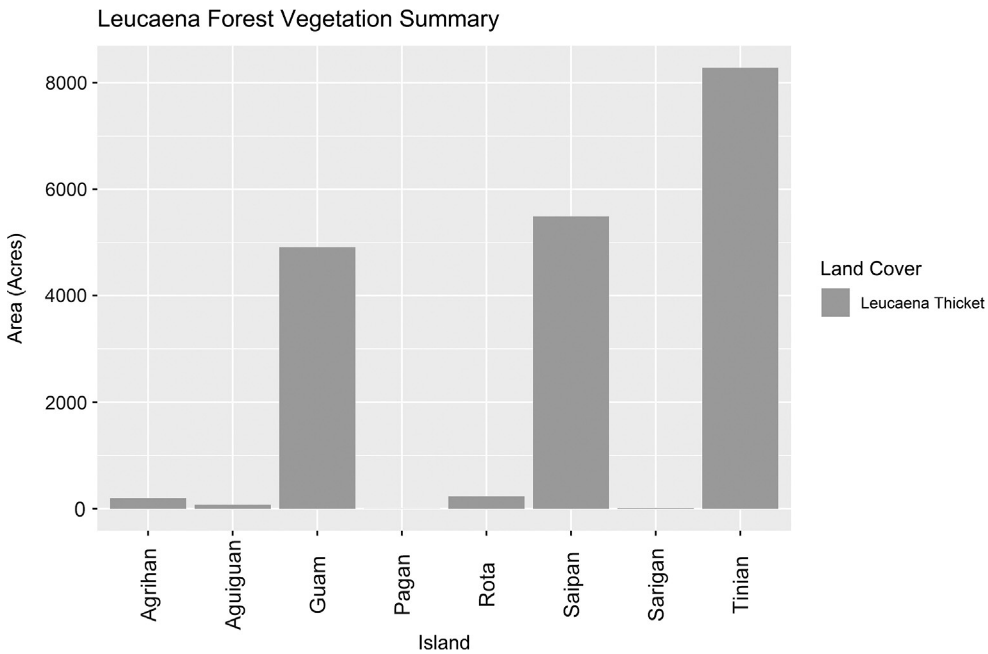

Fig. 8 Leucaena Forest Vegetation Summary with vegetation types (Reeves and Amidon, 2018).

in many areas. Archeological excavations indicate aboriginal human populations, including the Chamorro peoples, arrived in Micronesia 2000–4000 years ago and initiated major alterations to the native forests through a variety of activities such as the clearing of lands for agriculture. The human population during this initial period was relatively high compared to the islands' populations today and may have reached 20,000 on Tinian alone (Farrell, 1992). Studies of the pollen record strongly suggest human activities had transformed native forest into savanna over broad areas of the interior upland areas of Guam as early as 2000 years ago (Athens and Ward, 2004).

Fig. 9 Leucaena forest on the island of Saipan, CNMI. Photo credit: Tyler Willsey.

The arrival of Europeans in the 16th century also caused widespread damage to the forests. Reports from the 1700s indicate that Tinian's original forests were largely destroyed during early efforts to develop cattle ranching (Fosberg, 1960; Barratt, 1988). Later, during the 18th century, Spanish governors depopulated residents from the island to maintain it as a large pasture for cattle used to supply meat to the Guam garrison (Farrell, 1992).

During the German occupation of the Marianas from 1899 to 1917, native forest on several islands was converted to copra (*Cocos nucifera*) production. Several of the northern islands including Anatahan, Sarigan, Alamagan, Pagan, and Agrihan were likely dominated by native forests, but much of the lower coastal slopes were converted to copra plantations during this time (Spoehr, 1957). Extensive copra plantations likely existed in the southern islands as well but those areas were cleared by war time activities or development so little evidence of the plantations remain. Between the years of 1917 and 1944, large swaths of land were converted to sugarcane (*Saccharum* spp.) on the southern islands of Rota, Aguiguan, Tinian and Saipan during the Japanese colonization of those islands (Spoehr, 1957).

Changes in forest distribution and composition continued during the considerable destruction that occurred during World War II. During this time, Guam, Rota, Tinian, and Saipan were heavily bombed prior to the landing of Allied forces in 1944. Following the initial bombings and weeks-long battles in the Marianas, the U.S. military quickly began to develop the islands to maximize their strategic potential. Extensive military infrastructure was constructed on Guam, Tinian, and Saipan. Although the full extent of habitat loss during WWII is difficult to determine, photos from the time period show extensive alteration to the landscape and native forests in general. For example, based upon some reports, between only 3% and 5% of Tinian's forest was estimated to remain on the island following the conclusion of wartime activities (Engbring et al., 1986).

Invasive Species

Invasive species have had tremendous impacts upon the habitats in the Marianas. Table 3 lists the key invasive species known to be established in the Marianas that impact forests.

Forest degradation by invasive animals

Following the end of WWII, the widespread introductions of nonnative plants and animals accelerated with the advent of new and additional human activity and commerce. The brown tree snake (*Boiga irregularis*) (BTS) (Savidge, 1987) was inadvertently introduced to Guam following WWII and has caused the extirpation or extinction of forest birds on Guam (Savidge, 1987). The loss of the birds has caused significant effects within the forest, most notably the loss of a major seed dispersers (Egerer et al., 2018). Seeds from native trees that depend upon the birds for dispersal are no longer being moved. Therefore, seeds fall directly from the parent tree and sprout beneath, but the high density of seedlings causes almost complete mortality (Rogers et al., 2017; Egerer et al., 2018).

Table 3 Invasive species of concern in Mariana Islands forests.

Common name	*Scientific name*	*Primary species affected*	*Impacts to forest*	*Island impacted*
Coconut rhinoceros beetle (CRB)	*Oryctes thinocerosrhin overos*	Coconut palms	Loss of forest and brush cover and edible flowers (i.e., fruit bat)	Guam Rota
Cycad aulacaspis scale	*Aulacaspis yasumatsui*	Cycads	Loss of dominant native forest component	Guam Rota
Vines (Ivy Gourd, Bitter Melon, Mile-a-Minute, Mikania, Woodrose, Chain of Love)	*Coccinia grandis*, *Momordica charantia*, *Mikania scandens*, *Mikania micrantha*, *Merremia tuberos*, *Antigonon leptosus*	Native vegetation	Highly degraded forest by outcompeting other plants for resources such as water and sunlight. If left unchecked vines can smother full grown trees and prevent recruitment	Saipan, Tinian, Guam
Feral ungulates (goats and pigs, deer)	(*Capra hircus*, *Sus scrofa*, *Rusa marianna*)	All forest types	Dig up soils, facilitating erosion, compete with native species for resources, consume or otherwise destroy natural resources, spread pest species through moving seeds, soil compaction	Guam, Aguiguan, Tinian, Rota, Anatahan, Pagan, Agrigan
Rodents (black rats)	*Rattus rattus*	Native vegetation, prey on native and non-native fauna, including birds	Prevents recruitment, damage to crops, compete with forest birds for seeds/fruit	All Islands
Brown tree snake	*Boiga irregularis*	Prey on birds, reptiles	Without birds, the vegetation has reduced dispersal ability and germination success	Guam
Other non-native plants Lantana, Fountain grass, tangantangan, Bidens, Koster's curse, and Wedelia	*Lantana camara*, *Cenchrus setaceus*, *Leucaena leucocephala*, *Bidens alba*, *Clidemia hirta*, *Sphagneticola trilobata*	Native vegetation	Competition with native vegetation for space, light, water, and other resources	All islands

Native forests have also been severely degraded by the introduction of ungulates including cattle, deer, goats, and pigs on the islands of Guam, Rota, Aguiguan, Tinian, Saipan and several of the northern islands (Liske-Clark, 2015). On all of these islands, populations of feral ungulates browse the forest understory impeding recruitment and leading to increased erosion (Kessler, 2011). Aerial photos from before and after the introduction of pigs and goats on Sarigan and Anatahan illustrate the tremendous impacts of the browsing to forests (Kessler, 2011). Pigs were already established on Anatahan during the late 1890s (Fritz, 1902) and goats are thought to have been introduced in about 1960 (Reichel, 1988). From 1890 until 2002, approximately 2153 ha of forest was converted to swordgrass or bare ground by browsing ungulates on the island of Anatahan (CNMI, DFW, 2000). On Guam, invasive pigs and deer are known to have species-specific negative effects on seedling dispersal and recruitment. On Rota, deer in particular, are responsible for high seedling mortality rates thereby playing a major role in forest species structure and composition (Gawel et al., 2018).

Forest degradation by invasive insects

Coconut Rhinoceros Beetles (CRB) primarily impact coconut palms by boring into the crowns or tops of the tree damaging growing tissue and feeding on tree sap, potentially destroying the trees (CNAS, 2016). The CRB also feeds on a variety of other plant species including other palms, banana, pineapple, and sugarcane. Coconut trees have been heavily decimated on Guam where the CRB was first detected in 2005 and has since been found in Rota (CNAS, 2016). The loss of coconut palms may have direct negative consequences such as overall loss of forest cover.

The nonnative cycad aulacaspis scale (*Aulacaspis yasumatsui*) quickly causes mortality of all life stages of *Cycas micronesica* or fadang, an endemic species that was once dominant in the native limestone forests on Guam (USFWS, 2015a). It was introduced to Guam in 2003, possibly via importation of the landscape cycad, *Cycas revoluta* (Marler and Lawrence, 2012). In 2002, prior to the scale infestation, *C. micronesica* was the most abundant tree species on Guam (Donnegan et al., 2002). By 2005, the cycad aulacaspis scale had spread throughout the forests of Guam causing more than 90% mortality in once healthy populations in certain areas (Marler and Lawrence, 2012). To date, release of biocontrols to abate the scale infestation have been unsuccessful (USFWS, 2015a). In addition, three other insects a nonnative butterfly (*Chilades pandava*), a nonnative leaf miner (*Erechthias* sp.), and a native stem borer (*Dihammus marianarum*), opportunistically feed on *C. micronesica* weakened by the cycad aulacaspis scale, compounding its negative impacts (Marler, 2013). The significant ongoing loss of this once dominant component could result in a negative cascading effect for native limestone forests (Marler and Lawrence, 2012).

Forest alteration by invasive plants

The negative impacts of nonnative plants on forests are seen throughout a majority of the Marianas. The impacts include the alteration of the wildfire regime and the creation of large swaths of monotypic stands of nonnative species that outcompete and

crowd out native forest plant species. Historically and presently, the most likely source of introduction of nonnative plant species is inadvertent or intentional transport of soil, seeds, or plants intended for ornamental or farm use, often without knowledge of their deleterious effects (Space and Falanruw, 1999).

Over 100 plant taxa have been introduced to the Marianas, and at least one-third of these have become pests (i.e., injurious plants) (Stone, 1970; Mueller-Dombois and Fosberg, 1998). Of these approximately 30 nonnative pest plant species, at least nine species are known to be habitat-altering, including trees such as lantana (*Lantana camara*), grasses such as fountain grass (*Cenchrus* (=*Pennisetum*) *setaceus*), and tangantangan (*Leucaena leucocephala*) (Space et al., 2000).

The greatest risk posed by nonnative plant species in the Marianas is aggressive displacement of native species. One of the most invasive plants in the Marianas is lantana, a branched shrub up to 10 ft. (3 m) tall, first brought to the Marianas as an ornamental plant and first reported as naturalized on Tinian in 1930 (Space and Falanruw, 1999). Lantana is aggressive, thorny, and forms thickets, crowding out and preventing the establishment of native plants (Davis et al., 1992; Wagner et al., 1999). Recognized as a serious pest species in Micronesia by the 1940s (Denton et al., 1991), lantana was reported as abundant and widespread on the islands of Tinian and Aguiguan in the 1990s (Denton et al., 1991; Space and Falanruw, 1999). Ungulates can exacerbate the spread of lantana and other nonnative plants as has occurred on the island of Aguiguan, where goats facilitate lantana's spread by eating nearly everything else with the exception of lantana (Thaman, 1974; Denton et al., 1991).

Another nonnative plant species of concern is tangantangan, widely considered invasive in many parts of the world. Native to the neotropics, tangantangan is a nitrogen-fixing shrub and an aggressive competitor that often forms the dominant element of the vegetation (Geesink et al., 1999). It alters the chemistry of soils to its own benefit and this competitive advantage has allowed it to now cover approximately 29% of Tinian (Marler et al., 2016).

Additional invasive plant species are located on Rota, Tinian, Saipan, and Guam including ivy or scarlet gourd (*Coccinia grandis*), molasses grass (*Melinis minutiflora*), and fountain grass (*Pennisetum setaceum*) (Space et al., 2000), all of which often cause harm to forests where they are introduced through military or civilian activities. In 2004, more than one third of all trees in Saipan, Tinian, and Rota were affected by invasive vines which can grow into dense patches that smother and kill host trees by blocking out sunlight (Liske-Clark, 2015). Invasive vines also reduce light availability under the canopy, impacting understory plant species composition and the rate of forest regeneration. Furthermore, many nonnative species including lantana, molasses grass, and fountain grass alter fire ecology (Space and Falanruw, 1999) with detrimental effects on forests.

Forest Loss From Volcanic Activity

As noted previously, volcanism has historically caused periodic destruction of forests of the northern islands. For example, Anatahan's eruption in 2003 and Pagan's eruption in 1981 caused major alterations to the island's forests (Kessler, 2011). In particular, the large amount of ash and cinder produced by these events completely wiped out large sections of forest which are just now recovering by colonization from early successional species. At the north end of the archipelago, the island of Uracas still lacks native forest (or forest of any kind) due to being one of the most active volcanoes of the western Pacific. Additionally, the islands of Asuncion, Agrigan, and Guguan have all experienced eruptions since 1900 resulting in significant forest loss (Tanakadate, 1940).

Development

Development is a major factor impacting forests throughout the Mariana Islands. Since humans first arrived in the islands, forests and other land cover types have been cleared and modified for human activities. The U.S. military claimed nearly one-third of the lands on Guam after World War II and have modified large areas of former forest. Forest destruction continues with the military build-up, as roughly 862 ha of native and secondary forest are being converted into a Cantonment and a Live Fire Training Range (USFWS, 2017). As part of the rebalancing of military forces to the Asia Pacific region, the northern portion of Pagan Island and the northern two-thirds of Tinian Island are being considered for live fire ranges and training as part of the Commonwealth Joint Military Training (CJMT). The area leased by the military for CJMT is 6195 ha and contains roughly 4593 ha of forests (U.S. Navy 2017). Based on preliminary planning documents, the military does not intend to develop or clear the entirety of the area and large tracts of land will be preserved or even enhanced for wildlife usage. The CJMT build-up is still in its planning stage and areas of proposed development or clearing will likely change making it difficult to determine the amount of forests that will be impacted.

Commercial and residential development continues to have a significant impact on all land cover types in the southern inhabited islands. The direct clearing of land for both large and small scale projects often results in the permanent loss of forests. Guam is the most populated and developed of the islands. The increase in population from the military build-up will likely result in a corresponding increase in commercial and residential development which may impact forests. In the CNMI, there have been several periods of rapid development coinciding with increased tourism. Several large-scale resorts are proposed on both islands in areas that are primarily forested. On Rota, small scale development for homes or agriculture is common. The islands north of Saipan are either uninhabited or contain very small populations, however infrastructure in the northern islands has begun to allow for people to reside on Alamagan, Pagan, and Agrihan.

Typhoons

Typhoons and super typhoons have had major impacts on forests in the Marianas. Intense winds can defoliate trees, break primary branches, and uproot or topple trees. Forests can take several years to recover and during this time the habitat is susceptible to encroachment from invasive trees, shrubs, and vines (Marler, 2001). "Dry" typhoons have very little rainfall, causing salt water to be carried by the wind and deposited far inland. This causes the leaves on most dicot trees to wither and fall within 2 days of a storm and can cause mortality (Kerr, 2000). While some coastal land cover types are adapted to salt spray, native, secondary, monoculture, and Leucaena forests in the Marianas are heavily impacted. The salt spray kills large amounts of vegetation, which may not regenerate until rains have washed away the salt (Kerr, 2000). Most forest types typically recover and are refolliated within 1 year (Kerr, 2000), but the temporary change in canopy cover can allow for the encroachment of invasive plants.

Fire

Wildfire is very rare in the Marianas as most fires are typically caused by humans either intentionally for the clearing of land or unintentionally from improper disposal of lit cigarettes. In addition, some hunters on the southern inhabited islands start grassland fires to attract deer since deer forage on the new grass shoots following a fire, the exposure making them easier to hunt. The lack of rainfall during the dry season desiccates grasses, trees, and leaf litter providing additional fuel for fires. These fires, which are often set in the dry season, can spread and cause significant damage to adjacent forests converting these forests to bare ground and facilitating the colonization of invasive plants.

Climate Change

Climate change related stressors (i.e., increased precipitation, sea level rise, increased typhoon intensity and frequency) cause ongoing impacts to this and other land cover types. However, the magnitude of the impacts are not discrete events but occur continuously on a longer time scale. Therefore, we do not see climate change related stressors as the primary threat to the forests at this time.

Conservation Efforts

Impacts from stressors are addressed through various management approaches such as active (on-the-ground) management (i.e., predator and invasive species control, fencing, reintroduction, etc.), land protections, laws and regulations, and education and outreach. These approaches are implemented by numerous government agencies (federal, territorial, and commonwealth), private organizations, and non-governmental organizations (NGOs).

Federal

Endangered species act

The Endangered Species Act of 1973 (ESA) aims to provide a framework to conserve and protect endangered and threatened species and their habitats. As habitat loss is the primary threat to most imperiled species, the ESA allowed the U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS) to designate specific areas as critical habitat zones. In 1978, Congress amended the law to make critical habitat designation a mandatory requirement for all threatened and endangered species.

Approximately 3355 ha has been designated as critical habitat on Guam and Rota for four species (Mariana crow, Mariana fruit bat, Guam Micronesian Kingfisher, and the Rota bridled white-eye) under the ESA. On Guam, 152 ha of critical habitat was designated for the Mariana crow, Micronesian kingfisher, and Mariana fruit bat and is comprised of 97 ha of native forest and 30 ha of monoculture forest. On Rota, approximately 3059 ha of native forest, 83 ha of secondary forest, 51 ha of monoculture forest, and 35 ha of Leucaena forest was designated for the Mariana crow and Rota bridled white-eye.

Sikes act and the integrated natural resources management plan

The Sikes Act (16 U.S.C. 670) was originally passed in 1960 to direct the United States Department of Defense (DoD) to carry out conservation and natural resource rehabilitation projects on military installations in coordination with local and federal fish and wildlife agencies. Installations are required to create an Integrated Natural Resources Management Plan (INRMP) which describes future and ongoing conservation projects on military lands. In the Mariana Islands, the DoD manages large tracts of lands on Guam, Tinian, and Farallon de Medinilla (FDM). Many of the projects proposed in the INRMP are required or recommended by other laws and regulations, including the Endangered Species Act and Clean Water Act. The U.S. military owns nearly 7689 ha of forests on Guam and roughly 4047 ha of forest on Tinian which are included in several conservation actions proposed in their INRMPs. Table 4 below shows the forest types on DoD lands on Tinian and Guam.

Guam Micronesian kingfisher memorandum of agreement (MOA)

In 2015, the U.S. Fish and Wildlife Service (USFWS) entered into an agreement with the Department of the Navy (DON) on conservation efforts to protect habitat (which includes forest habitat) in northern Guam for the benefit of the Guam Micronesian

Table 4 Forest types on Department of Defense (Dod) lands on Guam and Tinian (Reeves and Amidon, 2018).

Forest subtype	*Acres on Guam*	*Acres on Tinian*
Native	11,735	183
Secondary	5203	4198
Monoculture	1208	5375
Leucaena	18,698	10,537

kingfisher. For the kingfisher to be recovered in Guam, 4659 ha of habitat is needed, with 3309 ha of that on DoD lands. Through the Integrated Natural Resources Management Plan (INRMP) the DON plans to restore and manage 2118 ha to offset the loss of 540 ha of kingfisher habitat due to the planned military relocation from Okinawa to northern Guam (USFWS, 2015a,b). Projects include fencing in large areas of forest, removing ungulates, replanting native trees (including threatened and endangered species), and removing invasive plants.

Local Permitting

In Guam, Public Law 25–152 was put in place to control accelerated soil erosion and manage nonpoint source pollution. This regulation allows for the Guam Department of Agriculture (GDOA), Division of Aquatic and Wildlife Resources (DAWR) to review all development projects which will involve the clearing of forest (and other) habitat prior to the start of project activities to ensure there are no negative impacts to protected species or resources.

In the CNMI, the Northern Mariana Islands Administrative Code (NMIAC) Chapter 65-30, § 65-30-101 details the permit requirements for any land clearing activities. It states "No person shall commence or continue any earthmoving activity including grading, filling, or clearing of vegetation without a DEQ Earthmoving and Erosion Control Permit issued in accordance with the regulation." In order for land clearing to commence, CNMI DFW, historic preservation, coastal resource management, and zoning must all approve the permit. It is the role of CNMI DFW to review all land clearing projects and determine whether locally or federally protected species or resources will be impacted. This mechanism was put in place to ensure no unauthorized clearing of forest (or other) land cover types occurs in the CNMI.

Protected Lands

There are several categories of protected lands in the Marianas including conservation areas, national parks, a national wildlife refuge, and the only mitigation bank in the Pacific islands. These lands were designated by federal or local governments for the conservation of natural resources and have protections regarding development, hunting, fishing, wildlife-oriented recreation, and other uses. Regulations vary among protected areas, as each area has a distinct history and purpose for protection (Liske-Clark, 2015).

There are conservation areas established on Guam, Rota, Tinian, and Saipan. These areas are set aside by the local government or the DoD to restrict the activities in an effort to minimize impacts to natural resources. In the CNMI, these lands are designated through the passage of a congressional bill and are under the ownership of the CNMI Department of Lands and Natural Resources. On Guam, lands are placed under the ownership of the Government of Guam or DoD.

Conservation lands comprise 22% of Rota, 4% of Tinian, and 9% of Saipan. Of the northern islands, the entire island of Sarigan is regulated by the Division of Fish and Wildlife and Guguan, Asuncion, Maug, and Uracas are designated wildlife conservation areas. No people are allowed on these islands without prior approval from the Director of the CNMI DFW, so human impact to forest lands is minimal. CNMI conservation lands total approximately 5560 ha, representing 12% of the total land area (Liske-Clark, 2015).

Approximately 10,182 ha of forest are classified as reserves or protected areas across the Mariana archipelago including 7263 ha of native forest, 2103 ha of secondary forest, 466 ha of monoculture forest, and 349 ha of Leucaena forest (Reeves and Amidon, 2018). Table 5 summarizes the protected areas in the Marianas (Figs. 10–13).

Invasive Species Management and Control

Biosecurity

A major biosecurity focus within the Mariana Islands is preventing the spread of BTS to the Northern Mariana Islands from Guam. In this effort, federal agencies support local capacity both in Guam and the CNMI. On Guam there are extensive efforts to keep BTS out of the transportation chain, effectively reducing the potential for BTS to be accidentally transported from the island (Brown Tree Snake Technical Working Group (BTSTWG), 2015). In the CNMI, efforts are undertaken to ensure that high risk cargo and craft arriving from Guam are inspected to reduce risks of BTS accidentally arriving and establishing. These efforts include inspection of all arriving cargo from Guam to the CNMI by BTS detection dogs as well as specialized trapping around all major ports of entry. Control and management activities in regards to the BTS are highly effective and since enacted, credible BTS encounters outside of Guam and its native range have been reduced and at present there are no known populations established outside of its native range

Table 5 Conservation areas of the Marianas (Berger et al., 2005; Guam Division of Aquatic and Wildlife Resources (DAWR), 2006; SWCA Environmental Consultants, 2010a,b; U.S. Fish and Wildlife Service (USFWS), 2007; Cogan et al., 2013; Reeves and Amidon, 2018).

Conservation area (forest subtypes)	*Location*	*Purpose*	*Enabling law or agreement*
Sabana heights wildlife conservation area (N S M L)	Rota, Sabana plateau	Terrestrial, for wildlife conservation	Rota Local Law 9-1 and regulations promulgated under Public Law 2-51
I Chenchon Park Wildlife Conservation Area and Bird Sanctuary (N S M)	Rota, cliffs along eastern coast	Terrestrial, for wildlife conservation and especially for sea birds	Rota Local Law 9-1 and regulations promulgated under Public Law 2-51
Wedding Cake Mountain Wildlife Conservation Area (N S M L)	Rota, Taipingot Peninsula on southwest end of island	Terrestrial, for protection of all wildlife, plants, and soils	Rota Local Law 9-3 and regulations promulgated under Public Law 2-51
Saipan Upland Mitigation Bank (N S L)	Saipan, upland areas of Marpi region on north end of island, encompassing the Marpi Commonwealth Forest	Terrestrial, to provide “credits” for sale to developers as a mitigation measure for the take of Nightingale Reed Warblers; and for preservation of wildlife	CNMI Public Law 10-84; Saipan Upland Mitigation Bank Agreement between CNMI and USFWS; and regulations promulgated under Public Law 2-51
Bird Island Wildlife Preserve (N S L)	Saipan, lands on Saipan island to the west of Bird Island	Terrestrial, for preservation of wildlife	CNMI Public Law 10-84
Bird Island Sanctuary (N S L)	Saipan, lands and waters surrounding and including Bird Island (N L)	Terrestrial and marine, no-take zone for all natural resources; natural laboratory for educational purposes	CNMI Public Law 12-46
Kagman Wildlife Conservation Area (N S M L)	Saipan, lands on eastern side of Kagman Peninsula	Terrestrial, for preservation of wildlife	CNMI Public Law 10-84
American Memorial Park National Park (N S M L)	Saipan	To commemorate those who lost their lives on the Mariana Islands in military campaigns during World War II. Protects several historical and cultural sites and provides recreational areas for the public	P.L. 95-348 (1978)
CNMI Mitigation Area (N S M L)	Tinian, north of airport	Compensate for loss of Tinian monarch habitat as a result of airport expansion	Biological Opinion (1-2-98-F-06) for the Federal Aviation Administration
Asuncion Island (N M)	Asuncion Island	Terrestrial, to be maintained as an uninhabited place and used only for the preservation and protection of natural resources, including but not limited to bird, wildlife and plant species	CNMI Constitution, Article XIV, Section 2 and CNMI Public Law 14-49
Guguan Island (N)	Guguan Island	Terrestrial, to be maintained as an uninhabited place and used only for the preservation and protection of natural resources, including but not limited to bird, wildlife and plant species	CNMI Constitution, Article XIV, Section 2 and CNMI Public Law 14-49
Maug Island (N M)	Maug Island	Terrestrial, to be maintained as an uninhabited place and used only for the preservation and protection of natural resources, including but not limited to bird, wildlife and plant species	CNMI Constitution, Article XIV, Section 2 and CNMI Public Law 14-49
Uracas Island (None)	Uracas Island	Terrestrial, to be maintained as an uninhabited place and used only for the preservation and protection of natural resources, including but not limited to bird, wildlife and plant species	CNMI Constitution, Article XIV, Section 2 and CNMI Public Law 14-49
Anao Conservation Area (N M)	Northeastern Guam	Wildlife, species conservation, outdoor recreation	Guam PL 16-62
Bolanos Conservation Area (N M)	Southern Guam	Hunting, outdoor recreation, species conservation	Guam PL 16-62
Cotal Conservation Area (S M)	Southern Guam	Species conservation	Guam PL 16-62
Guam National Wildlife Refuge (Ritidian Unit) (N M)	Northern Guam	Conservation of threatened and endangered plants and wildlife and their ecosystems, migratory birds, wildlife-oriented recreation	Proposed Guam NWR and Finding of No Significant Impact (USFWS, 1993)
	Northern and southern Guam		

Table 5 (Continued)

Conservation area (forest subtypes)	*Location*	*Purpose*	*Enabling law or agreement*
Guam National Wildlife Refuge Overlay—Air Force (N S M)		Conservation of threatened and endangered plants and wildlife and their ecosystems, wildlife-oriented recreation, Air Force mission responsibilities	Cooperative Agreement between USFWS and Navy (March 10, 1994)
Guam National Wildlife Refuge Overlay—Navy (N S M L)	Northern and southern Guam	Conservation of threatened and endangered plants and wildlife and their ecosystems, wildlife-oriented recreation, Navy mission responsibilities	Cooperative Agreement between USFWS and Navy (March 4, 1994)
Haputo Ecological Reserve Area (N M)	Northwestern Guam	Preserving examples of ecosystems and genetic diversity while providing opportunities for scientific research. Mitigation for construction of Kilo Wharf, Outer Apra Harbor; part of Guam NWR Overlay	Chapter 15, OPNAVINST 5090.1; Chapter 17 of the NAVFAC P-73 Real Estate Manual; 36 CFR 251.23; 40 FR 38; and HR 5602, The National Heritage Policy Act of 1979 (March 15, 1984)
Orote Ecological Reserve Area (N S L)	Southern coast of Orote Peninsula, western Guam	Same as Haputo Ecological Reserve Area	Same as Haputo Ecological Reserve Area
War in the Pacific National Park (N S L)	Guam, 7 units Asan Beach, Asan Inland, Agat, Piti, Mt Alifan, Mt. Tenjo/Mt. Chachao, Fonte Plateau	To commemorate the bravery and sacrifice of those participating in the campaigns of the Pacific theater of World War II and Conserve and interpret outstanding scenic and historic values and objects for the benefit of present and future generations	Public Law 95-348, 92 Stat. 492, 16 USC 460dd (1978)

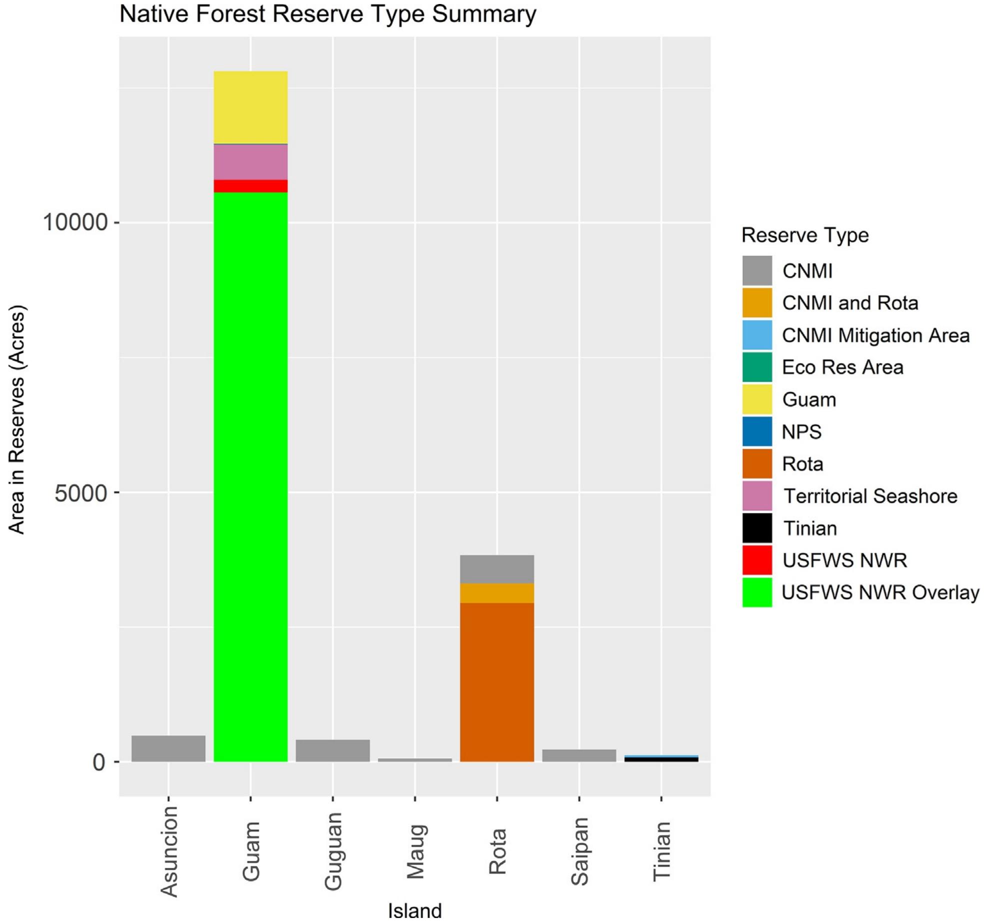

Fig. 10 Native forest reserve type summary (Reeves and Amidon, 2018).

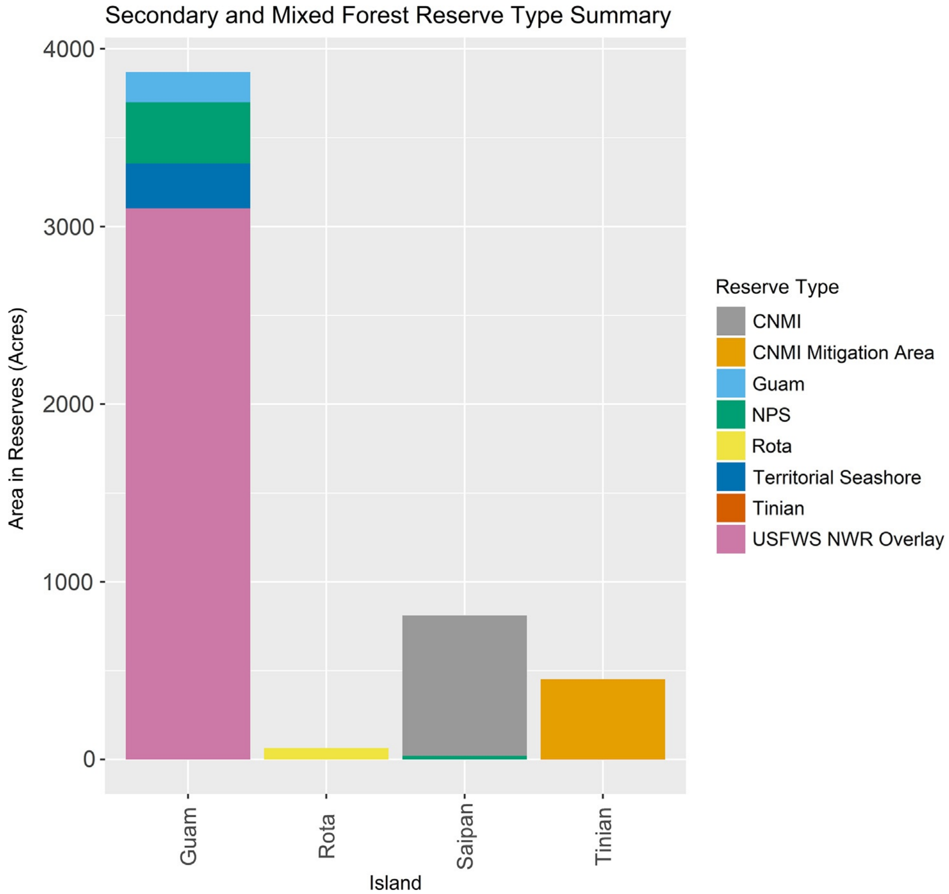

Fig. 11 Secondary forest reserve type summary (Reeves and Amidon, 2018).

and Guam (Brown Tree Snake Technical Working Group (BTSTWG), 2015). Nevertheless, biosecurity mechanisms rarely eliminate the risk and the situation with the BTS on Guam needs to be continually monitored, enforced and adjusted as needed to best ensure that BTS do not accidentally become established in the CNMI or elsewhere.

The University of Guam and the College of the Northern Mariana Islands provide research and extension services which in part support invasive species management. Activities include CRB monitoring and management and research programs (Brown Tree Snake Technical Working Group (BTSTWG), 2015). Similarly, both the CNMI and Guam governments have staff which support management of various established pest species and provide natural resource management, conservation and restoration efforts. The DoD on military lands also has active natural resource programs including BTS management, feral ungulate control, habitat restoration and fencing (Brown Tree Snake Technical Working Group (BTSTWG), 2015).

These efforts to reduce the presence or impact of invasive species offer the potential to protect both the quality and quantity of vegetation within any habitat, including forests, as well as species that depend on the vegetation.

Partnerships

Micronesian Challenge

In 2006 the Republic of Palau, the Federated States of Micronesia, the Republic of the Marshall Islands, the U.S. Territory of Guam, and the U.S. Commonwealth of the Northern Mariana Islands committed to conserve at least 30% of the near-shore marine resources and 20% of the terrestrial resources across Micronesia by 2020. This pledge has become known as the Micronesia Challenge. The Challenge aims to preserve these resources for the benefit of future generations, to sustain livelihoods, and to sustain each island's unique biodiversity (Micronesia Challenge, 2012).

Interactions of All the Above

The primary stressors to forests include habitat loss and destruction caused by development and the introduction of invasive plants and animals. These stressors are significant and ongoing, act in concert with other stressors, and are expected to continue or increase in magnitude and intensity into the future without effective management actions to control or eradicate them.

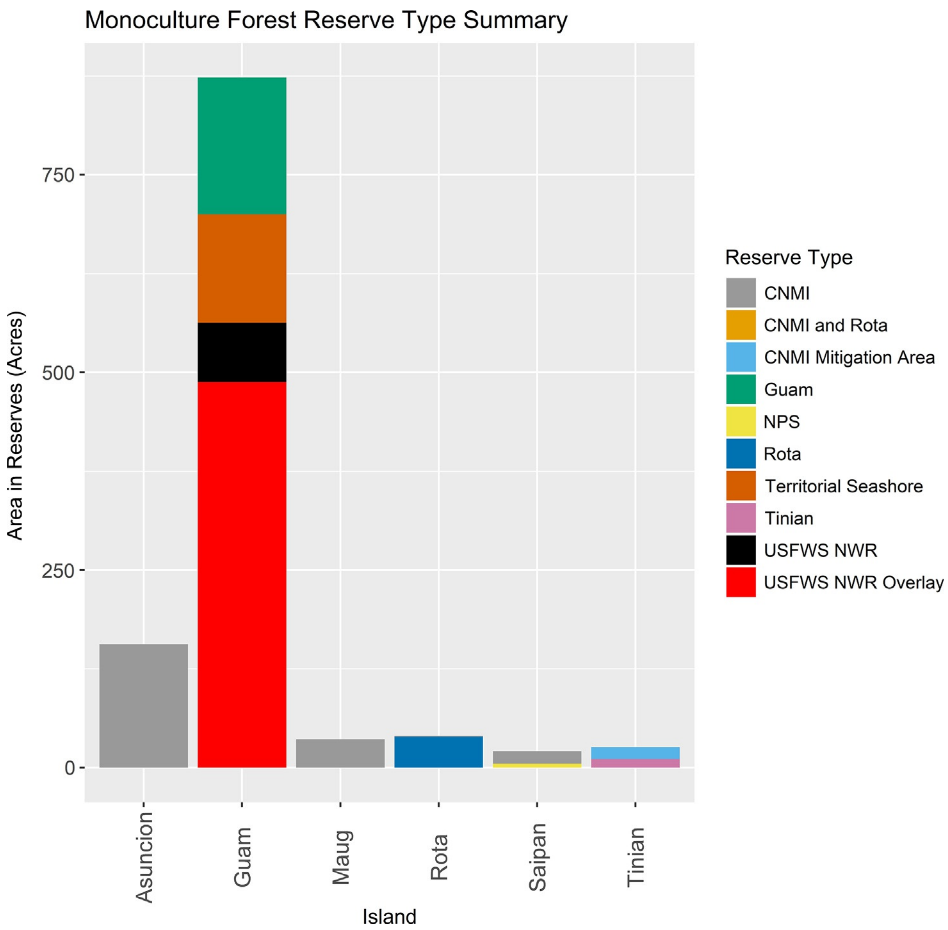

Fig. 12 Monoculture forest reserve type summary (Reeves and Amidon, 2018).

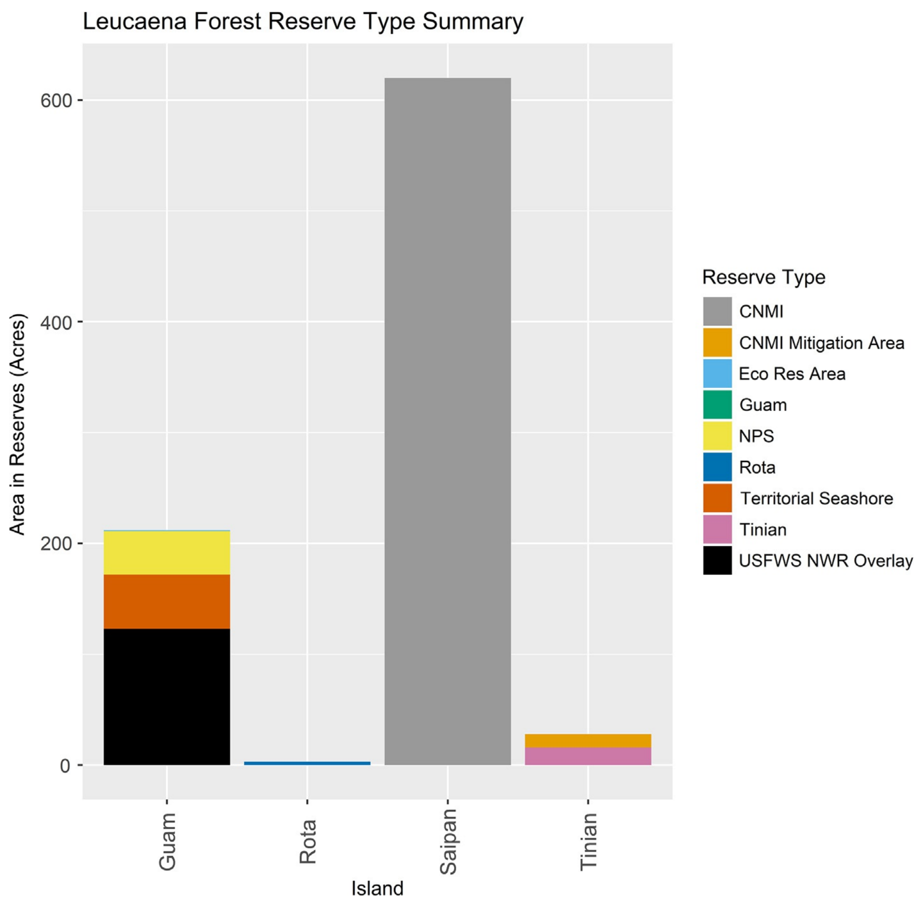

Fig. 13 Leucaena forest reserve type summary (Reeves and Amidon, 2018).

Current conservation efforts taken by Federal, State, private, and agency partnerships combined with laws and regulations limit some of the effects of the stressors on forests, but do not eliminate them. Without active management, forests will continue to be degraded and destroyed. Increased levels of restoration and conservation efforts such as invasive species management, restoration of lands to native dominated forests and a reduction in the level of development have the potential to limit the degradation or loss of forests or even reverse any ongoing degradation occurring for these forest subtypes.

In summary, all forest sub-types across the Marianas are moderately resilient, aside from Leucaena forests which are highly resilient. Their rapid growth, and possibly allelochemical attributes allows it to form dense thickets that crowd out other vegetation making it highly resilient (Little and Skolmen, 1989). Development and invasive species have negatively impacted the quantity and quality of native forests and to some degree secondary forests. Development has reduced the quantity of native forests primarily on the southern islands. However, all forest types remain distributed across several islands throughout the Marianas (moderate redundancy). The current stressors or conservation actions do not seem to have significantly reduced the species richness or genetic variation, therefore representation remains moderate (Table 6).

Future Scenarios

The condition of Mariana Islands Forests in the foreseeable future is based on potential changes in three conservation management parameters (CMPs). These conservation parameters capture the social and legal mechanisms under which natural resource conservation is carried out. The CMPs are as follows:

1. *Conservation Values*: stakeholder involvement and public opinion determine the formulation, implementation, and funding of natural resource conservation within laws and development plans.
2. *Laws and Biosecurity*: national, state, county, and city laws and regulations are the means by which natural resource conservation and biosecurity are supported and implemented (e.g., hunting regulations, Clean Water Act, Endangered Species Act, and local laws, etc.).
3. *Development or Conservation Planning*: national, state, county, city, and private development plans or conservation plans define specific actions that result in losses or gains in natural resource conservation and biosecurity (impacts are only realized at the time of implementation).

These conservation management parameters are critical factors that drive the direction and magnitude of natural resource conservation, and determine foreseeable future scenarios. The year 2035 is the extent of the "foreseeable future," and is based on the projected divergence of IPCC Representative Concentration Pathway (RCP) climate change scenarios (van Vuuren et al., 2011; Miller, 2018).

The four foreseeable future scenarios considered in this assessment are:

Future Scenario One, *Status Quo*—the most likely foreseeable future; no change in natural resource conservation in the CMPs, so the current rate of change in land cover continues through the foreseeable future.

Future Scenario Two—a slight increase in natural resource conservation in the CMPs marginally improves conservation management.

Future Scenario Three—a slight to moderate decrease in conservation actions in the CMPs substantially decreases conservation management.

Future Scenario Four—a moderate to large increase in conservation actions in the CMPs substantially improves conservation management.

The future condition of Marianas Forests in Scenario One, the status quo, was characterized from an assessment of change over time in Forest land cover obtained from existing land cover maps (Reeves and Amidon, 2018). Based on these land cover maps, an annual rate of change for each forest subtype was estimated, and a projected change (in acres/ha) was calculated for the year 2035 (Amidon and Reeves, 2018). The resulting information on changes in land cover by 2035, as derived from existing land cover change estimates, is the extent of Marianas Forest ecotypes that is expected in the foreseeable future under Scenario One, the status quo, where conservation efforts remain unchanged and the current rate of change in land cover is also unchanged.

The future conditions of Marianas Forests for Scenarios Two, Three, and Four cannot be quantitatively (acres/ha) estimated. However, the Scenario One estimate can provide a "baseline" for a qualitative characterization of changes in the future condition of Mariana Forests under Scenarios Two, Three, and Four.

Table 6 Assessment of native forest resiliency, redundancy, and representation of forests in the Mariana Islands in their current condition.

Forest sub-type	*Resiliency*	*Redundancy*	*Representation*
Native forest	Slightly reduced but still moderate	Slightly reduced but still moderate	Slightly reduced but still moderate
Secondary forest	Moderate	Moderate	Moderate
Monoculture forest	Moderate	Moderate	Moderate
Tangantangan forest	High	Moderate	Moderate

Changes in human population are captured only by the changes in the "developed" land cover footprint derived from land cover map analysis (Amidon and Reeves, 2018). Impacts from other sources of human activities or human-caused stressors (e.g., plant and animal diseases, wildfires, invasive species, etc.) are not well characterized in the land cover changes, but significantly contribute to increases in the land cover area dominated by nonnative vegetation. For an assessment of island-by-island changes in human population, see Amidon (2018).

Also, note that island-wide implementation of the CMPs is unlikely to have a significant effect on climate-related stressors (temperature, precipitation, and severe weather) resulting from global warming by 2035. This lack of CMP climate effects is due to the global lag in climate response to changes in greenhouse gas emissions which occurs on the order of centuries rather than years (Solomon et al., 2009; Gillett et al., 2011; Jevrejeva et al., 2012). Evidence of climate effects is also confounded by the large annual variation in the Pacific islands climate parameters, which is much greater than projected climate change by 2035. Although impacts from climate-related stressors do not change across the four scenarios, they were included in this analysis because of their overall magnitude of potential importance to future ecotype viability.

Future Scenario One: Status Quo

Under Scenario One there is no change in the implementation of the three CMPs between 2018 and 2035. A continuing current rate of change in land cover through this foreseeable future results in a slow but continuous change in Mariana forest subtypes. The anticipated changes, under Scenario One, of each stressor important to the four Mariana forest subtypes are given in Table 7. The summary of the change in quality and quantity of the four Mariana forest subtype under Scenario One can be found in Table 8.

Table 7 Responses of Mariana Forest stressors in foreseeable future scenarios.

Conservation management parameters (CMPs)				
Conservation values	Stakeholder involvement and public opinion influence the formulation, implementation, and funding of natural resource conservation and biosecurity (NRC/B) within laws and development or conservation plans			
Laws and biosecurity	National, state, county, and city laws and regulations are the means by which NRC/B are supported and implemented			
Planning for development or conservation	National, state, county, city, and private development plans or conservation plans define actions that result in losses or gains in NRC/B (impacts realized at implementation)			
Foreseeable Future Scenarios and the resulting Mariana Forest conditions				
Use Foreseeable Future Scenario One as a "baseline" to characterize changes in *Conservation Actions* and *Forest Conditions* in Future Scenarios Two, Three, and Four	*Scenario One*: CMPs: unchanged in support for NRC/B *Conservation Actions*: no change; current rate of land cover change continues through the foreseeable future *Forest Condition*: area, quality, and sustainability slowly decrease through the foreseeable future	*Scenario Two*: CMPs: small increase in support for NRC/B *Conservation Actions*: marginal increase *Forest Condition*: area is unchanged through the foreseeable future; quality and sustainability are slightly enhanced through the foreseeable future	*Scenario Three*: CMPs: small to moderate decrease in support for NRC/B *Conservation Actions*: substantial decrease *Forest Condition*: urban and agricultural uses are prioritized over conservation; area, quality, and sustainability substantially decrease through the foreseeable future	*Scenario Four*: CMPs: moderate to large increase in support for NRC/B *Conservation Actions*: substantial increase *Forest Condition*: robust, sustained effort to restore, manage, and expand conservation; area, quality, and sustainability substantially increase through the foreseeable future
Stressors	Responses of Mariana Forest stressors			
Development	Small to moderate increase	No change (redevelop)	Moderate to large increase	Small to moderate decrease
Altered hydrology	No change to small increase	No change	Larger increase	Small decrease
Recreation/access	Small increase	Small increase	Larger increase	Larger increase
Invasive species	Small increase	Small increase	Larger increase	Small decrease
Plant diseases	Small increase	Small increase	Larger increase	No change to small decrease
Fire	Small to moderate increase	Small increase	Larger increase	No change to small decrease
Erosion	Small increase	No change	Larger increase	Small decrease
Climate:				
Temperature	Small to moderate increase	Small to moderate increase	Small to moderate increase	Small to moderate increase
Precipitation	Small decrease	Small decrease	Small decrease	Small decrease
Storms	Small increase	Small increase	Small increase	Small increase

Table 8 (A–D). Estimated acreages and percent of island in each forest sub-type currently (2016) and in the foreseeable future (2035) for the islands of Guam, Rota, Tinian, and Saipan.

Island	*Current (2016)*		*Future (2035)*		*% Change 2016 to 2035*
	Acres	*% of Land*	*Acres*	*% of Land*	
Native forest[a]					
Guam	21,668	16%	21,681	16%	<1%
Rota	10,052	47%	7,207	34%	−28%
Tinian	1067	4%	471	2%	−56%
Saipan	427	1%	637	2%	49%
Secondary forest[b]					
Guam	33,270	25%	32,946	25%	−1%
Rota	2163	10%	2212	10%	2%
Tinian	6202	25%	4594	18%	−26%
Saipan	10,656	36%	6369	22%	−40%
Monoculture forest[c]					
Guam	1709	1%	1701	1%	0%
Rota	667	3%	772	4%	16%
Tinian	888	4%	1676	7%	89%
Saipan	526	2%	741	3%	41%
Leucaena forest[d]					
Guam	4914	4%	5137	4%	5%
Rota	229	1%	34	0%	−85%
Tinian	8279	33%	7567	30%	−9%
Saipan	5492	19%	5709	19%	4%

Percent (%) change is the difference between the % of land in 2035 and 2016. No data is currently available for projecting habitat change in the foreseeable future for the remaining islands in the archipelago (Amidon and Reeves, 2018).

[a]No change in Native Forest is expected on Guam, a moderate decrease is expected on Rota, a large decrease is expected on Tinian, and a large increase is expected on Saipan. The increase on Saipan is likely due to inconsistencies in classification. Native forest on Saipan is highly fragmented and has not been mapped well over the various assessments. Therefore, we consider that increases in native forest on Saipan are unlikely. The decline on Tinian is also likely to be due, in part, to classification inconsistencies. However, some decreases may occur on Tinian. Declines in native forest are expected on Rota as areas identified for homestead sites continued to be cleared.

[b]Secondary forest is projected to remain stable on Guam and Rota and decline on Tinian and Saipan. A decline on Saipan is expected as a large proportion of the island is secondary forest and the increases in developed land cover is likely associated with losses in this forest sub-type. A decline on Tinian is also expected as approximately a quarter of the island is in this forest sub-type and increases in scrub/herbaceous and developed habitats are likely related to the loss of this forest sub-type.

[c]Based on the analysis, monoculture forest is projected to remain stable on Guam and increase on the remaining islands. However, the increases on Rota, Tinian, and Saipan in this habitat are likely related to mapping error and inconsistent classification as new plantings of monoculture forest are not regularly encountered on these islands. The changes on Saipan and Rota are relatively small and consistent with mapping error. The increase on Tinian is substantial. However, review of the imagery from 2005 and 2016 indicates that the increase in this forest sub-type is likely due to misclassification. The monoculture forest in the 2016 map was present in the 2005 imagery and was likely misclassified due to the lower resolution of the imagery. Therefore, we conclude that changes in monoculture forest are unlikely under the status quo scenario.

[d]The analysis indicates that *Leucanea* Forest is projected to remain stable on Saipan, increase slightly on Guam, and decrease on Rota and Tinian. The projected decline on Rota is likely related, in part, to mapping and classification errors. Review of the imagery from 2016 and 2005 indicate that the extent of this forest type was consistent between both images and that the decline may be related to over estimates in the 2005 maps. The decline on Tinian is expected as approximately 1/3rd of the island is classified as this habitat and increases in Developed and Scrub/Herbaceous land cover types (see associated sections in Amidon and Reeves, 2018) on this island are likely related to the loss of this forest sub-type.

Under Scenario One, an expanding human population and increased development and general land use on all inhabited islands is anticipated (Amidon, 2018; Amidon and Reeves, 2018), and therefore Mariana forest stressors are expected to increase at a small annual rate. Exceptions are a small to moderate annual rate of increase for development, wild fires, and surface air temperature, and a small annual rate of decrease for precipitation. On average, the percentage of land developed for residential, commercial, and agricultural purposes on the inhabited islands is expected to increase by 25% from 2016 to 2035. This rate is only true for the southern inhabited islands of Guam, Rota, Tinian, and Saipan. Data on rates of development for the remaining islands does not exist at this time. Based on the rate of development and land cover data, estimates of the amount and percent change in each forest sub-type from 2016 to 2035 on the southern inhabited islands of Guam, Rota, Tinian under Scenario One were calculated.

Overall, the continued gradual decline of all forest subtypes in the Marianas is predicted under Scenario One. Most development (agricultural, commercial, military, or residential) occurs within forests, resulting in ongoing forest loss and fragmentation reducing resilience and redundancy of all forest types. No change in native forest is expected on Guam (<1%) and a moderate decrease is expected on Rota (28%) as areas identified as homestead sites continue to be cleared. Secondary forest is projected to remain stable on Guam (1% decrease) and Rota (2% increase), and decline on Tinian (26%) and Saipan (40%) as forests are converted to scrub/grass and developed land cover types. Monoculture forest is projected to remain stable in the foreseeable future on these islands.

Leucaena forest is projected to increase slightly on Guam (5%) and decline modestly on Tinian (9%) likely tied to increases scrub/grass and developed land cover types.

Future Scenario Two: There Is a Slight Increase in the CMPs That Marginally Improves Conservation Management

Under Scenario Two, conservation agencies and stakeholders work with increased but limited resources to slow or stop the degradation of landscape areas. Scenario Two is essentially 'status quo' with minor improvements in the three CMPs. This scenario is expected to have the second highest likelihood of occurring into the foreseeable future, being slightly less likely than Scenario One. The anticipated changes, under Scenario Two, of each stressor important to the four Mariana forest subtypes are given in Table 7. The summary of the change in quality and quantity of the four Mariana forest subtypes under Scenario Two can be found in Table 8.

Though there is an expanding human population in Scenario Two, development is not expected to substantially increase. A slightly improved biosecurity effort should help reduce invasive species and plant diseases but increases are still expected. The small increased support of natural resource management in the CMPs is not expected to greatly alter wildfire frequency and intensity, but these might (lower slightly) compared to Scenario One. The CMP supported conservation will not prevent, mitigate, or reverse the impacts of climate change-related stressors.

Under this scenario the decline of native and secondary/mixed forest subtypes in the Marianas is predicted to decrease or halt. Whereas, development (residential, commercial, or agricultural) in the past and present occurred largely within native forest, a slight increase in planning could target development to areas of past development or disturbance. Disturbed open fields or abandoned buildings could be developed to accommodate an increase in population allowing for tracts of all forest types to remain undeveloped and possibly move through successional stages towards native or secondary forest on the islands with functional seed dispersal systems.

Future Scenario Three: There Is a Small to Moderate Decrease in Conservation Actions in the CMPs That Substantially Decreases Conservation Management

Under Scenario Three, all natural resource management actions in the CMPs are set aside in deference to land use for economic development. With extensive localized management, some native species may persist in park-like settings or in areas where land development is not possible. The anticipated changes, under Scenario Three, of each stressor important to the four Mariana forest subtypes are given in Table 7. The summary of the change in quality and quantity of the four Mariana forest subtypes under Scenario Three can be found in Table 8.

Under this scenario the quality and quantity of all forest types in the Marianas is expected to rapidly decline. Development (residential, commercial, or agricultural) will increase substantially and continue to disproportionately impact Mariana forests relative to other land cover types. Overall, this will result in fragmentation and degradation of forests reducing resiliency, redundancy, and representation across all forest types.

Future Scenario Four: There Is a Moderate to Large Increase in Conservation Actions in the CMPs That Substantially Improves Conservation Management

Under Scenario Four, an overt and robust, active, ongoing effort is made to engage partners and stakeholders in identifying and prioritizing landscape areas needed for the conservation of native ecosystems, and to actively restore and expand these areas. A substantial emphasis on natural resource conservation is present in the three CMPs, reflecting increased societal concern for declines in natural habitats and biodiversity. Active and well-supported natural resource management begins to restore these habitats and ecosystems and expand their landscape areas. The anticipated changes, under Scenario Four, of each stressor important to the four Mariana forest subtypes are given in Table 7. The summary of the change in quality and quantity of the four Mariana forest subtypes under Scenario Four can be found in Table 8.

Under this scenario the rate of decline of all forest types in the CNMI is expected to halt allowing forests to regenerate and expand. The BTS will continue to hinder the natural regeneration of forests lost due to the absence of seed dispersers, but active restoration efforts by DOD and conservation agencies will aide in the creation of native forest habitat. Whereas, development (residential, commercial, or agricultural) in the past and present occurred largely within forest habitat, with a robust increase in planning, development in forest habitat will be virtually non-existent and almost entirely occur in areas of past development or disturbance. Disturbed open fields and impaired forests will then be actively targeted for reforestation and restoration resulting in an increase in the quality and quantity of forested habitat.

Conclusion

Prior to the arrival of humans in the Mariana archipelago, native forest was likely widespread, contained a high amount of diversity, and recovered quickly from storms; thereby exhibiting high levels of resiliency, redundancy, and representation. As a result of

natural and anthropogenic disturbance since the arrival of humans, a significant proportion of native forest was converted to three additional forest sub-types: secondary, monoculture, and Leucaena forests resulting in the current condition of Mariana forests.

Currently, the primary stressors to Mariana forests include invasive species, development, volcanic eruptions, typhoons, and fire. These stressors are serious and ongoing, and are expected to continue or increase in magnitude and intensity into the future. Without changes in current laws or regulations, biosecurity will continue to be an issue and continuing the spread and introduction of invasive plants, animals, and insects and their impacts throughout the archipelago. In addition, the threat of introduction of the BTS to the CNMI is ongoing, and will also continue to prevent the recovery of seed dispersing avian species hindering native forest restoration on Guam. And without active management to halt or reduce the impacts of development and invasive species, the quantity and quality of Mariana forests will continue to decline and result in reduced resiliency, redundancy and representation.

Native and secondary forests are biologically important as they support native species and provide the conditions needed for their survival. The majority of remaining native (90%) and secondary forests (99%) are found on five of the southern islands (Guam, Rota, Tinian, Saipan, Aguiguan) which underscores the importance of these areas for biodiversity conservation in the Mariana archipelago. However, these islands also support the highest concentration of the human population and military activities which presents a greater risk of forest degradation and destruction as result of the ongoing impacts of development and invasive species.

Though conservation efforts by Federal, Territorial, Commonwealth, and multiple agency partnerships have been beneficial in helping to conserve and protect some of the remaining forests in Marianas, without increased efforts to address biosecurity, development, and invasive species, a decrease in the viability of Mariana forests is expected. Because the remaining native and secondary forests and reserve areas occur across public, private, and Department of Defense lands (including the USFWS Overlay Refuge), conservation of these areas will require continued efforts by all stakeholders.

Finally, in the foreseeable future, Scenario One, has the highest likelihood of occurring in relative to the other scenarios. Under Scenario One there is no change in the implementation of the conservation management parameters (CMPs). Scenario Two is based on a slight increase in the implementation of the CMPs, which marginally improves conservation management. Thus Scenario Two is expected to have the second highest likelihood of occurring into the foreseeable future, being slightly less likely than Scenario One. Scenario Three is based on a slight to moderate decrease in conservation actions in the CMPs which substantially decreases conservation management. Because there is a decrease in the implementation of the CMPs, Scenario Three would severely degrade and fragment native and secondary forest subtypes and result in reduced resiliency, redundancy, and representation. In Scenario Four, the substantial improvements in restoration for native and secondary forest subtypes would result in increased resiliency, redundancy, and representation. However, Scenario Three and Four have the lowest likelihood of occurring in the foreseeable future.

Overall, the CMPs are critical factors that drive the direction and magnitude of natural resource conservation and determine the foreseeable future scenarios. Any increase in the implementation of the CMPs will result in the greatest conservation returns for native and secondary forests (Scenario's Two and Four). Conversely, any decrease in the implementation of the CMPs will result in the least conservation returns for native and secondary forests (Scenario's One and Three). Thus, realistic expectations of the implementation of the CMPs were considered when determining the likelihood of occurrence for each scenario in the foreseeable future.

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